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Carola, a computer system for automatic documentation in anesthesia

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Abstract

A computer system has been designed for documentation and data acquisition during open heart surgery. This computer system (called 'Carola') processes all patient data during cardiac surgery. More than 50 analogue or digital signals are scanned. These are derived from a monitoring rack, a Siemens Servo 900B ventilator with its accessory devices and a heart lung machine. All these values are plotted as well as off line data, such as medications, fluids, laboratory results and user comments, on an A3 format anesthetic record using an eight pen flat bed plotter. Simultaneously all data is written onto a cassette tape. These tapes are then transferred to a database for storage and statistical processing. The sampling frequency is every 10 seconds, averages being calculated over one minute periods. The chart is updated once a minute normally or every 15 minutes for slowly changing signals e.g. temperatures.

Hardware and software of the computer have modular design. The hardware consists of two Motorola 6809 based microprocessor systems. The software is entirely written in Pascal. The user interface is implemented on a menu driven basis. A terminal with a keyboard is used for the communication with the users, namely anesthetic nurses and anesthesiologists. The system was readily accepted by the users. The menu structure proved to be easy to learn and allowed fast entries, even when the users were not previously accustomed to the use of a keyboard. The clear and detailed presentation of the data on the plotted chart helped to detect trends early and facilitated therapeutic decisions. From december 1983 the first prototype was used on a routine basis, followed by a second unit in June 1984 and a third in December 1985. Up to now more than 12.500 anesthetic hours have been recorded. Since then almost 100% of all anesthetics performed in our cardiothoracic unit have been documented by the computers, including all short procedures without invasive monitoring and all emergencies.

Introduction

With the increasing number of useful parameters measured during anesthesia, such as those done routinely for open heart surgery, the conventional methods of anesthetic record keeping are becoming obsolete. However satisfactory alternatives offering adequate presentation and documentation have not been available. Therefore several institutions have independently started development of automatic documentation and display systems [1, 2, 4, 5, 6, 7], with great variation in tasks, design, hardware and software. We started the development of our own computerized documentation system for cardiac anesthesia in 1978. Our system had to fulfil the following criteria:

(1) The measured parameters of a patient should be documented on a clear anesthetic record with high resolution allowing evaluation of various patient responses, to an administered drug for example.
(2) The record should be comprehensive. It must

be possible to include all medication, i.v. fluids, all laboratory values, and comments on the progress of the operation.
(3) The system must be 'user friendly'. In the event of system failure easy transition to documentation by hand must be possible.
(4) Flexibility in use: the system must be adaptable to the changing demands of the users.
(5) The system must have enough reserve capacity for future growth.
(6) It should facilitate data storage and processing.
(7) The system must be compatible with existing central hospital computer systems.

Description of the system

After a period of development of five years the following solution was finally conceived:

(a) The computer system

The computer system consists of the following parts (Table 1): Two 6809 microprocessors were used because it became clear during development of the system that the task was too great to be handled by one. One microprocessor is used as a central system, the second as a satellite system. The former

Table 1. Components of the hardware of the Carola system.

1. a central system Motorola 6809 (64 K RAM)
– 1 magnetic cassette unit DEC TU 58
– 1 Plotter, Hewlett Packard 7220, eight pens
– 1 AD-card, resolution 12 bits, 16 differential inputs
– 2 AD-cards, resolution 12 bits, 32 single ended inputs each
– 'real-time' clock
– 4 serial lines (RS232/Current loop)
– parallel lines
– timing facilities
2. a satellite system Motorol 6809 (64 K RAM)
– 1 Terminal, CIT-101, VT 100 compatible
– 2 serial lines (RS232/Current loop)
– timing facilities
Power supply: Uninterruptable, Euroguard-500

(1) scans the three analogue-digital converter cards,
(2) interfaces with the Dinamap device,
(3) handles communication with the satellite system,
(4) controls an eight-pen, A3 flat bed plotter for the display of the measured data,
(5) transmits all data to a magnetic tape cassette recorder.
(6) handles, via an interface, communication with the Hospital Information System, for example for the transmission of the results of laboratory analysis.

The only task of the satellite system is to interact with the user through the terminal. Both systems, mounted into one case communicate via a 9600 Baud serial RS-232 line.

(b) Signals and signal transfer

A schematic view of the structure of the system is shown in Fig. 1. No effort was made to analyse or store waveform details, but only to document the more slowly changing derived values as listed in Table 2.

Most of these preprocessed signals were available in analogue form from the front end monitors and were passed on the computer system for further processing. To facilitate the eletrical connection of the various devices we made use of junction boxes. All analogue inputs (currently more than 50) are digitalized within the 'Carola' computer system. Some signals were only available in digital form, such as the output of the non-invasive bloodpressure and heart rate monitor ('Dinamap').

(c) Sampling frequencies

The 'rapidly' changing signals are sampled at 10 seconds intervals. An average is calculated from six samples discarding the highest and the lowest value. Every minute this value is plotted, and stored on the cassette. The use of diathermy is detected and sampling is postponed to prevent error.

The sampling and averaging for the more slowly changing values is principally the same, but they are sent to the cassette tape only at 5 minute intervals, and plotted at 15 minute intervals (Table 2). Values from the Dinamap are processed, whenever the Dinamap are processed, whenever the Dinamap completes a determination. The choice for these intervals was based on previous experience both with hand documentation and the use of moving paper trend recorders.

(d) Software

The software is entirely written in PASCAL. As a high level programming language, PASCAL allows a structured and modular approach. The structure of the software on both computers is the same. It is based on parallel processes and 'Semaphoor' synchronisation [3]. The basic layer pro-

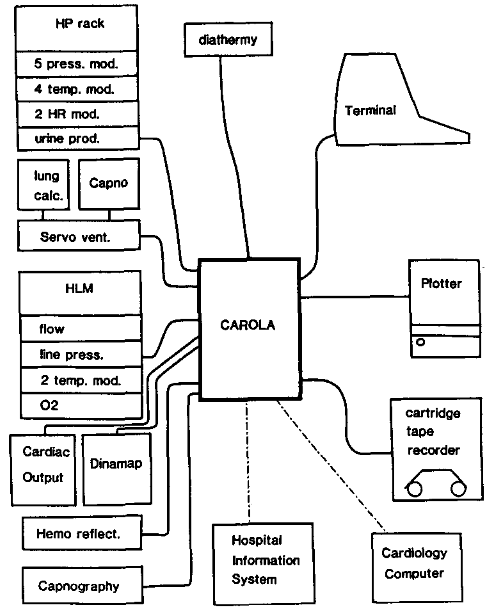

Fig. 1. Scheme of Carola and connected devices.

Table 2. On line measured values documented by the 'Carola' system.

Variables:	(Storage interval in minutes)	derived from:
temperatures	(5)	6 temperature monitors (2 at the heart lung machine [HLM])
heart rate	(1)	ECG, arterial pressure, 'Dinamap' device
systolic pressure value	(1)	6 pressure units, standard settings for arterial bloodpressure,
diastolic pressure value	(1)	pulmonary artery pressure, central venous pressure, left atrial
mean pressure value	(1)	pressure, 'line' pressure of HLM, and from the 'Dinamap'
insp. peak pressure	(5)	Servo Ventilator 900 B and Siemens lung function calculator 920
end expiration pressure	(5)	
respiratory frequency	(5)	
inspiratory resistance	(5)	
expiratory resistance	(5)	
compliance	(5)	
ineffective tidal volume	(5)	Siemens CO2 analyser 930
effective tidal volume	(5)	
CO2 tidal volume	(5)	
effective ventilation	(5)	
CO2 production	(5)	
endtidal CO2 conc.	(1)	
inspir. O2 conc.	(5)	Criticon 'Oxycheck' oxygen analyser
oxygenator inlet O2 conc.	(5)	Criticon 'Oxycheck' oxygen analyser
oxygen. outlet CO2 conc.	(5)	Godard mk II capnograph
Hlm bloodflow	(1)	rotation speed of HLM pump (Stoeckert)
venous oxygen saturation	(1)	Schwartzer 'In Vivo' Oxymeter

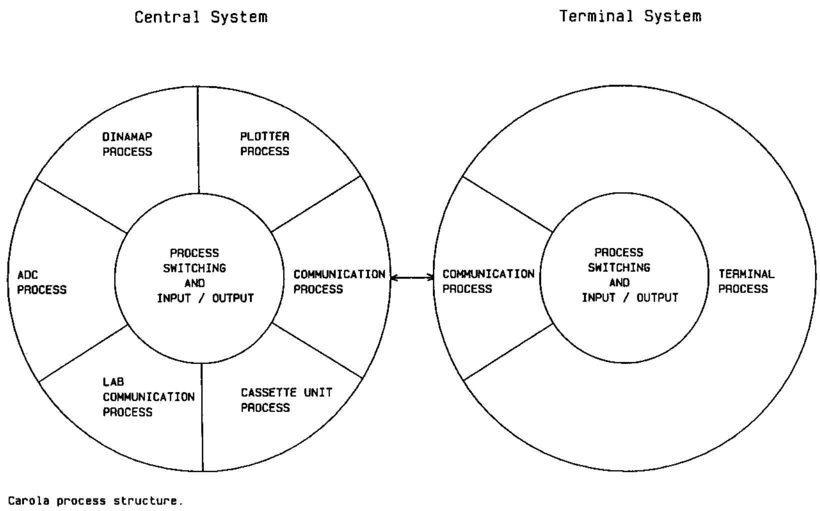

Fig. 2. Main flow of data-packets and process structure.

vides process creation and switching, synchronisation and I/O handling.

Processes are created once during initialization and remain in existence during the use of the system. It can be considered as a special purpose operating system. Procedures handled by the central computer control the AD-converters, the plotter, the cassette unit, the Dinamap and the communication line with the satellite computer. On the satellite computer there are procedures for the terminal and the communication with the central computer. Each device has its own procedures, i.e. programs, and information is exchanged in batches called packets. Besides the information being transferred a packet also contains information such as time and identification. The main flow of the packets and the process structure is shown in Fig. 2.

At the higher level the terminal procedures provide the user interface of Carola. It is implemented on a menu driven basis. The menu structure is hierarchical and easy to use. The different items are selected numerically. Some items contain one or more sub-menus with further lists of items for selection. In some cases the selection of an item is a complete action (e.g. the beginning or the end of an operation), in other cases the user is asked to type additional information (e.g. the quantity of a drug given). In several menus by typing letters instead of the requested numbers free text can be entered. This will be automatically recognized by the system and as such indicated on the screen. A detailed description of the menu structure is given in Fig. 3.

The terminal has two main functions. The first is the output of data, that cannot be entered automatically (e.g. medications, fluid, state of the operation etc.). The second is feedback from the system to the user. This will be either system messages, such as errors and system requirements (e.g. new paper needed on the plotter) or utilities. Examples of these utilities are:

(1) display of various elapsed times (e.g. time on cardiopulmonary bypass (CPB), aortic occlusion time, duration of cardioplegic infusion, etc.),
(2) calculation of cumulative fluid quantities (urine, bloodloss, infusions),
(3) a warning when no heparin has been given before CPB,
(4) a warning when the same blood bag number is accidentally entered twice,
(5) automatic interruption of pressure recordings while taking blood samples,
(6) automatic switching off of the pulmonary artery pressure during measurement of the pulmonary capillary wedge pressure.

Fig. 4. The Carola System in use.

accepted by its users. Examples in the past have suggested that computer systems are not easily integrated into the working routine of a busy operation room (OR) because they were insufficiently user friendly [2]. However our 'Carola' system proved to be readily accepted. Keyboard entry of data was less inconvenient than expected. The menu driven system proved to be practical and to be more or less self-teaching, obviating the need for special instruction.

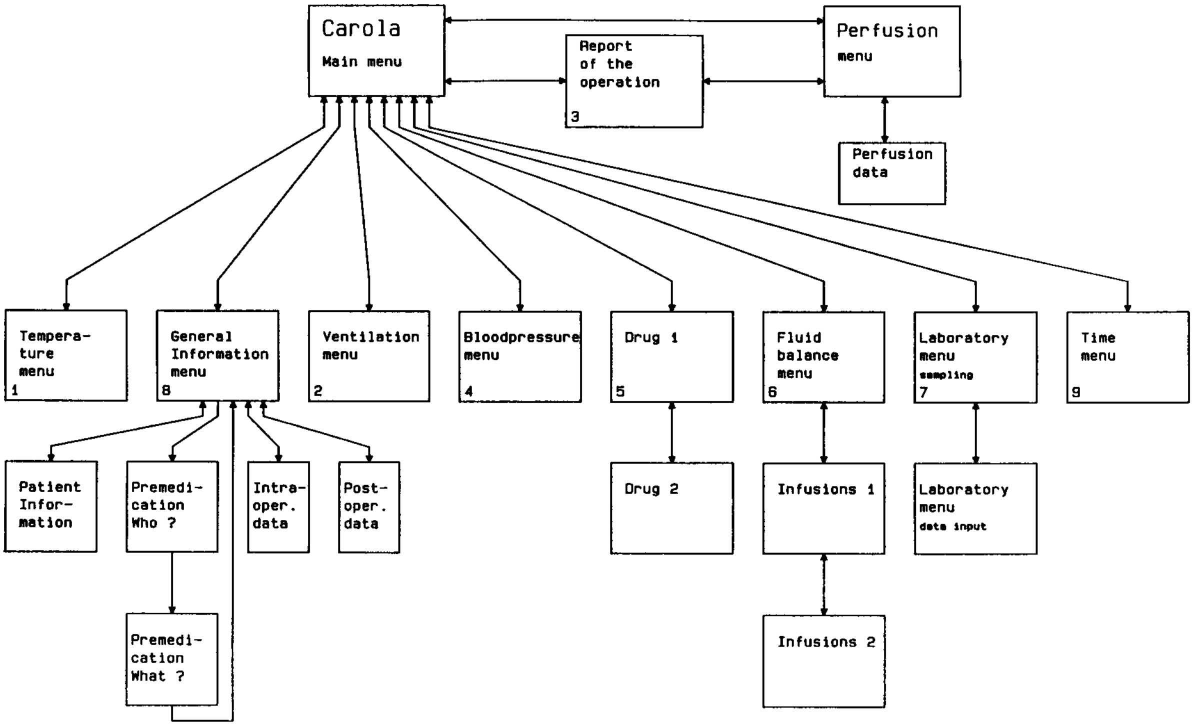

Fig. 3. The menu structure of the user interface.

(e) Miscellaneous programmes

A special test- or service-program can be run for the following purposes:

(1) Control of proper signal transmission (cables and connections)
(2) Setting the clock
(3) Control of adequate function of diathermy suppression
(4) Testing of several interfaces

Reproduction of records:
To print anesthetic records stored on cassette tape a special program was developed, to reproduce an anesthetic chart.

Special plot programs:
A special plot program was made for the graphic display of values that were plotted on the original record in numerical form, for example temperatures.

Experience with the Carola system in practice

The Carola computer system was first installed in an operating room in November 1983. Within four weeks numerous software faults had been eliminated and a diathermy detection system installed, because it had become evident that the diathermy completely disrupted most measurements. The unit was installed in a special housing (Fig. 4) to suppress the noise of the plotter and the cooling fans, and was placed next to the ventilator to provide good access and visibility for both anesthetic nurse and anesthesiologist.

From December 1983 our first prototype was used on a routine basis and a second device was installed six months later. Since then almost 100% of our anesthetics have been automatically documented. Up to November 1986 about 3100 cases have been logged, representing more than 12.500 'anesthetic-hours'.

The most important question arising from this project was whether or not the system would be

User acceptance became apparent during the first 6 months, when the system was installed in only one of the two OR's. Prior to this emergency operations had been preferentially performed in the smaller one. The computer, however, was installed in the larger. After a few weeks the anaesthetic nurses started to insist on the use of the computerized OR, so that very soon all emergencies were done there. Let us now discuss to what extent the various components fulfilled the requirements:

The computer

Failure of the computer ('crash') is a most unpleasant experience during anesthesia. Early experience indicated that these fallures were due to overheating. This occurred if the ambient temperature exceeded 27 degrees celsius or if the ventilation filters became obstructed by dust. Both problems have been solved in the meantime, but has not entirely eliminated the possibility of a crash, which necessitates restarting the system and re-entering all of the patient data. This is impractical and so we are implementing a restart procedure that automatically restores the status quo before the crash, which would eliminate the need for a rather bulky uninterruptable power supply.

The terminal

Clinical practice has shown that not all terminals could withstand OR conditions. The Beehive type repeatedly failed and was finally replaced.

The cassette recorder

Before each use the program is loaded. Loading the programme from cassette takes approximately four minutes. Initially this was felt to be too long. However the procedure has been smoothly integrated into our routine so that no time is wasted. Cassettes are also used for data transfer to the disk memory. A sophisticated cassette examination programme had to be developed to reject a rather high percentage of faulty cassettes that either still contained data from a previous recording or were otherwise faulty. This has the advantage that the data from the previous recording will not be lost and can still be entered into the disk memory.

We chose cassettes instead of floppy discs because they were robust and they provided more protection for the data, e.g. in the case of system failure. Failure of the cassette recorders has occurred only once. In future, data transfer to the disk memory will be direct with the cassette (or floppy disk) unit retained as a back up.

The plotter

The plotter is the most spectacular and most expensive part of the Carola system. We chose a flat bed plotter because it was the only display device that combined the following properties:

(1) The possibility to write on preprinted (anesthesia) forms,
(2) Good visibility of the record during writing,
(3) High resolution,
(4) Multiple colours,
(5) Stationary paper for better visibility, also permitting the amendment by hand in case of system failure or during normal operation.

The use of this system has confirmed that these considerations can be met, but has demonstrated some disadvantages:

- The plotter is noisy, but this can be rendered acceptable by a plexiglass cover.
- Due to the number of moving parts, it must be serviced at regular intervals. This was initially underestimated and thus the plotter has been responsible for the majority of the 'down time' of our system. A standby plotter should be available.

Although not really a part of the computer, we will discuss the method of charting the anesthetic record in the plotter.

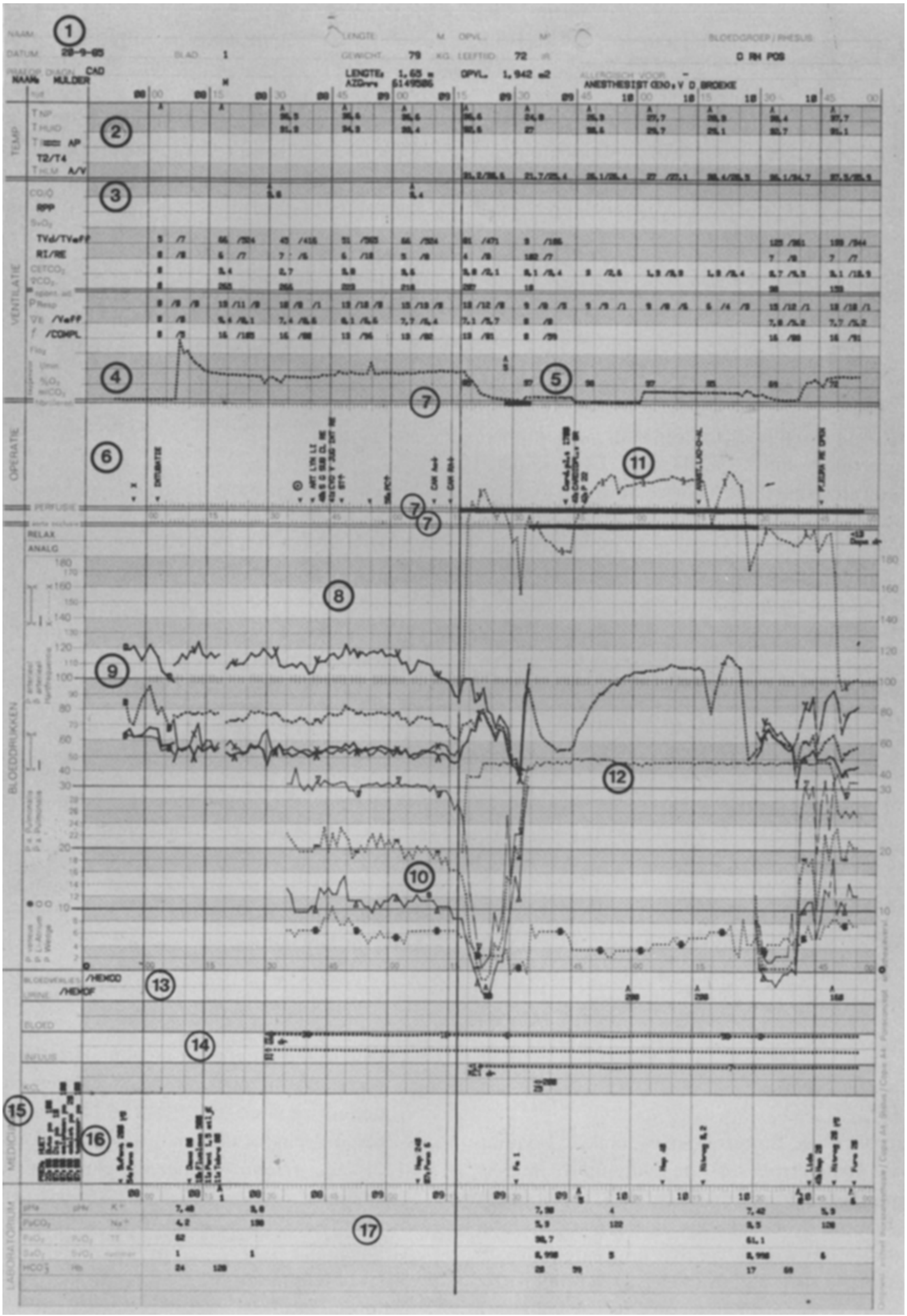

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Fig. 5. Overview of entire record: (1) section for patient identification and operation data; (2) temperature section; (3) section for miscellaneous respiratory and circulatory data: CO/Q = cardiac output, TVd/TV eff = ineffective and effective tidalvolume, RI/RE = inspiratory and expiratory resistance, CETCO2 = endtidal CO2 concentration, VCO2 = CO2 minute production, p resp = peak-, pause-, endexpiratory airway pressure, VE/Veff = expiratory minute volume and effective minute volume, f = respiratory frequency, FIO2 = fractional concentration of inspired oxygen (not recorded on this chart); (4) trendcurve of end-tidal CO2 concentration; (5) section for settings of gas flows and concentrations in oxygenator during cardiopulmonary bypass; (6) section for comments on anesthesia and operation; (7) bars indicating periods of cardiopulmonary bypass, ventricular fibrillation, aortic occlusion and cardioplegia; (8) section for representation of heart rate, pressures and the flow rate of the heart lung machine (HLM); (9) heart rate and bloodpressure measured by a non-invasive bloodpressure monitor; (10) pulmonary artery wedge pressure; (11) 'line' pressure of the HLM; (12) flow of the HLM; (13) section for the volumes of urine output, hemofiltrate and blood loss; (14) the section for the infusions can be extended over heart rate/pressure section; (15)premedication; (16) medications; (17) laboratory result section.

The anesthetic chart

A plotted record is shown in Fig. 5.

The original is plotted in four colours. It would have been technically easier to plot the record onto a blank sheet of paper. However the reasons why we decided to plot directly onto our special A3 format anesthetic chart were as follows:

(1) The ability of this anesthetic chart to display multiple parameters clearly had already been shown, this record having been designed earlier when all entries were made by hand.
(2) The users were already accustomed to this kind of presentation.
(3) In case of system failure one could easily continue with hand documentation.

In the beginning we plotted data only at two minute intervals. This proved to be unsatisfactory and plotting rate was increased to once per minute. The rather large time axis of approx. 8 cm/h used in this chart provided good resolution. Various patient responses could be well distinguished, for example the haemodynamic response to a given drug. The instantly updated anesthetic record (unlike the handwritten paper) proed to be a satisfactory trend recorder. So, although not planned in advance, the Carola system took over the function of a trend recorder. Consequently the moving paper trend recorder could be removed from the OR and the plotter placed next to the anesthesiologist. However, the numerically written data was less adept at demonstrating trends and so it has been decided that, in future, all vital parameters will be presented in graphic form.

Reliability

The overall failure rate of the system has been evaluated from July 1984 to Juy 1986 (2620 anesthetics). Recording was without incident in 92.8%, i.e. a 7.2% failure rate. In 5.4% the program was restarted during anesthesia, but this caused no significant interruption of the documentation. The percentage of completely computer written records was 97.3%. We had to write by hand in 0.6% for less than 30 minutes and in 2.1% for longer than 30 minutes. These results were achieved with neither a standby system available in the department, nor computer technicians in the operating room, nor anyone competent available outside office hours. The conclusion is, that as for other equipment, standby parts must be immediately available on site in order to achieve 100% operability.

Veracity

Another aspect of reliability is the question of absolute veracity of the data being plotted and stored by the computer system. Three major sources of faults can be identified:

(1) Artefacts, for example those caused by a disconnected sensor, can in most cases be easily detected as such. In trend recording they are not really a problem – but irritate the user's esthetic feelings. In regard to statistical analysis, artefacts are detrimental. To eliminate the most frequent artefacts we automatically interrupt sampling during diathermy and during sample taking. When cardiopulmonary bypass

is started or stopped, various measurement modes are automatically allocated to new requirements. However these precautions exclude only some of many possible artefacts, measures have to be taken to avoid them if possible, but if not, provisions will then to be made to label them.

(2) Shift of the voltage of the signal output from the front end monitor. Though not strictly a prolem of the computer, this leads to faulty data which can be very hard to detect. The recalibration of the monitor output usually cannot be done by the user himself on the spot, because it requires the help of the technician. Provisions therefore have to be made to allow the user to make temporary adjustments by means of the software. This problem will also be minimized by application of the digital data transmission technique, which is now increasingly available in medical monitoring.

(3) Finally the user himself makes mistakes. On the paper record these mistakes can easily be corrected by hand. However, as regards data storage, these faulty entries ideally should be either erased or labelled as faulty. Thus more facilities to correct faulty entries have yet to be made.

Discussion

We have not yet compared our system with similar systems being developed in other institutions [1, 2, 4, 5, 6, 7] because the methods, devices and tasks opted for have differed widely and so comparisons between the various systems and the experiences gained from them cannot easily be made. For this reason the other systems will not be discussed in detail henceforth. However, it would appear that they confirm our impression that automatic documentation in anesthesia is not only useful but even invaluable and, as a logical progression automatic documentation could be extended in various ways:

(1) Installation on the intensive care unit, where documentation and display problems exist similar to those in the OR.

(2) Installation in other, non cardiac, ORs. However the costs of the hardware ($17,300), especially of the plotter ($3,500), remains high, and this will hinder widespread application. Also, due to the number of mechanically moving parts, the plotters need too much maintenance to be used in every OR. However, up till now, we have not yet found a satisfactory substitute for the plotters with the same visibility, resolution and multicolour capability. A possible alternative is a presentation on a high resolution colour display, whilst print copies could be made out on a device outside the OR as needed. Recently marketed PC's have colour screens with reasonable resolution combined with highly developed programmes for graphical editing at rather low prices. Hence we are now investigating how far these PC's can be used as a future replacement for the plotter.

(3) More functions. It appears logical that a system that automatically displays and processes all vital signals could provide further aids such as intelligent alarming or regulating tasks (closed looped functions).

(4) A departmental system. For later and complete analysis of patient data more information is needed, and at present we add preoperative and postoperative results to the operation record separately. This data is not entered via 'Carola' but via our department computer, DEC PDP 11/73 running a UNIX operating system. On this device is also installed a database which manages the storage and retrieval of data and performs statistical work.

The value of such systems can be assessed in terms of its effect on the quality of patient management. Two aspects have to be considered, firstly the effect of improved data presentation and, secondly, of better data storage. the benefits of improved display of data have been emphasized throughout current use, namely:

(1) The improved presentation of data facilitates the making of clinical decisions.

(2) The supervisor called by the anaesthestist in training will benefit from the accurate record,

that helps him to elucidate the patients situation and to act appropriately.

(3) Also a detailed record is very valuable for the discussion of critical situation in clinical conferences etc.

(4) Although, theoretically, better information must result in better treatment, it has been shown by others [5], that it is difficult to express this improvement in decreased morbidity or mortality.

The effects of improved data storage cannot yet be properly assessed.
The database has been in use for too short a time to allow a final statement. However it is becoming evident, that the statistical work up of this rich source of data is beginning to influence clinical decision making in our department.

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