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A pilot study of cerebrovascular reactivity autoregulation after pediatric cardiac arrest

Jennifer K. Lee, MD[1], **Ken M. Brady, MD**[2], **Shang-En Chung, MS**[3,4], **Jacky M. Jennings, PhD**[3,4], **Emmett E. Whitaker, MD**[1], **Devon Aganga, MD**[1], **Ronald B. Easley, MD**[2], **Kerry Heitmiller, BA**[1], **Jessica L. Jamrogowicz, BS**[1], **Abby C. Larson, BS**[1], **Jeong-Hoo Lee, BS**[1], **Lori C. Jordan, MD, PhD**[5], **Charles W. Hogue, MD**[1], **Christoph U. Lehmann, MD**[6], **Mela M. Bembea, MD**[1], **Elizabeth A. Hunt, MD, PhD**[1], **Raymond C. Koehler, PhD**[1], and **Donald H. Shaffner, MD**[1]

[1]Department of Anesthesiology and Critical Care Medicine, Johns Hopkins University, Baltimore, MD (JHU)

[2]Department of Anesthesiology, Texas Children's Hospital, Houston, TX

[3]Department of Pediatrics, Division of General Pediatrics and Adolescent Medicine, JHU

[4]Center for Child and Community Health Research, JHU

[5]Department of Neurology, Vanderbilt University, Nashville, TN, USA (VU)

[6]Departments of Pediatrics and Biomedical Informatics, VU

Abstract

Aim—Improved survival after cardiac arrest has placed greater emphasis on neurologic resuscitation. The purpose of this pilot study was to evaluate the relationship between cerebrovascular autoregulation and neurologic outcomes after pediatric cardiac arrest.

Methods—Children resuscitated from cardiac arrest had autoregulation monitoring during the first 72 hours after return of circulation with an index derived from near-infrared spectroscopy in a pilot study. The range of mean arterial blood pressure (MAP) with optimal vasoreactivity (MAP_{OPT}) was identified. The area under the curve (AUC) of the time spent with MAP below MAP_{OPT} and MAP deviation below MAP_{OPT} was calculated. Neurologic outcome measures included placement of a new tracheostomy or gastrostomy, death from a primary neurologic etiology (brain death or withdrawal of support for neurologic futility), and change in the Pediatric Cerebral Performance Category score (ΔPCPC).

Corresponding Author: Jennifer Lee, MD, Department of Anesthesiology and Critical Care Medicine, Johns Hopkins Hospital, Charlotte R. Bloomberg Children's Center, 1800 Orleans Street, Room 6321, Baltimore, MD 21287, Phone: 410-955-6412, FAX: 410-502-5312, jklee@jhmi.edu.

Results—Thirty-six children were monitored. Among children who did not require extracorporeal membrane oxygenation (ECMO), children who received a tracheostomy/gastrostomy had greater AUC during the second 24 hours after resuscitation than those who did not (P=0.04; n=19). Children without ECMO who died from a neurologic etiology had greater AUC during the first 48 hours than did those who lived or died from cardiovascular failure (P=0.04; n=19). AUC below MAP_{OPT} was not associated with ΔPCPC when children with or without ECMO were analyzed separately.

Conclusions—Deviation from the blood pressure with optimal autoregulatory vasoreactivity may predict poor neurologic outcomes after pediatric cardiac arrest. This experimental autoregulation monitoring technique may help individualize blood pressure management goals after resuscitation.

Keywords

pediatrics; heart arrest; blood pressure; brain injuries; cerebrovascular circulation

INTRODUCTION

Cerebrovascular autoregulation maintains cerebral blood flow (CBF) across changes in perfusion pressure. However, the mean arterial blood pressure (MAP) limits of autoregulation in children are unknown. We developed the hemoglobin volume index (HVx) to monitor vasoreactivity with near-infrared spectroscopy (NIRS).[1–3] HVx is based on the premise that autoregulatory vasoconstriction and vasodilation produce changes in cerebral blood volume (CBV) that are proportional to changes in relative tissue hemoglobin density (rTHb) measured by NIRS. Correlating rTHb to MAP generates an index of pressure vasoreactivity.[1–3] The optimal range of MAP (MAP_{OPT}) with the most robust autoregulation can then be identified.[4–6]

In this pilot study, we evaluated the relationship between autoregulation and neurologic outcomes after cardiac arrest. We hypothesized that children who spent more time with blood pressure below MAP_{OPT} and who had greater blood pressure deviation below MAP_{OPT} would have worse outcomes than children whose blood pressure was predominately at or above MAP_{OPT}. We also postulated that measurements based on HVx and MAP_{OPT} would have stronger association with outcomes than would regional cerebral oxygen saturation (rSO_2) or blood pressure in relation to the 50th percentile of MAP (MAP50).[7]

METHODS

This pilot study was approved by the Johns Hopkins University Institutional Review Board, which waived the requirement for written consent. Between July 2009 and March 2012, we screened all children who had a cardiac arrest, received ≥60 seconds of continuous chest compressions, and were admitted to the Johns Hopkins pediatric intensive care unit (PICU). Enrollment criteria included age ≤18 years, intubation, and arterial blood pressure and cerebral NIRS monitoring. Children were excluded if they had known intracranial lesions prior to arrest (because intracranial pressure [ICP] affects the limits of autoregulation),[8]

received isoflurane in the PICU (because isoflurane affects autoregulation),[9] or had >1 cardiac arrest during the hospitalization.

Children had HVx monitoring for 72 hours after return of circulation (ROC) whether ROC was spontaneous or required extracorporeal membrane oxygenation (ECMO). All clinical care was determined by the clinicians, who were blinded to HVx. Vital signs and laboratory measurements were extracted from a database replicated from the electronic medical record. Clinical histories were obtained by chart review.

Autoregulation Monitoring

Pediatric cerebral oximetry sensors (INVOS; Covidien, Boulder, CO) were placed bilaterally on patients' foreheads. HVx monitoring was initiated as soon as possible after ROC and after NIRS and arterial blood pressure monitoring were established. MAP measurements from the bedside monitor (GE Marquette, Garnerville, NY) were processed with an analog-to-digital converter (DT9804, Data Translation, Marlboro, MA). MAP and NIRS signals were synchronously sampled at 100 Hz and processed with a bedside computer using ICM+ software (Cambridge Enterprises, Cambridge, UK).[1–4,10] Artifacts in the MAP and NIRS signals were manually removed (e.g., arterial line flushes).

HVx was calculated continuously as a correlation coefficient between rTHb and MAP.[1] Consecutive, paired, 10-second averaged values from 300-second intervals were used for each calculation of HVx, thereby incorporating 30 data points for each index calculation.[10] HVx is a continuous variable that ranges from −1 to +1. Intact autoregulation with functional vasoreactivity is indicated by negative or near-zero HVx because MAP and CBV are either negatively correlated or not correlated. When vasoreactivity becomes impaired, HVx becomes positive because MAP and CBV correlate.[1–3] We averaged right and left HVx values, sorted them into 5-mmHg bins of MAP, and generated bar graphs to identify the MAP_{OPT} with the best vasoreactivity. As an additional measure to eliminate signal artifacts, we excluded bins comprising less than 1% of the recording period.[4] HVx monitoring was stopped early if the arterial catheter or NIRS sensors were removed.

MAP_{OPT} was identified in several time periods (first 12 hours, first 24 hours, second 24 hours, third 24 hours, first 48 hours, and first 72 hours after ROC) as the bin with the most negative HVx when the bar graph showed a trend of increasing index values as MAP deviated from this nadir[4] (Figure 1). Two physicians (JKL, CWH) who were blinded to the patients' outcomes independently interpreted the HVx bar graph. Agreement on MAP_{OPT} was required to include the patient in the analysis of MAP and outcome.[4]

Neurologic Outcomes

Outcome data were obtained by chart review and measured by (1) placement of a tracheostomy or gastrostomy, (2) primary neurologic death (declaration of brain death or withdrawal of support for neurologic futility), and (3) change in the Pediatric Cerebral Performance Category score (ΔPCPC) from the pre-arrest baseline to hospital discharge. Children were coded as receiving a new tracheostomy/gastrostomy if the procedure was performed after the arrest and before hospital discharge. Brain death was determined by a pediatric neurologist. Withdrawal of support for neurologic futility was determined by

physician documentation. Hospital discharge was defined as death or discharge to home, another hospital, or a rehabilitation facility. The PCPC score categorizes functional impairment based on neurologic status: 1=normal, 2=mild disability, 3=moderate disability, 4=severe disability, 5=coma or vegetative, and 6=death.[11] PCPC scores before the arrest and at hospital discharge were calculated independently and then adjudicated by three physicians (DHS, EEW, DA) blinded to HVx and MAP. Based on the distribution of ΔPCPC values, ΔPCPC was recoded as <3 or ≥3 to describe the proportion of children who had moderate to severe functional impairments and received vasoactive infusions.

Statistical Analysis

Data were analyzed with SAS v9.2 (SAS Institute Inc., Cary, NC). Graphs were generated with GraphPad Prism (v5.03, GraphPad Software Inc., La Jolla, CA). Data are reported as means with standard deviations (SD) or medians with interquartile ranges (IQR) when appropriate. The relationship between MAP_{OPT} and age was analyzed by linear regression. Right and left rSO_2 values were averaged. MAP50 was calculated as the age- and gender-specific 50^{th} percentile of MAP.[7] Time was analyzed as the duration of autoregulation monitoring obtained within the specified time periods. The area under the curve (AUC; min•mmHg/h) for time (minutes) spent with blood pressure below MAP_{OPT} (or MAP50) and blood pressure deviation (mmHg) below MAP_{OPT} (or MAP50) was calculated and normalized for monitoring duration (hours) in each period.[12]

A two-sided *P* value ≤0.05 was considered significant. AUCs below MAP_{OPT} or MAP50 and rSO_2 were compared with placement of a tracheostomy/gastrostomy and neurologic death by Wilcoxon rank sums tests. The relationships between AUCs below MAP_{OPT} or MAP50 and ΔPCPC and between rSO_2 and ΔPCPC were analyzed with Spearman correlations. Data were analyzed in the aggregate and also stratified by children who did or did not receive ECMO. Descriptive analyses explored the relationships between outcomes, AUC below MAP_{OPT}, and location of arrest (in- or out-of-hospital). We compared AUCs for in-hospital and out-of-hospital arrests with a Wilcoxon rank sums test. During 1 year of this pilot study, the PICU participated in the Therapeutic Hypothermia After Pediatric Cardiac Arrest Trials, and it was agreed that analyses would not be conducted with respect to temperature. Post-hoc power analyses for differences in AUC below MAP_{OPT} by outcome were conducted with SAS.

RESULTS

Seventy-one children were screened in this pilot study. Thirty-five ineligible children included nine without arterial catheters, eight with hydrocephalus, four with traumatic brain injuries, three with >1 cardiac arrest, three without NIRS, one with an intracranial tumor, one with meningitis and ICP ≥ 20 mmHg, one who received isoflurane, and one who was not intubated. HVx could not be monitored in three children because of technical problems and in one child because of insufficient resources. Thus, data were analyzed for 36 patients.

Tables 1–3 describe the arrests, medical histories, and pertinent clinical variables. (Supplementary Table I describes medications and blood transfusions.) Ten children received ECMO during autoregulation monitoring. Neuroradiographic studies obtained

during the autoregulation monitoring period demonstrated cerebral edema in 16 (44%) children, strokes in eight (22%), and small intracranial hemorrhages in two (6%). Fifteen (42%) children had seizures.

Among children who did not receive ECMO, the median PCPC scores were 1 (IQR: 1–3; range: 1–4; n=26) pre-arrest and 4 (IQR: 3–6; range: 1–6; n=26) at hospital discharge. The median ΔPCPC was 3 (IQR: 0–5; range: 0–5). The PCPC score did not decrease in any child between pre-arrest and hospital discharge. Two children received tracheostomies, two received gastrostomies, and one received both a tracheostomy and gastrostomy. Sixteen (62%) lived to hospital discharge and 10 (38%) died, including five (50%) who were declared brain dead and five (50%) who had support withdrawn for neurologic futility. Among the five children who received a tracheostomy/gastrostomy, four (80%) received a vasoactive infusion. Of ten children who died from a neurologic etiology, seven (70%) received a vasoactive infusion. Vasoactive infusions were administered to 50% of children with ΔPCPC <3 (n=12) and to 79% with ΔPCPC ≥3 (n=14). In children who did not receive ECMO, the mean duration of chest compressions was 14.5 minutes (SD: 13.8; median: 10.0; IQR 3–25; n=26).

For children who received ECMO support, the median PCPC scores were 4 (IQR: 1–5; range: 1–5; n=10) pre-arrest and 5 (IQR: 4–6; range: 1–6; n=10) at hospital discharge. The median ΔPCPC was 2 (IQR: 1–3; range: 0–5). The PCPC score did not decrease between pre-arrest and hospital discharge in any child. Two children received gastrostomies. Five (50%) lived to hospital discharge and five (50%) died, including two (40%) who had support withdrawn for neurologic futility. Both children who received gastrostomies and both children who died from neurologic etiologies received vasoactive infusions. In addition, vasoactive infusions were administered to 100% of children with ΔPCPC <3 (n=7) and to 67% with ΔPCPC ≥3 (n=3). In children who received ECMO, the mean duration of chest compressions was 26.2 minutes (SD: 30.0; median: 14.0; IQR 3–40; n=10).

Autoregulation

Table 4 describes the autoregulation monitoring durations. The exact time of ROC (cessation of chest compressions or beginning of ECMO) was available in 28 children. HVx monitoring was initiated a median of 8 h (IQR: 4, 12; range 1–25.5) after ROC in these children. Ten children were not monitored through the full 72 hours. HVx was monitored through 48 hours and then discontinued in three children because the NIRS were removed before death and in two children with poor arterial blood pressure waveforms. Monitoring stopped before 48 hours in one child because of a poor blood pressure waveform. Four had HVx monitoring discontinued within 24 hours because the NIRS were removed due to good neurologic exams.

The proportions of children with identified MAP_{OPT} are described in Table 4. All children had an identified MAP_{OPT} in at least one time period. MAP_{OPT} increased with age (β=2.65; 95% confidence interval: 1.53–3.77; p<0.001). Unlike age-based blood pressure norms, values that were identified for MAP_{OPT} varied between patients of similar age and often differed from MAP50 (Figure 2).

Greater AUC below MAP_{OPT} during the second 24 hours after ROC was associated with receiving a tracheostomy/gastrostomy in children without ECMO. The mean rank sum scores were 8.7 (n=15) for children who did not receive a tracheostomy/gastrostomy and 15.0 (n=4; *P*=0.04) for those who received a tracheostomy/gastrostomy. Among children with ECMO and who had an identified MAP_{OPT} during the second 24 hours, only one received a tracheostomy/gastrostomy and eight did not. Among all children with an identified MAP_{OPT}, the AUC below MAP50 during the second 24 hours was not associated with tracheostomy/gastrostomy (*P*=0.72; n=28). (Supplementary Table II describes AUC data from the other periods.)

During the first 48 hours, greater AUC below MAP_{OPT} was associated with primary neurologic death in children without ECMO. The mean rank sum scores were 13.1 (n=8) for children with neurologic deaths and 7.7 (n=11; *P*=0.04) for those who lived or died of cardiovascular failure. Among children with ECMO and who had an identified MAP_{OPT} during the first 48 hours, two had neurologic deaths and eight lived or died of cardiovascular failure. Among all children with an identified MAP_{OPT}, greater AUC below MAP50 during the first 48 hours was associated with neurologic death (*P*=0.02; n=29). (Supplementary Table III describes AUC data from the other periods).

When all children were analyzed together, greater AUC below MAP_{OPT} during the first 48 hours correlated with greater ΔPCPC (r=0.42; *P*=0.02; n=29). However, when data were stratified by ECMO status, AUC below MAP_{OPT} during the first 48 hours did not correlate to ΔPCPC (r=0.37, *P*=0.14 for 19 children without ECMO; r=0.55, *P*=0.14 for 10 children with ECMO). Among all children with an identified MAP_{OPT}, the AUC below MAP50 during the first 48 hours negatively correlated with ΔPCPC (r= −0.49; *P*=0.01; n=29). (Supplementary Table IV describes AUC data from the other periods.)

Median pre-arrest PCPC scores were 1 (IQR: 1–1; range: 1–4; n=11) for out-of-hospital arrests and 2 (IQR: 1–4; range: 1–5; n=25) for in-hospital arrests. Among children with out-of-hospital arrests, 1 had ΔPCPC=0, 1 had ΔPCPC=2, 2 had ΔPCPC=3, and 7 had ΔPCPC=5. Of children with in-hospital arrests, 11 had ΔPCPC=0, 3 had ΔPCPC=1, 3 had ΔPCPC=2, 5 had ΔPCPC=3, 1 had ΔPCPC=4, and 2 had ΔPCPC=5. Furthermore, 8 (73%) children with out-of-hospital arrests and 4 (16%) with in-hospital arrests died of a neurologic etiology. However, the rates of tracheostomy/gastrostomy were similar by location of arrest—2 (18%) for out-of-hospital and 5 (20%) for in-hospital. The median AUC below MAP_{OPT} during the first 48 hours was 558 mmHg•min/h (IQR: 39–859; n=7) in children with out-of-hospital arrests and 197 mmHg•min/h (IQR: 10–484; n=22; *P*=0.17) in children with in-hospital arrests. The mean duration of chest compressions for children with out-of-hospital arrests was 23 minutes (SD: 16; median: 25; IQR: 10–39; n=11). For children with in-hospital arrests, the mean duration of chest compressions was 16 minutes (SD: 21; median: 6; IQR: 3–21; n=25).

Cerebral Oximetry

Right and left rSO_2 were similar. The range of mean rSO_2 values was 68–74% in all periods. The rSO_2 did not correlate with ΔPCPC (*P*>0.07), tracheostomy/gastrostomy (*P*>0.60), or neurologic death (*P*>0.07) in any time period (Supplementary Table V).

DISCUSSION

The results of this pilot study indicate that HVx can identify the hemodynamic range with optimal autoregulatory vasoreactivity after cardiac arrest. Spending more time with blood pressure below MAP_{OPT} and having greater blood pressure deviation below MAP_{OPT} during the first 48 hours after ROC was associated with receiving a new tracheostomy or gastrostomy, brain death, or withdrawal of support for neurologic futility in children who did not receive ECMO. The small population size in this observational pilot study limited power to detect differences in many of the relationships assessed, adjust for potential confounders, or make causal inferences. However, the findings suggest that this experimental technique of HVx autoregulation monitoring may be useful for individualizing hemodynamic goals in children recovering from cardiac arrest without ECMO.

Our pilot study was focused on blood pressure autoregulation and neurologic outcomes. Numerous factors influence these measures, including the duration of the arrest, resuscitation, post-resuscitation course, and underlying disease processes. Individualizing blood pressure goals to support autoregulation is one factor that may improve outcomes. Whether manipulating blood pressure to target MAP_{OPT} affects outcomes cannot be determined in this study.

Children who did not require ECMO and who received a tracheostomy/gastrostomy spent more time with blood pressure below MAP_{OPT} and had greater MAP deviation below MAP_{OPT} during the second 24 hours after ROC than did children who did not require a tracheostomy/gastrostomy in this pilot study. The endpoint of new tracheostomy/gastrostomy indicates a loss of skills required for daily living and suggests brainstem injury.[13] Whether hypotension with poor autoregulation increased the risk of brainstem injury or brainstem injury caused hemodynamic instability remains unclear.

Among children without ECMO, those with primary neurologic deaths spent more time with blood pressure below MAP_{OPT} and had greater MAP deviation below MAP_{OPT} during the first 48 hours after ROC than those who lived or died of cardiovascular failure in this pilot study. Whether children with severe brain injuries are more likely to have a mismatch in hemodynamic regulation relative to MAP_{OPT} or whether maintaining blood pressure closer to MAP_{OPT} would improve outcomes cannot be determined. It is possible that clinicians tolerated lower blood pressures when brain death or neurologic futility were anticipated. Blood pressure below MAP_{OPT} and ΔPCPC were not correlated once the data were stratified by ECMO status. This may be due to small sample sizes, or MAP_{OPT} may not relate to detailed functional neurologic changes. In a separate study, differences in the PCPC score correlated with psychometric tests in patients discharged from the PICU.[11]

HVx measures vasoreactivity in the frontal cortex, and global hypoxia may diffusely disturb autoregulation. Outcomes did not correlate to rSO_2. While AUC below MAP50 was associated with neurologic death, such a relationship was not identified for receiving a tracheostomy/gastrostomy. The observed associations between MAP_{OPT} and tracheostomy/gastrostomy and neurologic death in this pilot study seem reasonable because MAP_{OPT} identifies the MAP with best autoregulatory function even in patients with cerebral edema.

MAP_{OPT} increased with age and differed among children of similar ages. Unlike MAP_{OPT}, age-based blood pressure guidelines[7] do not account for evolving secondary brain injury. Following age-based blood pressure guidelines during intracranial hypertension could cause low cerebral perfusion pressure with hypoperfusion. Variability in MAP_{OPT} emphasizes the importance of using autoregulation monitoring to individualize hemodynamic goals.

The effects of ECMO on autoregulation are unclear and may vary with blood gas management strategies.[14] Cerebrovascular myogenic responses were impaired in an animal model of ECMO.[15] The sample size of children on ECMO in this pilot study was too small to infer whether MAP_{OPT} is associated with neurologic outcomes.

The effects of vasopressors on autoregulation after cardiac arrest are poorly defined. Epinephrine and dopamine were most frequently used in this study. In a piglet model, NIRS accurately measured CBF during epinephrine and dopamine infusions.[16] Epinephrine increased CBF more than dopamine as blood pressure increased,[16] suggesting that dopamine supported autoregulation better than epinephrine. In a piglet model of cardiac arrest, phenylephrine did not affect autoregulation.[3]

Given the small sample sizes in this pilot study, we conducted post-hoc power calculations for comparisons between children who did or did not receive a tracheostomy/gastrostomy, and children who did or did not die from a primary neurologic etiology. For the 19 children who did not receive ECMO, the power to detect a difference in the AUC below MAP_{OPT} was 26% between children who received a new tracheostomy/gastrostomy and those who did not. The power to detect a difference in the AUC below MAP_{OPT} was 30% between children who died from a primary neurologic etiology and children who lived or died from cardiovascular failure. Even with this limited power, we detected statistically significant differences in AUC below MAP_{OPT} in relation to these outcomes.

One limitation of our pilot study was that enrollment was limited to one institution. Given the small sample size, we were unable to control for additional factors that likely affect outcome, including ECMO status, vasopressors, temperature, location of arrest, and duration of chest compressions. Therefore, a multivariate analysis could not be conducted. It is possible that with a larger sample size, the effects of blood pressure autoregulation on neurologic outcomes would not be significant if these additional variables were accounted for in the analysis. Nonetheless, the findings in this pilot study suggest that a future study with a larger sample size and multivariate analysis that includes measurements of blood pressure and autoregulatory vasoreactivity might be valuable. Moreover, the duration of autoregulation monitoring differed among children because HVx calculations could begin only after arterial blood pressure and NIRS monitoring were established. To account for differences in absolute monitoring times, the AUC was normalized for the duration of monitoring. Early metabolic derangements may have caused alterations in vasoreactivity that were not captured because of the delay in monitoring. For instance, prostaglandins[17], metabolic acidosis[18], and altered adenosine homeostasis[19,20] after hypoxia could affect the regulation of CBF.[20–22] Some patients did not have HVx monitoring through the end of the 72 hour period. Associations between outcomes and blood pressure were only identified during the first 48 hours after ROC, and only five patients had HVx monitoring discontinued

before completion of this period. Nonetheless, exclusion of these patients' autoregulation status may have affected results. We did not use corroborating measures of CBF. HVx has been shown to correlate with transcranial Doppler measurements of CBF during cardiopulmonary bypass[6] and laser-Doppler measurements of CBF in a swine model of cardiac arrest.[1–3] Some patients were enrolled in a therapeutic hypothermia trial. Hypothermia after cardiac arrest may acutely decrease the blood pressure limits of autoregulation,[2] although this shift may not be sustained with prolonged hypothermia or rewarming.[23] Finally, the effects of seizures were not examined. Future studies are warranted to more robustly evaluate the usefulness of HVx monitoring in the various post-resuscitation states in the pediatric cardiac arrest population.

CONCLUSIONS

Continuous autoregulation monitoring with HVx identified the hemodynamic range with optimal vasoreactivity after cardiac arrest in this pilot study. Among children without ECMO, those who received a new tracheostomy/gastrostomy or had primary neurologic deaths spent more time with blood pressure below MAP_{OPT} and had greater blood pressure deviation below MAP_{OPT} than did children with better outcomes. The experimental technique of HVx autoregulation monitoring has the potential to become a clinically useful monitor to individualize neuroprotective hemodynamic goals after cardiac arrest.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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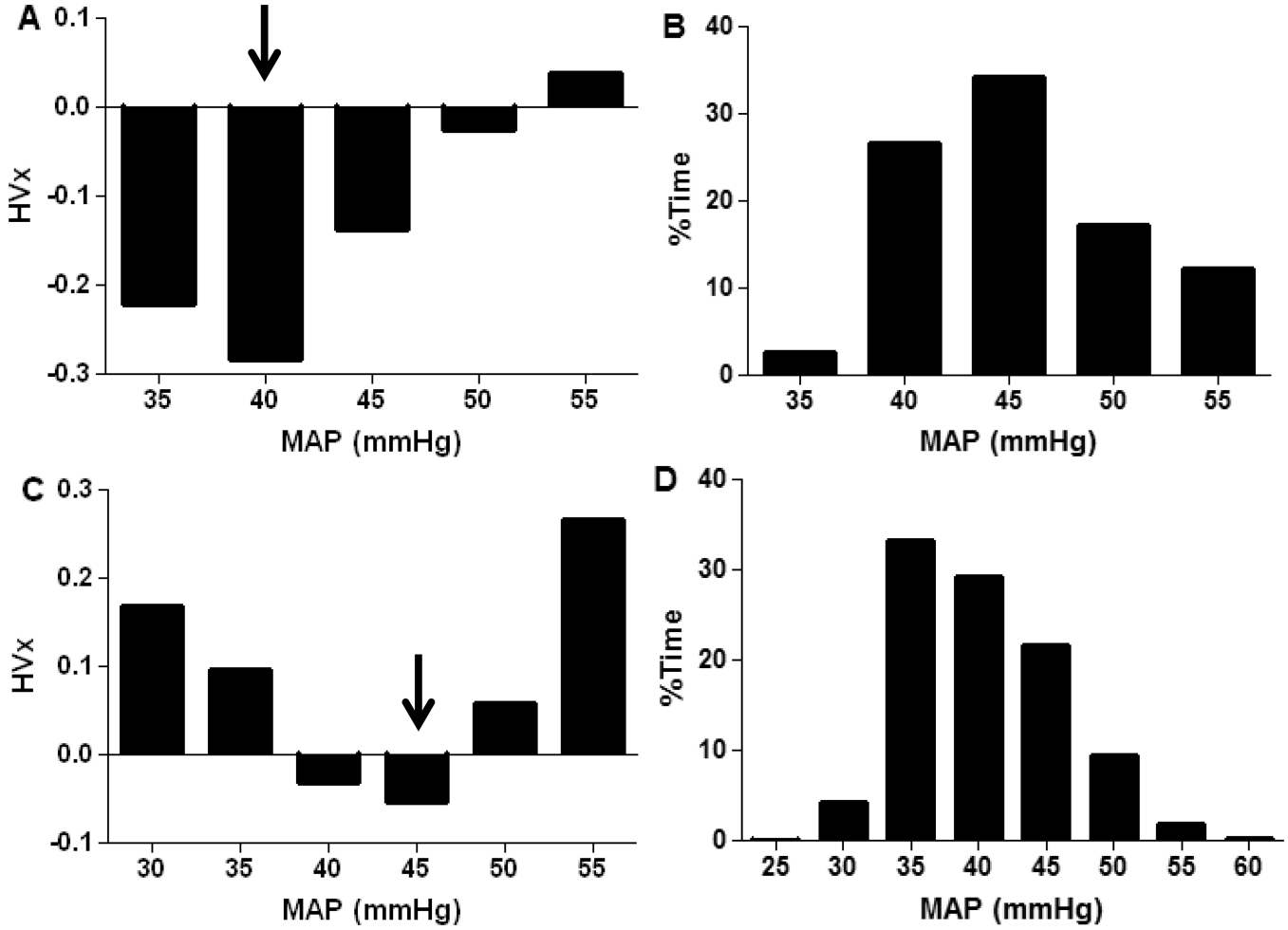

Figure 1.

Hemoglobin volume index (HVx) and mean arterial blood pressure (MAP) monitoring in two infants during the first 48 hours after return of circulation. (A, B) Patient 28 was 16 days old, had a change in the Pediatric Cerebral Performance Category score (ΔPCPC) of 0, and did not require a tracheostomy or gastrostomy. HVx showed an optimal MAP at 40 mmHg (nadir of HVx; arrow). (B) This patient spent 3% of the monitoring period with blood pressure below optimal MAP. (C, D) Patient 3 was 8 days old, had a ΔPCPC of 2, and received a new gastrostomy. HVx showed an optimal MAP at 45 mmHg (arrow). (D) This patient spent 67% of the monitoring period with blood pressure below optimal MAP.

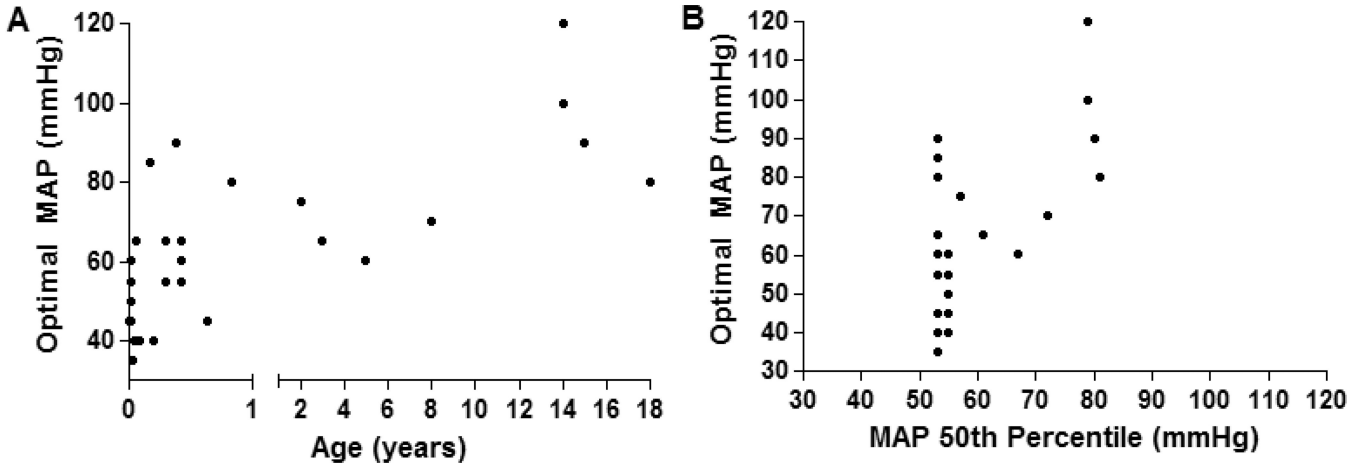

Figure 2.

Optimal mean arterial blood pressure (MAP) was identified during the first 48 hours after return of circulation in 29 children. (A) Optimal MAP increased with age. The discontinuous x-axis emphasizes the inter-patient variability in optimal MAP among patients of similar age. (B) Optimal MAP and the 50th percentile for MAP were mismatched in many children. Each circle represents one patient.

Table 1

Descriptions of Children and Cardiac Arrests

Characteristic	Number (%) (n =36)
Age	
< 1 year	20 (56)
1–10 years	10 (28)
11–18 years	6 (17)
Male gender	19 (53)
Arrest location	
In-hospital	25 (69)
Out-of-hospital	11 (31)
Duration of chest compressions	
1 min	4 (11)
2–10 min	15 (42)
11–30 min	11 (31)
31–90 min	6 (17)
First documented rhythm	
Sinus bradycardia	10 (28)
Asystole	8 (22)
PEA	6 (17)
V-fib or V-tach	4 (11)
SVT	1 (3)
Not documented	7 (19)
Etiology of cardiac arrest	
Respiratory	17 (47)
Cardiovascular	14 (39)
Trauma (no TBI)	1 (3)
Other	1 (3)
Unknown	3 (8)
Comorbidities after cardiac arrest	
Acute respiratory distress syndrome	8 (22)
Pneumonia	5 (14)
Sepsis	5 (14)

PEA indicates pulseless electrical activity; SVT, supraventricular tachycardia; TBI, traumatic brain injury; V-fib, ventricular fibrillation; V-tach, ventricular tachycardia.

Table 2

Medical Histories Prior to the Cardiac Arrest

Disease	No. (%) (n = 36)
Neurologic[a]	
No neurologic disease	25 (69)
Developmental delay	3 (8)
Seizure disorder	3 (8)
Intraventricular hemorrhage	1 (3)
Stroke	1 (3)
Meningitis	1 (3)
Cardiovascular	
Cardiac surgery ≤ 1 month before arrest	10 (28)
Single-ventricle congenital heart disease	4 (11)
2-ventricle congenital heart disease	3 (8)
Hypertension	1 (3)
Cardiomyopathy	1 (3)
Respiratory	
Asthma	6 (17)
ARDS	2 (6)
Tracheostomy	1 (3)
Gastrointestinal	
Gastrostomy for surgical feeding tube	4 (11)
Infectious	
Sepsis	3 (8)

ARDS indicates acute respiratory distress syndrome.

[a]Children did not have active neurologic diseases that would be associated with intracranial hypertension at the time of the cardiac arrest.

Table 3

Clinical Variables During Autoregulation Monitoring

Parameter	Mean (SD); 95% Confidence Interval (n=36)
Temperature (°C)	35.8 (1.2); 35.3–36.2
MAP (mmHg)	65 (19); 59–71
pH[a]	7.37 (0.07); 7.35–7.40
$PaCO_2$ (mmHg)[a]	44 (7); 41–46
PaO_2 (mmHg)[a]	121 (42); 106–136
Hemoglobin (g/dL)	11.3 (1.7); 10.7–11.9
WBC (no./mm^3)	9734 (5626); 7771–11697
Sodium (mEq/L)	147 (7); 145–150

MAP indicates mean arterial blood pressure; WBC, white blood cells.

[a]Arterial blood gas values.

Table 4

Autoregulation monitoring and identification of the optimal mean arterial blood pressure (MAP) by time period after return of circulation (ROC).

Period After ROC	No. of Patients	Duration of monitoring (hours; SD)	No. of Patients with identified optimal MAP (%)
First 12 hours	23	6 (3)	20 (87)
First 24 hours	30	15 (6)	26 (87)
Second 24 hours	30	23 (4)	28 (93)
Third 24 hours	26	19 (7)	26 (100)
First 48 hours	30	36 (8)	29 (97)
First 72 hours	26	55 (12)	24 (92)