Gastric tonometry as a method of visceral oxygenation monitoring in patients undergoing coronary revascularisation

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Abstract

Objective: The aim of the study was to assess gastric mucosal pH during certain parts of a major cardiac procedure (hypo- and normothermic), and then throughout the first postoperative day. Methods: Gastric mucosal pH was measured using a tonometer, in 15 patients subjected to elective CABG procedures. The patients were also assessed haemodynamically and serum lactate concentrations were measured. Results: It was found that cardiopulmonary bypass did not suppress visceral perfusion. The most critical was the period between 4th and 12th postbypass hour when a tendency towards decreased cardiac output and oxygen delivery was noted. At the same time oxygen consumption was increasing which resulted in triggering of anaerobic metabolic pathways, that was mirrored by significant rise in serum lactate levels. During this period of time the lowest, although not critical levels of gastric mucosal pH were recorded, suggesting a relative decrease in splanchnic perfusion. Conclusion: Extracorporeal circulation does not significantly compromise splanchnic perfusion. Tonometry is a valuable, non-invasive method of visceral oxygenation monitoring. The first postoperative day is an especially critical time for a cardiac patient—a frequent control of haemodynamic and acid-base balance parameters is absolutely mandatory. © 1997 Elsevier Science B.V.

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1. Introduction

Gastrointestinal complications are not frequently met after cardiac surgery (0–2%), although the associated mortality is extremely high and in various reports reaches up to 67% [4]. It is highly probable that mucosal ischaemia plays a major role in the pathogenesis of such problems. Gastrointestinal mucosa is especially sensitive to ischaemia, which is a natural consequence of low output states and hypovolaemia. Hypoperfusion causes shunting of oxygen from arterioles to venules in the mucosal counter-current system [10], making villous tips hypoxic. Thus, the integrity of the mucosal barrier may become disrupted, permitting bacteria and their endotoxins penetrate through [1]. The induced inflammatory response leads to myocardial depression, intravascular thrombosis, hypermetabolism, vasodilation, increased vascular permeability, and eventually to a multiorgan failure (MOF). Global haemodynamic parameters like cardiac output (CO), blood pressure (BP), heart rate (HR) or diuresis may not be sufficient for proper assessment of regional, visceral perfusion. Usually much earlier the decrease of gastrointestinal mucosal pH (pHi) is noted. Tonometry is a non-invasive and reliable, though indirect method of splanchnic oxygenation monitoring. Its principle depends on the fact that the pCO₂ of the fluid instilled into the lumen of a hollow viscous (such as ventricle or colon) equilibrates with that in the wall of the intestine. Knowing the bicarbonate concentration of the intestinal mucosa
which is assumed to be equal (nearly equal) to that of the arterial blood, one can calculate the pH of the mucosa using the Handerson-Hasselbach equation. Its validity as a tool for the monitoring of visceral perfusion or more precisely visceral oxygenation has been extensively proven in several experimental and clinical trials [7–9]. It has been confirmed that a decrease in pH below 7.25–7.35 [2,6] signifies a critical level of ischaemia in visceral vascular bed and is well correlated with a number of serious complications after major cardiac procedures and generally in seriously ill patients [2,5,11,12] (abdominal aortic surgery, intensive care).

The aim of the present study was to assess gastric mucosal pH during certain parts of a major cardiac procedure (hypo- and normothermic), and then throughout the first postoperative day.

2. Material and methods

Tonometry was used for gastric mucosal pH assessment in 15 patients subjected to elective coronary artery bypass surgery (CABG). Individuals were randomly selected from a cohort with good ventricular contractile function (LVEF > 45%). The local ethic committee as well as each patient’s approval was obtained. The same protocol of premedication (Morphine + Scopolamine + Diazepam im.) and anaesthesia (Fentanyl + Droperidol iv.) was utilised in all individuals. Muscular relaxation was achieved thanks to repeated doses of Pancuronium. All patients were given Cimetidine (200 mg iv. every 8 h, from the beginning of surgery until commencing of oral feeding). Arterial blood pressure was monitored in the radial artery. The balloon catheter inserted in the pulmonary artery permitted the calculation of a full haemodynamic profile. After the anaesthesia induction the catheter with a silicone balloon at its tip was introduced into patients’ stomachs in order to measure gastric mucosal pH. The catheter position was confirmed by means of epigastrum auscultation. The haemodynamic profile, pHı and blood lactate concentrations were assessed in following moments: (1) prior to anaesthesia induction (without pHı assessment); (2) postinduction; (3) in the 30th min of hypothermic cardiopulmonary bypass (CPB); (4) right before weaning from bypass; (5) 30 min after-; (6) 60 min after-; (7) 4 h after-; (8) 8 h after-; (9) 12 h after-; (10) 24 h after the weaning from bypass. All patients were cooled to the oesophagus temperature 32°C. For all procedures we used non-pulsatile pump flow. Blood was oxygenated during most of the surgery with Sorin Monolyth capillary equipment. The hearts were stopped and then intermittently or continuously perfused via either anter- or retrograde route using cold blood cardioplegia with warm reperfusion. For nine (60%) patients arterial (IMA) grafting to LAD was performed. On average 2.9 distal anastomoses were sutured (range from 2 to 5).

pHı was calculated from a modified Handerson-Hasselbach equation:

\[
pHi = 6.1 = \log_{10}\left(\frac{[\text{HCO}_3^-]}{p\text{CO}_2 \times K}\right)
\]

K is a value dependent on a time of CO₂ exchange between mucosa and a tonometer balloon.

At no times anaesthesiologists were informed of pHı results and patients were treated according to standards accepted in our institution.

3. Results

In Fig. 1 the changes in mucosal and arterial pH in respective moments of surgery are represented. At no time the parameters were significantly different and correlated well with each other. It is apparent that acidosis was most prominent between 4th and 12th postbypass hour, with a return to baseline values at the end of the first postoperative day.

The mean arterial pressure (MAP) was statistically lower during cardiopulmonary bypass. A successful surgery allowed for an increase of MAP over 80 mmHg, which is lower than baseline, although not significantly. But again 4 h postbypass, the mean arterial pressure began to fall (Fig. 2). Also cardiac index (CI) dropped down slightly following induction of anaesthesia. During cardiopulmonary bypass it is a ‘pump index’. Postbypass period was associated with a return of cardiac performance to preoperative levels (Fig. 2).

The curves representing oxygen delivery (DO₂) and consumption (VO₂) are plotted on Fig. 3. The oxygen utilisation is relatively low during a cardiac procedure performed with the use of CPB in mild hypothermia (32°C). Active rewarming, and then the whole postoperative course is associated with a gradual rise in tissue oxygen demand, which is not coupled with adequate increase in its delivery (negative correlation in early postbypass period).

![Fig. 1. Gastric mucosal pH (pHi) and arterial blood pH (pH). * On each deno... values that are significantly different (higher or smaller) than the baseline value of a respective partner.](image-url)
From the very beginning of CPB a gradual increase in serum lactate concentrations was noted. The increase was initially rapid, and lactate concentrations stabilised after weaning from bypass reaching highest levels between 4th and 12th postbypass hour. Then lactate levels decreased, yet remained significantly higher in comparison to preoperative values at the end of the first postoperative day (Fig. 4).

4. Discussion

The basic task of a cardiovascular system is to provide tissues’ metabolic requirements. Inadequate perfusion leads to the activation of anaerobic metabolism pathways, oxygen debt and tissue acidosis [5]. Such parameters as cardiac output, blood pressure, heart rate or diuresis say little about the state of the local organ blood supply [6].

Arterial and gastric mucosal pH were very similar at all moments they were recorded. We found their changes to correlate with each other, although we cannot say (at least not yet) that changes of pHi are dependent on pHa (arterial pH). Splanchnic vascular bed is quite an autonomous system, and mucosal acidosis may not only be a manifestation of systemic acidosis. During low output states (e.g. hypovolaemia) defensory reflexes divert blood flow to vital organs like brain. Profound haemodynamic changes during and early post cardiopulmonary bypass may further mask possible relationships. It is also worth to note that none of our patients was perfused with pulsatile flow. There are inconsistent data [13,14] as to how flow pattern affects the performance of cardiovascular system (or splanchnic in particular). Such distinction might also need to be investigated.

As seen in our group of patients the mean arterial pressure was sufficient throughout the whole surgery (controlled hypotension during cardiopulmonary bypass), as well as thereafter, in the intensive care unit (ICU), allowing for a proper diuresis. Anaesthetic agents cause insignificant decrease of Cardiac Index. During bypass pump flow is maintained at the level computed from patient’s weight and height, which is usually well below baseline CI levels (Fig. 2). After a surgery in patients successfully weaned off bypass, a heart is sufficient enough to maintain CI comparable with baseline levels. Only one individual from our group had to be supported with an infusion of Epinephrine and intraaortic counterpulsation (IABP). The others were receiving low doses (3–5 mg/kg per min) of Dopamine or Dobutamine.

The increasing serum lactate levels, which is especially expressed during a phase of active rewarming suggest an imbalance between oxygen delivery capacity and its consumption, which is markedly elevated at that time. Although a complex kinetics of lactate metabolism, as well as its diminished hepatic metabolism rate make it difficult to establish simple relationship between lactate levels and patient’s energetic state [3].

As it was proven, cardiopulmonary bypass did not cause hypoperfusion, at least in splanchnic (or more precisely gastric) vascular bed. Perhaps a hypometabolic state resulting from hypothermia protects from possible hypoperfusion, should it happen. It is worth to note however, that mucosal pH was assessed in intervals of at least 30 min, necessary for CO₂ to equilibrate. Therefore short periods of hypoperfusion may have happened and become unrecognised. The tendency for many haemodynamic and metabolic parameters to get worse between 4th and 12th postbypass h was also evident in respect to acid–base equilibrium. That is a time when most patients are already extubated and seem to be ‘stable’. But it is also a time requiring special vigilance from attending personnel.

There are reports suggesting that pulsatile flow results in better organ (including splanchnic) perfusion.
The first, preliminary part of the study was however conducted on ‘standard’ patients, without changing anything in our routine (routinely non-pulsatile flow is used in our institution). We intend to compose two other study groups; one including patients perfused with pulsatile pump flow and another built from individuals operated on in normothermic conditions. Comparing results will allow us to draw conclusions on how those settings influence gastrointestinal oxygenation during and post-surgery. It could be also interesting to see how visceral perfusion changes (if it does at all) when no inotropes are administered and when other drugs are used (selective β-agonists like Dopexamine or phosphodiesterase inhibitors like Amrinone).

It is a routine in our institution to administer Cymetidine intraoperatively and then until oral feeding is commenced (in selected cases longer). Histamine (H2) receptor antagonists suppress both the volume and concentration of gastric acid being one of the tools of stress ulceration prevention. However we do not know whether it could have changed the correlation between pHa and pHi. Interesting also might be how H+ pump inhibitors (e.g. Omeprazole) influence this relationship.

5. Conclusions

Gastric mucosal pH assessment is a valuable, non-invasive method of visceral oxygenation monitoring. The properly conducted extracorporeal circulation does not significantly compromise splanchnic perfusion. The first postoperative day is an especially critical time for a cardiac patient—a frequent control of haemodynamic and acid–base balance parameters is absolutely mandatory.

References


