Intraaortic Counterpulsation During Cardiopulmonary Bypass Impairs Distal Organ Perfusion

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Background. **Recent studies have focused on the use of fixed-rate intraaortic balloon pumping (IABP) during cardiopulmonary bypass (CPB) to achieve pulsatile flow. Because application of an IABP catheter may represent a functional obstruction within the descending aorta, we explored the effect of IABP-pulsed CPB-perfusion with special attention to perfusion above and below the IABP balloon.**

Methods. **Sixteen animals received an IABP catheter that remained turned off position (NP group, n = 8) or was switched to an automatic mode of 80 beats/min during CPB (PP group, n = 8). Flow-data and pressure-data were obtained above and below the IABP balloon. Tissue perfusion was evaluated by microspheres.**

Results. **IABP-pulsed CPB-perfusion, as assessed at 30 minutes on CPB, increased proximal mean aortic pressure ($p < 0.05$) and carotid artery blood flow ($p < 0.001$), but decreased distal mean aortic pressure ($p < 0.001$). The decrease of distal mean aortic pressure in the PP group was associated with a 75 % decrease ($p < 0.001$) of renal tissue perfusion. During nonpulsed perfusion the respective variables remained essentially unchanged compared with pre-CPB levels.**

Conclusions. **Using IABP as a surrogate to achieve pulsatile perfusion during CPB contributes significantly to lowered aortic pressure in the distal portion of aorta and impaired tissue perfusion of the kidneys. The results are focusing on effects that may contribute to organ dysfunction and acute kidney injury. Consequently, assessment of perfusion pressure distal to the balloon should be addressed whenever IABP is used during CPB.**

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The controversy of pulsatile vs nonpulsatile perfusion during cardiopulmonary bypass (CPB) remains unsolved [1, 2]. Although a number of studies are unable to demonstrate any advantage of pulsed CPB perfusion [2–4], pulsatile CPB flow has been associated with improved cardiac, renal, and pulmonary outcomes, better cytokine profiles, endothelin and hormone levels, and an improved respiratory index [1].

The limited clinical use of real pulsatile CPB perfusion has partly been related to the lack of suitable pump technology generating real physiologic pulsatility. A number of studies have, however, concluded that even nonphysiologic pulsatility achieved with conventional pumps is more beneficial than nonpulsatile perfusion in end-organ recovery, at least during pediatric CPB [5]. Similar results are also well documented from animal studies [6].

The intraaortic balloon pump (IABP) as an alternative to advanced and expensive pump technology delivering pulsatile perfusion during CPB, was first presented by Pappas and coworkers [7] as early as 1975. They included 56 patients who needed IABP support and compared IABP-pulsed perfusion during CPB with a nonpulsatile group. Postoperative low cardiac output syndrome did not occur in patients after pulsatile perfusion and even improved left ventricular performance could be demonstrated. In addition, supportive drugs and diuretics were not needed after pulsed CPB perfusion in contrast to the results obtained when nonpulsatile perfusion was used [7].

A number of more recent studies have focused not only on the beneficial effects of preoperative IABP application in high-risk patients allocated to coronary bypass operations [8, 9] but also on prolongation of fixed-rate IABP counterpulsation during cardiac operations because it contributes to improve whole-body perfusion, vital organ preservation, and reduced coagulative and fibrinolytic response [10–13]. In addition, pulsatility per se preserves endothelial nitric oxide release [14].

Despite the favorable effects of IABP counterpulsation, its use remains hampered with well-known adverse effects such as lower extremity ischemia and acute abdominal complications related to irreversible and fatal

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Abbreviations and Acronyms

AOP = aortic pressure
CPB = cardiopulmonary bypass
Dist = distal
EEP = energy equivalent pressure
erg/cm^3 = ergon per cubic centimeter
GI = gastrointestinal
IABP = intra aortic balloon pump
MAP = mean arterial pressure
NP = nonpulsatile perfusion
PP = pulsatile perfusion
Prox = proximal
SHE = surplus hemodynamic energy

organ damage that partly may be associated with misplacement of the IABP catheter [15]. The association between IABP use and the development of acute kidney injury (AKI) has also been part of the discussion, although still without any conclusion. However, further evidence on an association of IABP as an early postoperative risk factor for the development of AKI was recently presented [16]. In a previous report by Deakin and colleagues [17], the use of IABP was also associated with an intermittent obstruction of the descending aorta during cardiopulmonary resuscitation. With these aspects in mind, we evaluated the effect of intraaortic counterpulsation on vital organ perfusion in organs below the IABP balloon during CPB.

Material and Methods

This study was approved by the Institutional Animal Use and Care Committee under surveillance of the Norwegian Animal Research Authority, (Oslo, Norway), and the study was performed in accordance with the National Institute of Health *Guidelines for the Care and Use of Laboratory Animals*.

Animals, Animal Handling, and Anesthesia

Sixteen pigs (Norwegian Landrace, Norhybrid), randomized into pulsatile (PP group; n = 8) or nonpulsatile perfusion (NP group; n = 8), received humane care, and were acclimatized for 1 week within the laboratory housing area before the experiments. All animals were fasted overnight with continuous access to water. Anesthesia included midazolam, fentanyl, and pancuronium infusion, and isoflurane inhalation [18].

Instrumentation and CPB

A 7.5F, 25 mL IABP (Datascope Corp, Fairfield, NJ) was inserted through the left femoral artery to a roentgenogram-confirmed position in the descending aorta with the catheter tip at the level of the aortic valve. Correct position in relation to the left subclavian artery and diaphragm was recontrolled in the cardiac-arrested animals after the experiments were ended.

Flow measurements were done in the right carotid and femoral arteries (transit-time flowmetry; Med-Stim AS, Oslo, Norway). Millar MPC-500 pressure-tip catheters (Millar Instruments Inc, Houston, TX) were placed in the aortic arch and abdominal aorta for measurements of aortic pressure above (Prox AOP_{mean}) and below the IABP balloon (Dist AOP_{mean}). Transit-time flow probes and Millar catheters were applied in each position within a distance of approximately 4 cm. Blood flow and pressure signals were sampled and digitalized with a rate of 200 Hz by a Gould ES2000 system (Gould Instrument Systems, Valley View, OH).

A soft-tip catheter was placed in the left atrium for administration of baseline 15-μm Dye-Trak F fluorescent microspheres (Triton Technology, San Diego, CA). For reference sampling of microspheres in the aortic arch, a rigid catheter was introduced through the right mammary artery.

After administration of heparin (6 mg/kg plus 3 mg/kg after 1 h), the ascending aorta was cannulated with an 18F EOPA aortic arch cannula (Medtronic Inc, Minneapolis, MN) and the right atrium with a 29F MC2X 91429 three-stage venous return cannula (Medtronic). Standard equipment for an open heart operation was used, including a Quadrox-I Adult microporous membrane oxygenator, VHK 2000, venous hard-shell reservoir, and standard heart-lung machine tubings equipped with a Maquet Rotaflow Centrifugal Pump RF-32 (Maquet Cardiopulmonary AG, Hirrlingen, Germany), as recently described [19].

Stabilization for 60 minutes was allowed before initiation of CPB with nonpulsatile pump flow set at 100 mL/kg. On calculated flow, the IABP was switched to an automatic mode of 80 beats/min in the PP group or kept in the off position in the NP group.

Ventricular fibrillation was achieved with a 9V direct current battery held shortly onto the right ventricle.

Microspheres

Dye-Trak F fluorescent microspheres (15 μm, 6 mL, 1,000,000 spheres/mL) were used to calculate blood flow rate (mL/min/g) in the different organs. At baseline, the microspheres were delivered into the left atrium and into the arterial line of the CPB circuit after 30, 90, and 180 minutes on CPB. Reference arterial blood samples of 40 mL were simultaneously collected during sphere injections through the mammary artery at a rate of 20 mL/min for 2 minutes.

Energy Equivalent Pressure and Surplus Hemodynamic Energy

Precise quantification of arterial pressures and waveforms were done to facilitate hemodynamic comparisons between different perfusion modes and studies. Energy equivalent pressure (EEP) and surplus hemodynamic energy (SHE) were calculated before and after 30 minutes of CPB, as described by Undar and colleagues [20], to characterize pulsatile conditions proximal and distal to the IABP balloon. EEP was calculated according to the formula: $EEP = \int fpdt/\int fdt$ where f is blood flow, alternatively pump flow rate, p is mean arterial blood pressure, and dt is time period. The product of flow and