

Real-Time Measurement of Rectal Mucosal Microcirculation During Cardiopulmonary Bypass

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Objectives: Mesenteric ischemia is still a fatal event after cardiac procedures. No adequate intraoperative methods are available to monitor the gastrointestinal mucosal microcirculation in real-time conditions. The aim of the study was to assess a newly designed microprobe using laser Doppler flowmetry and remission spectroscopy.

Design: One-group, prospective, nonrandomized, open, pilot diagnostic study.

Setting: Monocenter university hospital.

Participants: 50 patients (n = 38 males, 67 ± 6 years) scheduled for cardiopulmonary bypass (CPB) were prospectively included.

Intervention: During anesthetic induction, the transrectal microprobe (30 × 15 mm) was positioned between the inferior and middle rectal valve (5-8 cm). Time periods were summarized at T1 = pre-CPB, T2 = CPB, T3 = post-CPB.

Measurements and Main Results: In 39 of 50 patients, data recruitment with the microprobe was successful.

ORGAN PERFUSION is difficult to monitor for diagnostic purposes during extracorporeal circulation in patients undergoing cardiac surgery. Surrogate parameters (eg, lactate) are used as diagnostic aids. Direct monitoring of functionality may be a challenge. The early postoperative phase is characterized by complications originating in the intraoperative, extracorporeal bypass time. These serious events in the intensive care setting include gastrointestinal tract complications, such as hemorrhage, ulceration, ileus, pancreatitis, peritonitis, intestinal ischemia, and mesenteric thrombosis. Ritz and Buhr showed that such complications are observed in 3% of cases.¹ Of their patients, 25% required a laparotomy, indicating that the diagnosis of a gastrointestinal complication sometimes was made only by the surgeon or pathologist. A high mortality rate is associated with gastrointestinal (GI) complications.² The most frequently described complication is gastrointestinal hemorrhage which, like most other gastrointestinal problems, is accessible to conservative or endoscopic therapy and has a comparatively favorable prognosis. Less common are ischemic events, which are associated with mortality rates between 70% and 100% and, therefore, represent a great challenge for cardiac surgical intensive care physicians.¹

The main problem presented by intestinal ischemia is late diagnosis, usually because of nonspecific symptoms. Other organ complications are noticed sooner, because cardiac, pulmonary, and renal functions are accessible to direct monitoring. This is not the case with intestinal ischemia, although rapid diagnosis is particularly important in this context because lethality is significantly lower with early versus late surgical intervention.¹ Intestinal ischemia is admittedly difficult to diagnose in patients under analgesic sedation. Since GI complications occurs late, every patient with rising lactate levels and persistent, therapy refractory metabolic acidosis, which usually is accompanied by leukocytosis and paralytic ileus, should be referred immediately for selective angiography of the mesenteric vessels. In cases involving nonocclusive mesenteric ischemia, local vasodilator therapy (eg, with papaverine) can be performed during the same session, which

usually rapidly improves the situation. If selective angiography is not available, immediate laparotomy is indicated. Even with rapid intervention, a mortality of 50% is to be expected, and survival is unlikely after 12 hours.³

Measurement failures were due to fecal contaminations and probe dislocations. Rectal blood flow and velocity significantly decreased after bypass initiation (T2). Lowest flow rates were recorded after cross-clamp removal and did not recover at the end of bypass (T3). No side effects of the probe were noted.

Conclusions: The new microprobe allows reproducible, safe, intraoperative, real-time evaluation of the rectal mucosal microcirculation. It could be a useful diagnostic tool to prevent mesenteric ischemia by optimizing extracorporeal circulation in future studies. However, first correlation of rectal blood flow and postoperative events (eg, ischemia, lactate) in a large cohort are necessary.

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KEY WORDS: cardiopulmonary bypass, microcirculation, laser Doppler flowmetry, mucosa, mesenteric ischemia

An intraoperative diagnostic method of real-time, direct measurement of intestinal mucosal blood flow would be desirable. The micro-lightguide spectrophotometer O2C (LEA Medizintechnik, Giessen, Germany) is a diagnostic tool for noninvasive determination of oxygen supply of tissues perfused with blood. The main measurement options using a glass fiber probe in the illuminated tissue are oxygen saturation of hemoglobin, relative hemoglobin quantity, relative blood flow, and blood flow velocity. The validity of the O2C device has been reported in numerous publications.⁴⁻⁷ Pathologic O₂ supply, which can lead to angiogenesis or cell death with subsequent organ failure, can be assessed at an early stage by local measurement. Impairments of microcirculation of the mucosa can be evaluated objectively. With few exceptions, however, data were generated in the past by transdermal measurements. Only the further development of a rectal probe has now made an intraoperative measurement possible. The aim of this diagnostic pilot study was to obtain initial information regarding the reproducibility and practicability of the new method.

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METHODS

Fifty patients ($n = 38$ males, 67 ± 6 years, $n = 41$ coronary artery bypass grafts, $n = 9$ valve procedures and/or combinations) fulfilled the inclusion criteria (age > 18 years, planned cardiac surgery procedure with use of cardiopulmonary bypass) and nonexclusion criteria (stoma, hemorrhoidal nodes, rectal cancer disease) and were prepared for rectal probe placement after induction of anesthesia. The characteristics and concomitant diseases reflected the usual cardiac surgery patient profiles (Table 1). Laxative measures (enema) were performed on the day before surgery to reduce fecal contamination. The probe was covered with a protective sheath coated with a local analgesic (Xylocain 2%, AstraZeneca, Wedel, Germany) and placed at a depth of 5-10 cm in the rectal ampulla with the aid of an introducer rod under digital control. The correct position and signal transmission were checked by observing the biphasic curve pattern.

After monitoring was initiated, general anesthesia was induced (0.3-1 $\mu\text{g}/\text{kg}$ of sufentanil (Sufenta, Janssen-Cilag GmbH, Neuss, Germany), 1-2.5 mg/kg of propofol (Disoprivan, AstraZeneca GmbH, Wedel, Germany), and 0.6 mg/kg of rocuronium (Esmeron, Essex GmbH, Munich, Germany). For maintenance of general anesthesia, all patients received 1 to 2 vol% sevoflurane (Sevoran, Abbott, Wiesbaden, Germany) and intermittent boluses of sufentanil. Isotonic crystalloid (Sterofundin, B. Braun GmbH, Melsungen, Germany) was infused perioperatively based on institutional standards. The indication for red blood cell transfusion was a hemoglobin < 7.5 mg/dL.

The extracorporeal circuit included a membrane oxygenator (Quadrox oxygenator, Maquet Cardiopulmonary AG, Hirrlingen, Germany) and a roller pump system (HL20, Maquet Cardiopulmonary AG) equipped with a cardioplegia heat exchanger (Plegiox, Maquet Cardiopulmonary AG). The circuit was primed with 1,250 mL of crystalloid solution (Sterofundin, B. Braun Melsungen AG, Melsungen, Germany) according to institutional standards. Heparin (Heparin-Natrium Braun, B. Braun Melsungen AG) was administered to maintain an activated coagulation time (ACT) greater than 400 seconds. During cardiopulmonary bypass (CPB), nonpulsatile flow was maintained at 2.6 to 3 L/min/m², and mean arterial pressure (MAP) was maintained at 50 to 70 mmHg by the administration of norepinephrine (Arterenol, Sanofi-Aventis GmbH, Hoechst, Germany). Myocardial protection was achieved with cold blood cardioplegia (20°C). Extracorporeal circulation was performed under mild hypothermia (32°C). On completion of surgery, the patients were warmed and weaned from CPB.

Table 1. Patient (n = 50) Demographic Characteristics, Intraoperative Data, and Postoperative Course

Age, years	67 \pm 6
Male	38/50
NYHA class \geq III	19/50
Elective surgery	50/50
ASA class > 2	11/50
LV function $< 30\%$	2/50
Diabetes type II	31/50
CPB (min)	120 \pm 48 min
CCT (min)	73 \pm 41 min
Operation time (min)	244 \pm 54 min
CABG	41/50
In-hospital mortality	2/50
30-day mortality	2/40
Redo-thoracotomy	4/50
Mesenteric ischemia	0/50

Abbreviations: ASA, American Society of Anesthesiologists; CABG, coronary artery bypass graft; CCT, cross-clamp time; CPB, cardiopulmonary bypass; LV, left ventricle; NYHA, New York Heart Association.

To reverse the anticoagulant effects of heparin, protamine sulfate (Protaminsulfat, Novo Nordisk Pharma GmbH, Vienna, Austria) was administered, guided by the ACT.⁸

The optical method used for measuring relative blood flow by laser Doppler, hemoglobin amount, and hemoglobin oxygenation has been described in detail in the literature.¹¹ In brief, the micro-light guide spectrophotometer O2C (Oxygen to See; LEA Medizintechnik, Giessen, Germany) transmits continuous laser light (830 nm and 30 mW) and white light (20 W, 500-800 nm, 1 nm resolution) to the tissue where it is scattered and collected at the surface (Fig 1). The collected light is split into its spectral components by a charge-coupled device array and is converted into an electrical signal. The laser Doppler shift is detected, and the product of moving erythrocytes and the time velocity of each erythrocyte are used to calculate the relative rectal blood flow (RBF). White light is used for the detection of oxygen saturation (SO₂) and relative amount of hemoglobin (rHb). The tissue hemoglobin value is determined by the amount of light absorbed by the tissue. This measurement represents a hemoglobin concentration per tissue volume and is independent of vessel density, vessel lumen, and hemoglobin quantity in the blood.⁷ The change in color of the reflected light is due to wavelength-dependent absorption of the applied white light and can be used to calculate the oxygen saturation of hemoglobin. Adjustment of the distance between the application of the light and the detection of the reflected light allows detection in different tissues.^{8,9}

In the present study, a newly developed transrectal probe (LFX 8, LEA Medizintechnik, Giessen, Germany) was placed before draping the patient in the operating room and was removed at the end of surgery. Rectal blood flow, rHb, and SO₂ measurements were performed continuously (Fig 2).

Interpretation of the measured results in the direct time interval was difficult. A high amplitude interval within the 1-second measurement cycles results in a large spread, which impedes an assessment of the measured values for SO₂, rHb, flow, and velocity. Calculation of the arithmetic means of the measured values for 5-minute intervals greatly improves on-screen interpretation of the measured values (Fig 3). For statistical processing, the means of the time intervals t₁ = pre-pump, t₂ = cross-clamp, and t₃ = reperfusion were calculated for all 39 patients. The evaluation and graphical presentation of the recorded data were performed with tables and line charts using Excel 2010 (Microsoft Corporation, Redmond, WA) and the statistics program SPSS 21.0 (IBM, Chicago, IL), which also was used for the statistical analysis. The data sets were evaluated by calculating the mean and standard deviation of all data sets. Two sample dependent *t* tests for comparing means were used according to their function. An error probability of $p < 0.05$ was defined by consensus as statistically significant. No sample size calculation was performed for this one-arm diagnostic pilot study. Patients gave written informed consent (Clinical Trials Gov No.: NCT01425931 /Ethics Committee No.: 318/11).

RESULTS

Because of patient disinfection, preparation for surgery, or fecal contamination, 11 patients experienced dislocation of the probe and loss of adequate signal strength. These were mainly coronary artery bypass graft procedures in which the legs were raised for disinfection before harvesting of venous bypass grafts. To avoid jeopardizing the sterility of the operative field, no repeat placement was attempted. None of the patients showed a probe-related complication. All of the patients had to be stabilized with vasopressors during perfusion to increase the MAP (norepinephrine, mean 0.08 $\mu\text{g}/\text{kg}/\text{min}$, range 0.05-0.5 $\mu\text{g}/\text{kg}/\text{min}$). No patient developed mesenteric ischemia or other gastrointestinal complications during the postoperative course. In-hospital mortality was 4%.

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