A COMPUTER CONTROLLED NON-INVASIVE HAEMODYNAMIC MONITORING SYSTEM

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The most important haemodynamic measurement is that of flow [1,2]. However, anaesthetists rely generally on heart rate and arterial pressure for assessment of the cardiovascular system. Invasive methods of measuring cardiac output, such as thermodilution and dye dilution, are expensive and not without risk. This has led to the development of methods to measure cardiac output non-invasively and prompted the development of a system incorporating a non-invasive cardiac output monitor, based on bio-electrical impedance, and an automatic arterial pressure recorder. These were linked to a microcomputer to provide a portable, non-invasive, automatic haemodynamic monitoring system (fig. 1).

MATERIALS AND METHODS

Cardiac output monitor

Cardiac output was measured using a non-invasive continuous cardiac output monitor (NCCOM 3, BoMed Medical Manufacturing Ltd). This uses a modification of the Kubicek equation for calculating stroke volume from impedance signals obtained with skin electrodes [3]. The NCCOM 3 uses four pairs of standard skin electrodes: two pairs on the patient's neck and two pairs on the lateral thoracic wall. From these, the NCCOM 3 calculates and displays a series of six indices:

1. Thoracic fluid index (TFI)—the total resistance of the thorax to electric current flow (Ω).
2. Ejection velocity index (EVI)—the maximum value of the rate of thoracic impedance change during the systolic upstroke (Ω s⁻¹).
3. Ventricular ejection time (VET)—duration of mechanical systole (s).
5. Heart rate (beat min⁻¹).
6. Cardiac output (CO) (litre min⁻¹).

The NCCOM 3 incorporates an RS232 interface for output of the calculated data.

Other materials

The NCCOM 3 was connected to a previously developed computer-based anaesthetic record system [4]. This system incorporates an Apple II microcomputer with a disc drive, visual display unit (VDU), printer and Dinamap automated arterial pressure monitor (Critikon). The original anaesthetic record program was modified to accept, display and store data from the NCCOM 3 and Dinamap monitor. The data are transmitted from the NCCOM 3 in the form of a string of characters every 12 heart beats, and passed to a serial card (California Computer Supplies) in the computer. The information is analysed and displayed continuously on the VDU. The frequency of arterial pressure recordings is determined by the switch setting of the Dinamap monitor and may range from every 1 min to every 30 min.

SUMMARY

A system for the non-invasive monitoring, recording and storing haemodynamic indices has been developed using an Apple II microcomputer, a Dinamap automatic arterial pressure monitor and a non-invasive cardiac output monitor based on bio-electrical impedance. This system was used during the induction and maintenance of anaesthesia. Numerical and graphical displays of heart rate, arterial pressure, cardiac output and systemic vascular resistance are available. A print-out of data can be produced for later analysis.
depending on circumstances of use. Data transmission from the Dinamap cause the computer to interrupt communication with the NCCOM 3, and to collect the information from the Dinamap. The program then calculates systemic vascular resistance (SVR) (dyne s cm$^{-5}$) from mean arterial pressure, cardiac output and, if known, central venous pressure (CVP); displays raw and derived data on the VDU; and stores the information on disc for later analysis. The data are “time-stamped” by a clock-card incorporated into the microcomputer. The computer then reverts to collection and display of data from the NCCOM 3.

Two methods of data display are available:
(1) Continuous digital display, as part of an option menu (fig. 2). This updates continually on reception of signals from either instrument. CVP may be entered from this menu.
(2) A colour graphical trend display, portraying changes in heart rate, systolic arterial pressure, cardiac output and systemic vascular resistance against time (fig. 3). The graph is updated automatically on reception of new data from the Dinamap. A print-out of stored data is also available for later analysis (fig. 4).

CLINICAL EXPERIENCE
The system was used during the induction of anaesthesia in patients undergoing cardiac surgery. Before induction, electrodes were placed on the patient as described above. Recordings were made every 1 min during the induction of anaesthesia, tracheal intubation and placement of intraarterial and central venous cannulae, and was discontinued on the transfer of the patient into
Dinamap/Bomed Patient Data Printcut

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I.D.: 
Age: 62
Sex: M
Diagnosis: CABG

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**Fig. 4.** Data print-out with trend-graph of patient during induction of anaesthesia for coronary artery surgery. Laryngoscopy was commenced at 08.36 and the trachea was intubated 5 min later. SYS/DIA/MEA = Systolic/diastolic/mean arterial pressures (mm Hg). For other units and abbreviations, see text.

The system was also used during aortic bifurcation graft procedures. The record from one patient was shown in figure 3. The effect of cross-clamping the aorta on systemic vascular resistance is demonstrated.

Theatre. A print-out of the patient’s results was made later. An example of the haemodynamic data obtained in one patient is shown in figure 4. This patient was a 62-yr-old man scheduled to undergo coronary artery surgery. Anaesthesia was induced with fentanyl 300 μg and midazolam 10 mg. Pancuronium 6 mg was given and his lungs were ventilated with oxygen, nitrous oxide and 0.5% halothane. Intubation of the trachea was difficult and required approximately 5 min manipulation before placement was achieved. The effect on the patient’s haemodynamic profile is demonstrated clearly.
Problems encountered with the system were related to electrode placement. On two patients, very poor contact was obtained which failed initially to produce an impedance signal strong enough to be measured by the NCCOM 3. In addition, during surgical diathermy, the NCCOM 3 did not detect an adequate signal.

DISCUSSION
The measurement of cardiac output during anaesthesia is desirable as it is one of the principal factors which govern oxygen delivery. Traditional methods of measuring cardiac output involve invasive techniques. Using the Fick principle requires steady state conditions and accurate measurement of oxygen uptake and, although this method has been used for on-line monitoring [5], it is not suitable for routine monitoring of patients during general anaesthesia. Dye dilution and thermodilution do not provide continuous measurements and, in the case of thermodilution, require pulmonary artery catheterization, with its concomitant risks and expense. Hence the use of non-invasive methods would be appropriate as a routine method of monitoring during anaesthesia.

It is important that, if a non-invasive system is used to estimate cardiac output, the method should give results as close as possible to those which would be obtained with a recognized method such as thermodilution. Electrical impedance is not a new method of estimating cardiac output and was first used to calculate cardiac output of astronauts [6]. The NCCOM 3 is based on a modification of this method of cardiac output measurement [3] and has been shown to give results comparable to thermodilution in various haemodynamic states in both animal [7] and human studies [8,9], the correlation co-efficient between the measurement methods being 0.84, 0.88 and 0.90, respectively. Appel and colleagues [9] also reported difficulties in measurement when patients suffered from severe tachycardia. In this situation, the NCCOM 3 underestimated cardiac output by 20% compared with the thermodilution technique.

The Dinamap automated arterial pressure recorder has been reviewed recently and shown to give adequate correlation with direct arterial pressure measurement [10,11]. Our method of calculating SVR has certain inherent limitations, since no value of left ventricular end-diastolic volume can be obtained, although an estimate may be made using CVP.

In its present form, the system is designed to accept all valid data from either monitoring device. In common with others [10], however, it is our opinion that, in the event of a marked discrepancy compared with a previous value, the measurement should be repeated manually. Identification of possible erroneous data is facilitated by the trend display.

Application of computing technology to monitoring systems provides a method of automatic data collection and storage thus leaving the anaesthetist free to perform other tasks [12]. While it has been suggested that the use of automated devices to measure arterial pressure may result in a decrease in vigilance [13], it is our experience that the advantages of continuous recording, storage facilities for later recall and trend display to alert attention to any sudden haemodynamic change, outweigh any such suggested disadvantages [4]. Furthermore, the graph display, while not as attractive visually as some contemporary graphical systems, has sufficient resolution to demonstrate clearly clinically important trends. It may also encourage consideration of haemodynamic indices not normally available to the anaesthetist.

By linking the NCCOM 3 into the monitoring system, we have provided a portable method of making continuous assessment of the patient's haemodynamic state without invasive monitoring. This system has particular relevance to those involved in research concerning the haemodynamic effects of anaesthetic agents or certain procedures known to cause cardiovascular disturbance. Since methods for determining flow have become more available, it may be that such a system becomes routine for patient monitoring during general anaesthesia.

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REFERENCES


