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Received: 9 May 2000
Final revision received: 25 October 2000
Accepted: 19 December 2000
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This study was supported by grant 32-43290.95 from the Swiss National Science Foundation

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Abstract  Objectives: To assess the hemodynamic and metabolic adaptations to enteral nutrition (EN) in patients with hemodynamic compromise.
Design and setting: Prospective study in a university hospital surgical ICU, comparing baseline (fasted) with continuous EN condition.
Patients: Nine patients requiring hemodynamic support by catecholamines (dobutamine and/or norepinephrine) 1 day after cardiac surgery under cardiopulmonary bypass.
Intervention: Isoenergetic EN via a postpyloric tube while catecholamine treatment remained constant.
Baseline (fasted) condition was compared to continuous EN condition.
Measurements and main results: Cardiac index (CI), mean arterial pressure (MAP), pulmonary and wedge pressures, indocyanine green (ICG) clearance, gastric tonometry, plasma glucose and insulin, and glucose turnover (6,6\(^{2}\)H\(_{2}\)glucose infusion) were determined repetitively every 60 min during 2 h of baseline fasting condition and 3 h of EN. During EN CI increased (from 2.9 ± 0.5 to 3.3 ± 0.1 \text{min}^{-1} \text{m}^{-2}), MAP decreased transiently (from 78 ± 7 to 70 ± 11 mmHg). ICG clearance increased (from 527 ± 396 to 690 ± 548 ml/min), and gastric tonometry remained unchanged, while there were increases in glucose (158 ± 23 to 216 ± 62 mg/dl), insulin (29 ± 23 to 181 ± 200 mU/l), and glucose rate of appearance (2.4 ± 0.2 to 3.3 ± 0.2 mg min\(^{-1}\) kg\(^{-1}\)).
Conclusions: The introduction of EN in these postoperative patients increased CI and splanchnic blood flow, while the metabolic response indicated that nutrients were utilized. These preliminary results suggest that the hemodynamic response to early EN may be adequate after cardiac surgery even in patients requiring inotropes.

Keywords  Carbon dioxide · Cardiac surgical procedures · Gastric mucosa · Lactate · Postoperative care · Splanchnic circulation

Introduction

Enteral nutrition (EN) is the currently recommended technique of artificial nutrition in critically ill patients. EN has many advantages over parenteral nutrition, such as maintenance of gut mucosal barrier function [1], reduction in nosocomial infections [2], better tolerance to carbohydrates, and reduced acute-phase response to inflammation or infection [3]. In addition to its metabolic effects, EN activates a series of physiological responses involving the digestive, cardiovascular, respiratory, and immune systems. In healthy subjects the digestion and absorption of nutrients induce typical hemodynamic changes, consisting of an increase in both cardiac output and mesenteric blood flow [4, 5].
EN is well tolerated in most ICU patients in whom the gastrointestinal tract is available as feeding route. In patients with severe circulatory failure, it is commonly thought that EN must be avoided since the systemic and splanchnic hemodynamic responses to nutrition may be altered, precluding a normal utilization of nutrients by the gastrointestinal tract [6]. However, preliminary observations from our ICU suggest that EN can be used in cardiac surgery patients with hemodynamic compromise [7]. In terminal cardiac failure the decreased cardiac output leads to splanchnic hypoperfusion and malnutrition, the so-called cardiac cachexia [8]. In this condition there is preliminary evidence that nutritional support may help improve the patient’s clinical condition [9], although the hemodynamic adaptation to artificial nutritional is poorly understood.

We conducted a prospective observational study to assess the early systemic and splanchnic hemodynamic and the metabolic adaptation to EN, in patients actively treated for low cardiac output and hypotension on the day after cardiac surgery.

Materials and methods

The study was conducted according to the principles established in the Declaration of Helsinki and was approved by the Ethics Committee of Lausanne University School of Medicine. Nine patients scheduled for cardiac surgery under cardiopulmonary bypass were enrolled after providing written, preoperative, informed consent. Included were high-risk patients with either reduced left ventricular function or complex valvulopathy, requiring a perioperative pulmonary artery catheter for circulatory monitoring as assessed by the anesthesiologist. Exclusion criteria were: absence of informed consent, age over 75 years, presence of preoperative liver, renal, endocrine or metabolic disorder (in particular diabetes requiring oral or insulin treatment), and cardiogenic shock.

The patients were anesthetized by a standard technique, including etomidate, fentanyl, and vecuronium for induction, and midazolam and fentanyl for maintenance. Cardiopulmonary bypass was performed under moderate hypothermia (28-32°C), using a membrane oxygenator and a nonpulsatile flow. At the end of anesthesia patients were transferred to the ICU, where they were managed according to a standardized protocol, including: (a) controlled mechanical ventilation and respiratory weaning; (b) morphine and propofol for sedation and analgesia; (c) fluid resuscitation with normal saline and starch solutions; (d) blood transfusion to maintain hemoglobin concentration at 9.0 g/dl or higher; (e) dobutamine as inotrope after full fluid and blood resuscitation; (f) norepinephrine in continuous infusion to achieve mean arterial pressure of 70 mmHg or higher. Femoral arterial and thermocatheter pulmonary arterial catheters (Thermocatheter catheter, Abbott, North Chicago, Ill, USA) were used for monitoring and blood sampling. Upon ICU arrival a postpyloric feeding tube was inserted under endoscopic control.

Study design

Patients were studied in the morning of the first postoperative day after a total fasting period of 30 h. Each patient was his own control; data obtained during EN were compared to baseline fasted data.

General procedures

Prior to the study the anthropometric data and the operative risk score [10] were recorded, and biochemical measurements were performed. The experiment lasted 300 min, starting with a baseline period of 120 min. Thereafter a continuous infusion of enteral polymeric diet containing 22% of calories as protein, 53% as carbohydrate, and 25% fat at 130% of the measured energy expenditure (see below) was administered for 180 min. The following variables were measured: systemic and pulmonary hemodynamics, ST segment analysis, pulmonary gas exchange, gastric tonometry, indocyanine green (ICG) clearance, and glucose turnover. Hemodynamic measurements included mean arterial pressure (MAP), heart rate, cardiac index (CI) by thermodilution (average of five values using 10 ml glucose at room temperature, regardless of the respiratory cycle), pulmonary artery pressure (PAP), and pulmonary artery wedge (PAWP) pressure. Indexed systemic vascular resistance (SVRI) was computed. The measurements were repeated every 60 min. The infusion of catecholamines remained constant during the study period, and PAWP was maintained constant by fluid infusion. Electrocardiographic monitoring for cardiac arrhythmia and ST segment analysis was recorded continuously (II and V5, Merlin, Hewlett-Packard, Geneva, Switzerland). Oxygen consumption (VO2), carbon dioxide production (VCO2), and energy expenditure were determined using a Deltatrac indirect calorimeter (Datex Instruments, Helsinki, Finland) and the de Weir equation [11]. This measurement was performed by collecting the ventilator expiratory gases or with a ventilated hood in extubated patients. In three patients already extubated who did not tolerate the hood, VO2 was determined by the Fick method, based on cardiac output by thermodilution and oxymetry determinations of arterial (SaO2) and mixed-venous (SvO2) O2 saturation [12]. Energy expenditure was then computed by means of the de Weir equation [11], assuming a respiratory quotient of 0.8. Gastric tonometry was performed every 60 min by a Tri NG catheter (Tonometrics, Worcester, Mass., USA) using a buffer solution [13], a 238 pHa blood gas analyzer (Ciba-Corning, Basel, Switzerland), and the correction factor provided by the manufacturer. The pH and the arteriovenous gradient of CO2 were computed according to standard formula [14]. ICG clearance was determined before (at 90 min) and during EN (at 270 min) [15]. A primed (12 mg bolus) infusion of ICG (I-131, Akorn, Decatur, Ill., USA) was administered at 1.2 mg/min for 30 min. Two arterial blood samples were drawn after 25 and 30 min of infusion. Plasma concentrations were measured with a spectrophotometer at 805 nm (Perkin Elmer Lambda 2, Norwalk, Conn., USA), and the two values were averaged.

After blood collection to determine basal glucose isotope enrichment a primed continuous infusion of 6.6H2-glucose (prime 6 mg kg-1 mmol-1 fasting plasma glucose, continuous 60 µg kg-1 min-1) was started. After allowing 2 h for tracer equilibration, blood samples were collected at 60-min intervals for calculation of glucose turnover from 6.6H2-glucose enrichment. In addition, plasma glucose, insulin, free fatty acid, and lactate concentrations were monitored.

Analytical procedures

Plasma 6.6H2-glucose was measured by gas chromatography–mass spectroscopy on a Hewlett Packard instrument (GC