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Automated Cardiovascular Analysis and Treatment (ACAT)

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Introduction

In the evaluation of the critically ill, the focus of attention has shifted from intravascular pressures to blood flow and oxygen-derived variables. Indeed, the arterial pressure can still be well maintained within the normal range by strong compensatory mechanisms while the cardiac output has significantly changed following the alteration of one or several of its determinants. Hypovolemia, cardiac tamponade or heart failure can result in a significant fall in cardiac output before arterial pressure falls. Similarly, monitoring of heart rate remains a poor indicator of blood flow. Oxygen delivery, which depends on arterial oxygen content and cardiac ouput, is the most fundamental determinant of cellular function. Tissue hypoxia remains difficult to assess clinically, even though the determination of blood lactate levels can facilitate the diagnosis [1, 2].

The relationship between oxygen uptake and oxygen supply has become a subject of great interest in critical care medicine. Oxygen uptake can be either measured from the oxygen content differences of the inspired and expired gases or calculated from the Fick equation by multiplying cardiac output by the arterio-venous oxygen difference. In normal conditions, oxygen consumption remains constant when oxygen supply varies within a relatively wide range of values. This state is called oxygen-supply independent. It is only when oxygen supply has fallen below a critical value that oxygen uptake becomes oxygen supply dependent. This critical value occurs when oxygen extraction from the tissues become maximal [3].

Critical states associated with acute respiratory failure or sepsis are often characterized by a state of supply dependency despite a relatively normal value of oxygen supply [2, 4, 5]. The abnormal oxygen extraction characterizing these states has been attributed to various factors including local hypoxia, release of various mediators, endothelial edema and formation of microemboli, all resulting in maldistribution of blood flow and cellular hypoxia [2, 4, 5]. This so-called pathological oxygen supply dependency has been associated with the development of multiple organ failure and ultimate death [5]. Therefore, it appears fundamental to rapidly recognize these pathological states and correct them. Indeed, their presence could indicate that cardiac output even within the normal range, might not be high enough to meet the oxygen demand of the tissues.

Although this phenomenon has been well recognized, the appreciation of the adequacy of cardiac output remains vague. Similarly, the titration of vasodilators or inotropic agents is still often based either on clinical impressions or on measurements of pressure rather than blood flow. One reason for this is that optimization of cardiac output and oxygen supply necessitates repeated cardiac output measurements at regular intervals as this procedure requires time and disponibility. We therefore developed a system called automated cardiovascu-

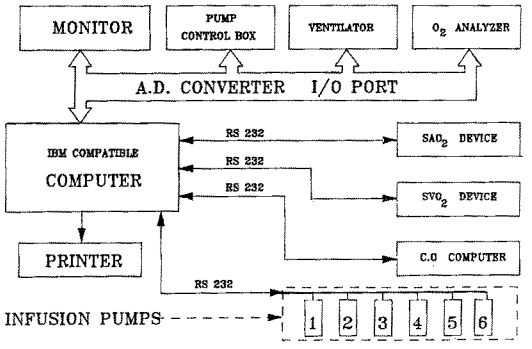

Fig. 1. Hardware and connections of the ACAT system.

lar analysis and treatment (ACAT) to have an on-line assessment of oxygen-derived variables in the critically ill.

Description of the system

The ACAT system can be used on any patient with a pulmonary artery (PA) catheter in place. Ideally, this catheter should be equipped with fiberoptic fibers to continuously measure mixed venous oxygen saturation ($S\bar{v}O_2$) [6]. This is not, however, an absolute necessity. A pulse oximeter can be attached to the patient's ear or finger to continuously measure arterial oxygen saturation (SaO_2) non-invasively. The two monitoring devices represent what is called dual oximetry, a technique which can provide valuable information on gas exchange and peripheral oxygen extraction [7, 8].

The hardware of the ACAT system is represented in Figure 1. The system includes an IBM-compatible computer connected to the standard cardiac motor, to a pump control box for automated cardiac output measurements, to the mechanical ventilator for patients who are mechanically ventilated, and to a praramagnetic oxygen analyzer for continuous measurement of oxygen consumption from the expired gases in the same patients. The computer is also connected by RS 232 ports to a pulse oximeter, a mixed venous oximeter, a cardiac output computer and an unlimited number of infusion pumps. The computer is also connected to a printer.

The entire system is transported on a cart easily

Fig. 2. The complete ACAT set-up at the bedside.

brought to the bedside (Fig. 2). From the top to the bottom are placed the computer with its hard disk and its printer, the paramagnetic oxygen analyzer, the pulse oximeter, the cardiac output computer and the venous oximeter. A second cardiac output computer is necessary because the SvO_2 device does not have the output protocol for cardiac output value. At the very bottom is the control box for automated cardiac output measurements by the thermodilution technique. A 10 ml seringe is connected to the proximal port of the PA catheter and to a closed Co-set infusion system (Edwards Laboratories). The syringe is fixed on a support at the patient's bedside. The air-driver system automatically withdraws 10 ml aliquots of cold dextrose in water and injects them into the patient. There is a bubble detection system which immediately stops the injection process if air is present.

In mechanically ventilated patients, the injection is synchronized with the ventilator and starts at end-inspiration [9]. Calculations are adjusted for

injectate temperature. Only three successive determinations are performed if the dispersion of values is within 5%. If it is higher, two additional measurements are performed. The values are then averaged.

The software allows the configuration of the system according to the devices used (mechanical ventilation, fiberoptic fibers with the PA catheter and pulse oximeter). The frequency of automated determinations of cardiac output should also be defined. Entries are also provided for concurrent treatment and hemoglobin concentration.

The ACAT system also facilitates the determination of complete hemodynamic evaluation including measurements of intravascular pressures (after automated zeroing and calibration) immediately before cardiac output measurements and withdrawal of arterial and venous blood gases. A hemodynamic report of ECG, intravascular pressures and gasometric data is automatically printed.

Finally, the computer display can present trends for the various monitored parameters, either graphically or numerically. Trend analysis of cardiac output includes either serial measurements by the thermodilution technique or continuous determination from oxygen consumption and the arterio-venous oxygen difference obtained from SaO_2 and $S\bar{v}O_2$. The relationship between successive values of oxygen consumption (in ordonnate) and oxygen transport (in abscissa) can also be graphically obtained to facilitate the optimization of oxygen-derived variables.

The monitoring system has been used in more than 60 patients with great convenience. We are presently developing the next stage which involves the control of the infusion pumps when carrying out treatment with vasoactive drugs and fluid infusion.

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