Assessment of Splanchnic Perfusion with Gastric Tonometry in the Immediate Postoperative Period of Cardiac Surgery in Children

Renato Lopes de Souza, Werther Brunow de Carvalho, Miguel Angel Maluf, Antonio Carlos Carvalho

São Paulo, SP - Brazil

Objective - *A prospective, nonrandomized clinical study to assess splanchnic perfusion based on intramucosal pH in the postoperative period of cardiac surgery and to check the evolution of patients during hospitalization.*

Methods - *We studied 10 children, during the immediate postoperative period after elective cardiac surgery. Sequential intramucosal pH measurements were taken, without dobutamine (T0) and with 5mcg/kg/min (T1) and 10 (T2) mcg/kg/min. In the pediatric intensive care unit, intramucosal pH measurements were made on admission and 4, 8, 12, and 24 hours thereafter.*

Results - *The patients had an increase in intramucosal pH values with dobutamine 10mcg/kg/min [7.19± 0.09 (T0), 7.16±0.13(T1), and 7.32±0.16(T2)], (p=0.103). During the hospitalization period, the intramucosal pH values were the following: 7.20±0.13 (upon admission), 7.27±0.16 (after 4 hours), 7.26±0.07 (after 8 hours), 7.32±0.12 (after 12 hours), and 7.38±0.08 (after 24 hours), (p=0.045). No deaths occurred, and none of the patients developed multiple organ and systems dysfunction.*

Conclusion - *An increase in and normalization of intramucosal pH was observed after dobutamine use. Measurement of intramucosal pH is a type of monitoring that is easy to perform and free of complications in children during the postoperative period of cardiac surgery.*

Keywords: pH, splanchnic perfusion, dobutamine, gastric tonometry, pediatric cardiac surgery

Universidade Federal de São Paulo - Escola Paulista de Medicina
Mailing address: Renato Lopes de Souza – Praça Louveira, 12 – 03080-050 – São Paulo, SP - Brazil - E-mail: acarloscc@cardiol.br

In critically ill patients, the fundamental and initial organic lesion mechanism is tissue or cellular hypoxia. When a lack of oxygen occurs, the adenosine triphosphate (ATP) hydrolysis rate exceeds the synthesis rate, with a pH drop as a consequence. The low oxygen supply makes the organism mobilize its anaerobic sources of energy to meet the energy demand of cells and maintain their integrity [1]. Under such circumstances, CO_2 production in all tissues is directly related to the O_2 consumption rate.

The intracellular pH fall seems to be crucial for the cell deterioration process, and this information is fundamental for the diagnosis of anaerobiosis onset; it would be interesting to identify which tissues are the first to suffer hypoxia and acidosis and to find feasible ways of determining this acidosis [2].

The use of regional measures is essential, assuming that these areas might be early markers of systemic hypoperfusion. Other cellular metabolism markers can be used, such as arterial lactate, which is also a systemic measurement, frequently with a late elevation, because the liver has a great lactate oxidation capacity [3]. Global measurements give us little information about oxygen utilization and requirements at the tissue level [4]. Gastric tonometry contrasts with the poor sensitivity of some invasive methods for systemic assessment of oxygenation. Intramucosal pH measurement has been evaluated as a minimally invasive method capable of providing early information about inadequate tissue oxygenation even in clinically stable patients. However, intramucosal pH needs further study for the establishment of its critical value, where O_2 consumption becomes transport-dependent [5].

Approximately 50-60% of patients in the postoperative period of major surgeries and 80% of patients in intensive care units are believed to be liable to develop transient episodes of dysoxia (imbalance between oxygen supply and consumption), which are not diagnosed because apparently these patients are normal, that is, without detectable hemodynamic changes by the conventional methods, and

their compensation mechanisms maintain them this way [6].

Our objective in this study was to identify the intramucosal pH alterations during the patients' evolution in the immediate postoperative period of cardiac surgery in clinically stable children and to find out whether any alteration occurs in gastrointestinal perfusion when increasing doses of dobutamine are administered.

Methods

The study protocol was approved by the ethics committee of the university, and a written consent was obtained from the parents or responsible persons. The prospective, nonrandomized clinical study was carried out in the pediatric intensive care unit, including only patients who had undergone elective cardiac surgery with extracorporeal circulation, and excluding those who had any kind of contraindication for the passage of a nasogastric lead.

Ten children with a mean age of 41.3±25.1 months, a mean weight of 12.12±2.98kg, and a mean height of 92.2± 13.53 cm were evaluated. Their congenital cardiopathies and respective surgical corrections are presented in Table I. Patients were not divided into groups of those with cyanogenic or acyanogenic cardiopathies.

The patients received as a preanesthetic medication either midazolam or ketamine. Induction was made with an oxygen mask and isoflurane at a maximum concentration of 1%. Neuromuscular block was performed with pancuronium and anesthesia maintenance with fentanyl. Patients were medicated before surgery and during the postoperative period, with 3mg/kg/day intravenous ranitidine every 8 hours [7]. Extracorporeal circulation was carried out by nonpulsatile flow, and slight hypothermia or normothermia was applied.

In the operating room, NGS Catheter Trip tonometry leads were available (*gastric tonometer and sump* - Tonometrics, Inc., Worcester, MA, USA). After ensuring the localization of the lead in the stomach through auscultation followed by X-rays, 2.5mL of 0.9% saline solution were infused into the tonometer balloon (Fig. 1).

To calculate intramucosal pH, the Radiometer Copenhagen ABL 330 gasometry device was considered the standard. The intramucosal pH was calculated using the saline solution pCO_2 measurement (pCO_{2ss}), corrected by the equilibrium time as recommended by the manufacturer, and arterial bicarbonate (HCO_3 art.) with the Henderson-Hasselbach equation.

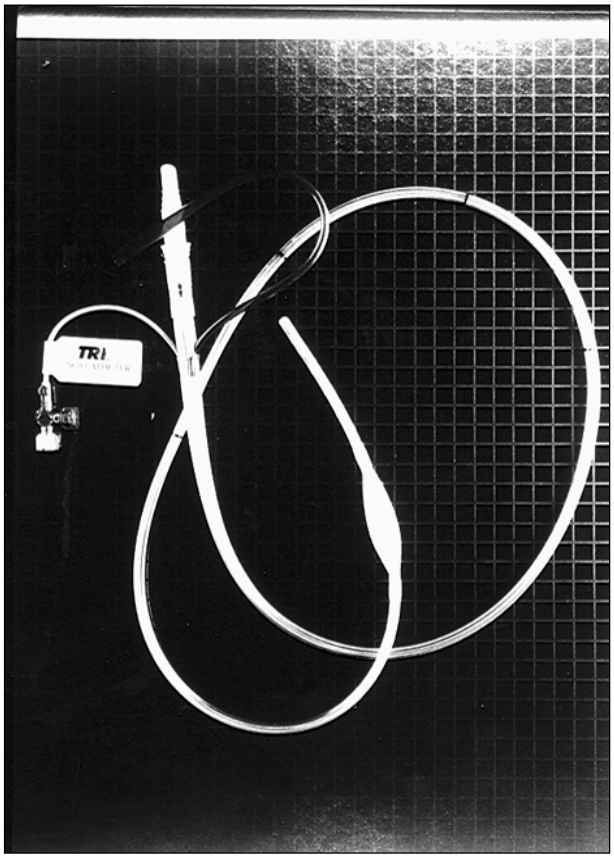

Fig. 1 – Assessment of splanchnic perfusion by using gastric tonometry during the postoperative period of cardiac surgery in children.

Upon admission to the pediatric intensive care unit, the patients' temperature was normalized, and they were put on intermittent mandatory ventilation. Intramucosal pH measurements were taken until the lead was removed, which occurred after extubation or when enteral feeding started. None of the patients was extubated or received enteral fee-

Table I – Distribution of patients by age, weight, height, congenital heart disease, and the respective surgical corrections performed

Age Months	Weight kg	Height cm	Diagnoses	Surgical Correction
87	17.2	115	Mitral failure	Mitral valvoplasty
36	12	92	Double entrance of LV and pulmonary artery bandage	Bidirectional cavo-pulmonary shunt
22	11.3	85	Abnormal origin of left coronary	Reimplantation of left coronary artery into the aorta
68	14.5	106	IVC	Ventriculoseptoplasty
24	10.4	85	Ib tricuspid atresia	Enlargement of IAC and bidirectional cavopulmonary
74	16.8	112	Double exit of LV + IVC + PS	Total correction with RV- PT tube
26	9.8	83	Double exit of RV + PS	Atrioseptectomy and central aorto-pulmonary shunt
27	10.1	82	Residual IVC in PO Fallot's Tetralogy	Closure of residual IVC
32	10	82	IVC	Ventriculoseptoplasty
17	9.1	80	IVC	Ventriculoseptoplasty

LV- left ventricle; RV- right ventricle; PT- pulmonary truncus; PS- pulmonary artery stenosis; IVC- interventricular communication; IAC- interatrial communication.

ding within the first 24hr of hospitalization. The assisting doctor's conduct was not influenced by the tonometry results, because they were unknown to him. The first measurements were made without any drug being given (immediately after admission), then with 5 mcg/kg/min and 10 mcg/kg/min of dobutamine, after a 90-minute waiting period from the change in drug infusion until the measurement was made. After patients were admitted to the pediatric intensive care unit, the measurements were compared, all of them having been made with patients receiving dobutamine (except on admission), at the following times: admission, 4, 8, 12, and 24hrs.

Clinical parameters (diuresis, heart rate, RR, capillary filling, thermal gradient), electrocardiography, mean invasive arterial pressure, central venous pressure, and pulse oxymetry were used to monitor patients.

The effect of giving dobutamine was analyzed by comparing the variables in 3 different situations: without dobutamine, with dobutamine 5mcg/kg/min and 10mcg/kg/min. For this analysis, the Friedman assay (χ^2_r) was used. The significance level adopted was 0.05 (α=5%).

Results

The intramucosal pH values and mean in the 3 scenarios (no drug, 5mcg/kg/min dobutamine, and 10mcg/kg/min dobutamine) are shown on Table II. These values did not show any statistically significant difference (p=0.103), but the patients showed a tendency toward an increase in intramucosal pH.

The mean period of extracorporeal circulation was 62.4 min and of anoxia was 43.5min. Surgery was performed with 5 patients under slight hypothermia and the other 5 under normothermia, with a similar intramucosal pH occurring at the end of extracorporeal circulation in all these patients (7.25±0.07 under hypothermia, and 7.27±0.09 under normothermia).

The mean intramucosal pH values during the patients' evolution in the pediatric intensive care unit are shown in table III. As compared with the intramucosal pH on admission, the patients had a significant rise in intramucosal pH after 12 hours, and this measurement remained stable after 24 hours (p=0.0459) (Fig. 2).

Table II – pHi values and mean of 10 children in 3 three situations: no dobutamine, 5mcg/kg/min, and 10mcg/kg/min dobutamine

	No dobutamine	5 mcg/kg/min	10 mcg/kg/min	
pHi	7.32	7.27	7.26	
pHi	7.09	7.01	7.52	
pHi	7.06	7.10	7.55	
pHi	7.09	7.05	7.17	
pHi	7.29	7.26	7.29	
pHi	7.18	7.14	7.30	
pHi	7.23	7.28	7.55	
pHi	7.20	7.08	7.37	
pHi	7.34	7.42	7.18	
pHi	7.18	7.04	7.08	
(Mean ± S.D.)	7.17± 0.11	7.14± 0.11	7.35± 0.15	χ^2_r = 4.55 p=0.103

Table III - pHi values and mean of during the internation.

	On admission	After 4hr	After 8hr	After 12hr	After 24hr
pHi	7.21	7.55	7.30	7.21	7.44
pHi	7.13	7.37	7.22	7.31	7.35
pHi	7.09	7.10	7.26	7.29	7.54
pHi	7.15	7.18	7.40	7.50	7.30
pHi	7.45	7.57	7.36	7.53	7.43
pHi	7.00	7.19	7.24	7.33	7.33
pHi	7.37	7.29	7.19	7.36	7.23
pHi	7.19	7.16	7.22	7.13	7.41
pHi	7.27	7.14	7.16	7.25	7.38
pHi	7.16	7.19	7.30	7.29	7.39
(Mean ± S.D.)	7.20± 0.13*	7.27± 0.16	7.26± 0.07	7.32± 0.12 *	7.38± 0.08 *

Admission ≠ (12hr = 24hr).

The patient's hemodynamic picture remained stable, with adequate hemoglobin saturation levels, and no metabolic or respiratory acidosis occurred, their mean hematocrit value being 33%. Only 3 patients had transitory hypotension, which was accompanied in 2 patients by heart rhythm disorders (junctional rhythm or bradycardia) during the immediate postoperative period.

None of the patients had renal failure, developed a multiple organ or system dysfunction, or died. All patients were removed from mechanical pulmonary ventilation without any intercurrent anomalies and were released from the pediatric intensive care unit 6 to 8 hours after extubation. Hospitalization time in this unit was at least 1 day and at most 3 days.

Discussion

During states of shock, a loss of the splanchnic self-regulation mechanism occurs, and both the humoral and neural mediators produce a selective vasoconstriction, leading to splanchnic ischemia. Note that the gastrointestinal tractus has endocrine, metabolic, immunologic, and barrier functions, in addition to its role in food absorption, and can therefore no longer be viewed as a passive organ. Intestinal ischemia and reperfusion can bring about an increase in permeability, allowing bacterial or toxin translocation to oc-

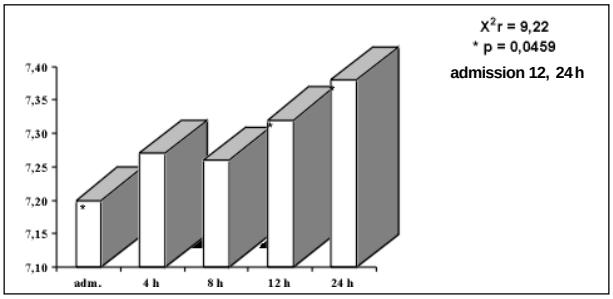

Fig. 2 – Graphical representation of elevation and normalization of pHi of the 10 patients during the first 24hr after admission to the pediatric intensive care unit.

cur, invading the portal circulation. Inadequate hepatic perfusion leads to a decreased clearance of bacteria and their products. Intestinal ischemia can be an important cause of multiple organ failure and death in critically ill patients [8].

The use of intramucosal pH measurements to predict complications after surgery was studied by Fiddian-Green and Baker [9], who measured intramucosal pH in 85 patients in the postoperative period of elective cardiac surgery and compared it with other monitoring methods. The high sensitivity of this method led the authors to recommend the utilization of intramucosal pH to reduce the risks of complications, without increasing the risks for the patients. In studies carried out by Mythen and Webb [10,11] on a total of 51 patients, an increase occurred in the number of complications in elective surgeries, with an increase in hospitalization costs in patients with a low gastric intramucosal pH during surgery; 14 patients developed complications (7 with multiple organ dysfunction) and 6 died.

During and after extracorporeal circulation, an increase in mediators causing vasoconstriction occurs, mainly in the levels of circulating angiotensin II, the hormone responsible for selective splanchnic vasoconstriction, being potentially able to alter the intramucosal pH. Gaer et al [12] compared the gastric tonometry alterations with the use of pulsatile and nonpulsatile flow and found a reduction in gastrointestinal perfusion, with gastric intramucosal acidosis and the development of postoperative complications. Landow et al [13] observed a drop in intramucosal pH during extracorporeal circulation, which continued even after reheating.

The data reported in the literature concern adults; in our study, we selected children in the immediate postoperative period of corrective surgeries congenital cardiopathies with extracorporeal circulation, to observe and assess the applicability of this kind of monitoring and to characterize the evolution of this variable (intramucosal pH) during the immediate postoperative period. The definition of a normal behavior curve is the first step toward the subsequent definition of its role and of the true benefit of using it in complicated cases.

Volemic replacement may be insufficient to maintain intestinal perfusion and improve the intramucosal pH during the immediate postoperative period of cardiac surgeries. It seems that adrenergic agents play an important role in the improvement of splanchnic circulation and in the reversal of intramucosal acidosis, and dobutamine seems to be an effective agent in the improvement in splanchnic blood flow [14]. Inotropic support is usually necessary after heart surgery, particularly when long lasting myocardial ischemia is present. In the pediatric intensive care unit, the great majority of children are placed on dobutamine during the immediate postoperative period and until they become hemodynamically stable, always after correction of volemia, of hemoglobin, and of metabolic acidosis, whenever necessary. In this study, we attempted to assess whether progressive increases in the drug would bring about a better splanchnic flow normalization response during the first hours after admission to the pediatric intensive care unit.

In addition to its use as a diagnostic method, some authors suggest monitoring intramucosal pH for therapeutic evaluation and triaging purposes. Comparing dobutamine infusion and infusion of packed red blood cells in 21 septic patients, Silverman and Tuma [15] concluded that it was better to give dobutamine than packed red blood cells to reverse intramucosal acidosis. Dobutamine also seems to prevent the reduction of the intestinal blood flow during endotoxemia; consequently its prophylactic use can limit intestinal ischemia and prevent the development of multiple organ and system dysfunction [16]. Hernández et al [17] obtained a greater improvement in intramucosal pH using dobutamine in patients with inflammatory systemic response syndrome and shock than with amrinone.

According to Parviainen et al [18], the effects of dobutamine on intestinal perfusion during the cardiac postoperative period may not be uniform. In their article, they report that dobutamine increased cardiac output, splanchnic flow, and systemic and splanchnic oxygen transport (TO_2), but splanchnic O_2 consumption was not altered (leading to a reduction in systemic and regional O_2 extraction). Intramucosal pH was not different between the control and the normal cardiac output groups, but it was lower in the group with low cardiac output, suggesting an alteration in the flow distribution within the splanchnic territory.

In our cohort, several patients maintained a low intramucosal pH (pHi<7.32), without major clinical alterations, even after the initial volemic replacement by plasma or albumin or even packed red blood cells. Patients had an increase in intramucosal pH as dobutamine was progressively increased, but the values were not statistically significant. With the 5mcg/kg/min dose, no increase occurred in the intramucosal pH, but with 10mcg/kg/min dobutamine it reached a value considered normal (7.32), which might reflect a recovery in the intestinal blood flow, either by spontaneous recovery from extracorporeal circulation or by the use of the inotropic drug. Because we did not use subgroups with and without dobutamine, we cannot define whether an actual benefit was brought about by the use of the drug.

Not all authors agree that inotropic drugs have this improving effect on intramucosal pH. A study by Uusaro et al [19] suggests that patients with an uncomplicated postoperative period might tolerate a low intramucosal pH for a short time without ulterior complications, whereas in another study they conclude that dobutamine seems to improve splanchnic perfusion during the immediate postoperative period of cardiac surgery [20].

Niinikoski and Kuttila [21] reported an initial drop in the intramucosal pH after cardiac surgery with extracorporeal circulation. This drop reached its lowest values by the end of surgery and during the first 3 hours of hospitalization in the pediatric intensive care unit, and later on the patients a slow improvement in the intramucosal pH, similar to our own experience. In some studies, even using inotropic and vasodilating substances, no postoperative normalization of the intramucosal pH was observed 24hrs after admission [22,23].

Rey et al [24] analyzed the postoperative intramucosal

pH of children and found that its decrease preceded hemodynamic complications, whereas Casado-Flores et al [25] found a higher mortality rate in patients with an intramucosal pH below 7.30 on admission.

In our work, intramucosal pH stabilized 12hr after patients entered the intensive care unit, where they all received dobutamine. Despite the low initial values of the intramucosal pH, no patient experienced multiple organ dysfunction or died. So many questions still must be addressed, such as how long can the low intramucosal pH levels be maintained without further consequences.

In 19 trauma patients, Kirton et al [26], observed that survivors who were unable to normalize their intramucosal pH within the first 24hr had an increased global time of stay in the hospital and in the intensive care unit. The monitoring of the gastric intramucosal pH may therefore benefit patients at risk of developing low cardiac output or shock and also to those whose hemodynamic variables are impossible to monitor [27].

This experience enabled us to conclude that tonometry is a safe technique, easy to perform, and uncomplicated, even in the pediatric population.

In summary, hemodynamic monitoring with gastric tonometry is, according to the literature, a valuable procedure during the immediate postoperative period of cardiac surgery in children. In our patients, intramucosal pH rose to normal values 12hr after cardiac surgery, showing the probable normalization of blood flow in the gastric region.

Invasive hemodynamic measurements provide us with more data and greater safety for the change of inotropic and vasoactive drug dosages, yet major difficulties exist for their regular use in pediatrics. Perhaps gastric tonometry can improve the titration of these drugs in pediatric patients with severe hemodynamic instability. As we had no cases of multiple organ dysfunction or low cardiac output in our cohort sample, we were unable to evaluate the intramucosal pH alterations in this kind of patient. Our results can, however, be used as a guide to outline the behavior of intramucosal pH during the immediate postoperative period of cardiac surgery in children who do well. Dobutamine may be partially responsible for the improvement in splanchnic circulation, thus reducing the risks of postoperative complications, but proper conclusions need targeted studies to define its role.

Controlled, randomized clinical studies, with protocols accompanied by intramucosal pH monitoring should be carried out before dobutamine is used routinely in pediatric patients after cardiac surgery.

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