Evaluation of gastric intramucosal pH during and after pediatric cardiac surgery

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Abstract

Objectives: In adult patients, intramucosal pH (pH$_i$) has been advocated to detect postoperative complications. The purpose of our study was to evaluate this technique in pediatric patients during and after cardiac surgery. Methods: Thirty-five infants (age: 5 days to 15 years, median 1.8 years; and weight: 3.2–32 kg, median 9.8 kg) were studied. pH$_i$ was measured before cardiopulmonary bypass (CPB), after 30 min of CPB, prior to weaning off CPB, at intensive care unit arrival, and 6, 12, 24, 48 and 72 h after surgery. Results: There were no complications related to the tonometer. A pathologically low pH$_i$ $<$ 7.32 was found during surgery in less than 17%, at intensive care unit arrival in 83% and after 48 h in 18%. pH$_i$ values were lower ($P < 0.05$) at intensive care unit arrival ($7.25 \pm 0.08$) and after 6 h ($7.28 \pm 0.09$) than afterwards. pH$_i$ correlated with arterial pH ($r = -0.66$), central–peripheral temperature difference ($r = -0.36$), lactate ($r = -0.32$) and central venous pressure ($r = -0.21$). Patients after a Fontan procedure had postoperatively a lower pH$_i$ than after other operations ($P < 0.05$). None of the patients died or developed organ failure. Six patients had signs of organ dysfunction. Their pH$_i$ (median 7.23, range 7.14–7.28) could not differentiate them from the other patients. Conclusions: With current equipment, tonometry cannot be recommended for the management of pediatric patients after cardiac surgery. However, as a semi-invasive method tonometry deserves further evaluation. © 1997 Elsevier Science B.V.

Keywords: Cardiac surgery; Infants; Intramucosal pH; Neonates

1. Introduction

Adequate tissue oxygenation is the major therapeutic goal in severely ill patients. Failure to do so results in an oxygen debt, anerobic metabolism and tissue acidosis. Global indices of the adequacy of tissue perfusion such as blood pressure, heart rate, cardiac output, urine flow or lactate concentration may not reflect regional perfusion [1–4]. Therefore, the need exists for additional parameters that should be organ specific, to help to establish the adequacy of tissue oxygenation.

The intestinal mucosa is known to be highly susceptible to ischemic injury [5,6]. Disturbances in the microcirculation induced by cardiopulmonary bypass (CPB) appear to be an especially important cause of gut mucosal ischemia. Non-pulsatile bypass is a potent stimulus for the release of endogenous vasoconstrictors including angiotensin II [7,8] which further reduces splanchnic blood flow.

In experimental models [2,5,9,10] and in adult intensive care patients [11,12], the intramucosal pH of the gut or the stomach (pH$_i$) has been shown to be a reliable index of local tissue perfusion. Gastric pH$_i$ can be measured semi-invasively and reliably using a silicone balloon tonometer placed in the lumen of the stomach [1]. In adults, an abnormally low pH$_i$ is associated with increased morbidity and mortality in patients...
Table 1
Median pH_i after different procedures

<table>
<thead>
<tr>
<th>Operation of:</th>
<th>n</th>
<th>Median pH_i</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ICU arrival</td>
<td>6 h Post</td>
<td></td>
</tr>
<tr>
<td>Atrioventricular septal defect</td>
<td>5</td>
<td>7.29</td>
<td>NS</td>
<td>7.29</td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>9</td>
<td>7.28</td>
<td>NS</td>
<td>7.28</td>
</tr>
<tr>
<td>Transposition of the great arteries</td>
<td>4</td>
<td>7.26</td>
<td>NS</td>
<td>7.32</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>6</td>
<td>7.27</td>
<td>NS</td>
<td>7.23</td>
</tr>
<tr>
<td>Fontan procedure</td>
<td>5</td>
<td>7.13</td>
<td>P &lt; 0.01</td>
<td>7.20</td>
</tr>
<tr>
<td>Others</td>
<td>6</td>
<td>7.25</td>
<td>NS</td>
<td>7.36</td>
</tr>
</tbody>
</table>

The table shows the numbers of patients after different procedures and their median pH_i at ICU arrival and after 6 h. NS, not significant. ‘Others’ include two patients with a Rastelli procedure, three patients with aortic or mitral valve reconstruction or replacement, and one patient with cor triatriatum. This group had a higher pH_i after 6 h. P-values show significant differences to the rest of the patients.

after cardiac [1,13,14] or general [15] surgery, in ICU patients with sepsis [16,17] and in multiple trauma patients [18].

Purpose of our study was to evaluate this technique in the pediatric age group, to describe the changes of the gastric pH_i after cardiac surgery for congenital heart disease, to compare it with other, more conventional forms of monitoring and to evaluate its utility as an early indicator of morbidity and mortality.

2. Patients and methods

The study was approved by the local ethics committee and all parents gave written informed consent. The study population consisted of 35 patients who underwent open heart surgery for congenital heart disease (Table 1). Patients age ranged from 5 days to 15 years (median 1.8 years) and weight ranged from 3.2 to 32 kg (median 9.8 kg). In the ICU the following parameters were recorded: arterial and central venous pressures, urine output, central and peripheral temperatures, arterial blood gases, and serum lactate levels. Cardiac output was measured in 14 patients using the Fick principle with directly measured oxygen consumption (Deltatrac, Datex, Finland).

After induction of anesthesia and endotracheal intubation, a tonometer (Tonometrics, Worcester, MA, USA) was inserted into the patient’s stomach together with a normal nasogastric tube. We choose to use the sigmoid tonometer which is used to measure sigmoid mucosal pH_i in adults. It is much smaller than the gastric tonometer for adults, but for neonates a much smaller device would be desirable. The tonometer has a silicone balloon at its tip. Saline injected into the balloon equilibrates with $P_{CO_2}$ in the superficial layers of the gastric mucosa, since its silicone membrane is permeable to gases but not liquids. The gastric intramus-

cosal pH (pHi) can be calculated by substituting the $P_{CO_2}$ of the saline aspirated from the tonometer and the arterial blood bicarbonate ($HCO_3^-$) in the modified Henderson Hasselbalch equation [19]: $\text{pHi} = 6.1 + \log [HCO_3^- / (P_{CO_2} \times a \times k)]$, where $a$ is the CO_2 solubility in plasma and $k$ is a time-dependent equilibration constant provided by the manufacturer. An equilibration time of at least 60 min was used. Saline $P_{CO_2}$ was determined using conventional blood gas analyzers (intraoperative period: Nova Stat Profile 5, Nova Biomedical, Waltham, MA, USA; and intensive care unit: ABL 520 Radiometer, Copenhagen, Denmark). Measurements were done before CPB, after 30 min of CPB, prior to weaning of CPB, at the arrival at the intensive care unit (ICU), and 6, 12, 24, 48 and 72 h after bypass if the patients were still intubated. The tonometer was removed before extubation or after 72 h. Based on the results of previous studies in adults [1,20], a pH_i of 7.32 was taken as the lower limit of normal. We evaluated the intraoperative and the ICU periods separately, because two different blood gas analyzers were used, which may lead to different results [21].

3. Statistical analysis

Differences between time points were evaluated by analysis of variance for repeated measures. In the presence of significant differences, multiple pairwise comparisons using the Student-Newman-Keuls method were performed. Association of pH_i values with other parameters was assessed by linear regression analysis (Pearson product moment correlation). The relationship between pH_i and postoperative complications was evaluated by comparing the pH_i in patients with and without postoperative complications using the Mann-Whitney rank sum test. Statistical significance was defined as $P < 0.05$. 
4. Results

In all patients the tonometer could be inserted without problems, but for the newborn a smaller device would be desirable. There were no complications related to the tonometer. The mean duration of non-pulsatile cardiopulmonary bypass and cross-clamping of the aorta was 135 ± 57.2 (range 60–295) min and 69 ± 37.4 (range 0–175) min, respectively. During surgery, 104 measurements were obtained. The pHi was within a normal range and only a minority of patients had pathological values (Table 1). There were no significant overall effects of time. During the ICU period, 160 pHi measurements were obtained. At ICU arrival, mean gastric pHi was 7.25 and increased slowly to 7.35 at 24 h post-bypass (Table 1). Measurements at 12, 24, 48 and 72 h were significantly different (P < 0.05) from those at arrival and 6 h. The pHi measured at 6 h was higher than on arrival (P < 0.05). At ICU arrival, 83% of the patients had pathologically low (pHi < 7.32) pHi; this incidence decreased over time to 18% of the intubated patients (Table 1, Fig. 1).

pHi was correlated with the pH of arterial (r = 0.66, P < 0.001) and central venous (r = 0.65, P < 0.001) blood and the standard base excess of arterial blood (r = 0.64, P < 0.001). There were weak negative correlations with serum lactate levels (r = −0.32, P < 0.001), central–peripheral temperature difference in the first 12 h (r = −0.36, P < 0.001) and central venous pressure (r = −0.21, P < 0.05). There was no correlation with cardiac index, oxygen delivery or the duration of bypass and cross-clamping of the aorta.

Patients had lower pHi after a Fontan procedure (P < 0.01) than after other operations at ICU arrival and after 6 h (Table 2). None of the patients died and none developed organ failure. Six patients had temporary signs of non-cardiac organ dysfunction. Four patients had an elevated alanine amino transferase (GPT) over 75 U/l (normal level < 25 U/l) and bilirubin over 29.1 μmol/l (normal level < 17 μmol/l), and two patients had an elevated serum lipase over 570 U/l (normal level < 190 U/l), one of them had additionally an elevated serum creatinine of 150 μmol/l (normal level < 53 μmol/l) and urea of 15.7 mmol/l (normal level < 6.4 mmol/l). All these patients had a pHi under 7.28 (median 7.23, range 7.14–7.28) within the first 6 h after the operation. However, this pHi was not significantly different (P = 0.65) from that in patients without organ dysfunction. The pHi had a sensitivity of 100% and a specificity of 13.9% to detect organ dysfunction, when using the lower normal of less than 7.32 for adults. None of the other parameters which were monitored, e.g. cardiac output, arterial pHi, etc., or bypass times could identify these patients.

5. Discussion

In the adult patient population, gastrointestinal tonometry has been extensively evaluated [1,11,15–18,22] and has even been used to guide therapy [23]. Its semi-invasive character makes it especially suitable for the pediatric age group. In contrast to another study in pediatric patients [24], we found no tonometer-related complications in our patients. Since we used the orogastric route in all patients, there was no epistaxis. However, it became apparent that smaller catheters are needed for neonates and prematures.
Because normal values of the pH\textsubscript{i} for the pediatric age group have not been established, we used the adult value of at least 7.32 [1,20]. During hypothermic cardiopulmonary bypass, adequate visceral perfusion seems to be preserved in comparison with the pre-bypass values and for the reduced oxygen consumption, which is in agreement with other studies [11,12]. In the immediate postoperative period, when the patients are normothermic and visceral oxygen consumption rises, we found a pathologically low pH\textsubscript{i} in 83% of our patients, whereas in series of adult patients 49% or less had a pathological pH\textsubscript{i}. The reason for this high incidence of gastrointestinal hypoperfusion remains to be evaluated. It can be speculated that it is due to the more extensive repair with longer bypass mains to be evaluated. It can be speculated that it is high incidence of gastrointestinal hypoperfusion re-

erations. In critically ill adult patients, pH\textsubscript{i} measure-

ment gastric tonometry cannot be recommended for

volvulus [26]. It is concluded that with current equip-

ment gastric tonometry cannot be recommended for

the perioperative management of infants and children undergoing cardiac surgery. We feel, however, that

the method as well as the device deserves technical refinement and further evaluation in the pediatric age group.

References


