Abstract

(J. Extra-Corp. Technol. 19[4]: p. 408-411 Winter 1987). Programmable calculators have become increasingly valuable to the conduct of cardiopulmonary bypass (CPB). We report the upgrading of our previous system with current technology. A Sharp PC-2500 portable microcomputer was chosen because of its low cost, easy programmability, rechargeable battery, and built-in printer. This system has allowed perfusionists to perform an increasing number of complex calculations with more accuracy and efficiency. In addition, it offers expanded memory and a permanent record of its calculations. We have used the new system in over 250 cases of CPB without problem. Although the flexibility of such a system allows customization to fit individual needs, we advise that any program be carefully tested and debugged to prevent serious mishap.

Introduction

In a previous communication we discussed the use of a programmable calculator by perfusionists for certain complex calculations during cardiopulmonary bypass. These calculations included heparin-protamine doses, body surface area, flow for cardiopulmonary bypass, and infusion rates for vasoactive drugs. Although the techniques described continue to be useful, the programmable calculator we employed in 1979 is now outmoded by the availability of inexpensive microcomputers. Therefore, it appeared desirable to update our equipment and improve our software. In selecting a programmable computer, we sought the following characteristics:

1. Easy programmability in a common computer language (eg. BASIC)
2. Power supplied by a rechargeable battery
3. Built-in printer
4. Ability to store and retrieve programs easily and permanently
5. Cost less than $400.00
6. Lightweight, small size—true portability

Having selected what appeared to be an appropriate computer, we then redesigned our software for more generalized utility during cardiopulmonary bypass. In so doing, we attempted to expand the capability of our programs, yet maintain an overall ease of operation that would allow a high degree of interaction with busy perfusionists. Accuracy, immediate utility of calculations, and a hard copy of our records (for review in the event of a questionable result) were also desired.

Materials and Methods

We selected the Sharp portable computer, model PC-2500 (Figure 1). The PC-2500 is equipped with both a built-in printer capable of printing graphics and a rechargeable battery. Programs are permanently retained within the computer memory even when the Sharp Electronics Corporation, Paramus, NJ 07652.
computer is turned off, as long as the batteries do not completely discharge. In addition, a more permanent recording of programs can be created using a separate audio cassette recorder that allows easy transfer of programs between computers and easy repair if a program is inadvertently damaged. Discount retail cost was less than $300 in late 1986; additional costs include the cassette recorder and the separate 16K removable RAM cartridges that expand the memory of the computer. The computer is programmable in BASIC, making our programs easily adaptable to the requirements of other computer users both within and outside our institution.

**BASIC Computer Program for Cardiopulmonary Bypass Calculations**

![Figure 1: The Sharp portable computer. Model PC-2500.](image)

Program Operation

The program (Figure 2) prompts the perfusionist to enter the patient's age group, height in inches, weight in pounds, and preoperative hematocrit (HCT). Priming volume (PV) for the pump, intravenous fluids (IF), activated clotting time (ACT) at various intervals, and all heparin or protamine doses are also entered. The age group is then used in conjunction with the height which is converted to centimeters (HT), and weight, which is converted to kilograms (WT), in order to calculate the estimated pump flow (QS) by the formula:

\[ QS = \frac{(WT \cdot .425) + (HT \cdot .725)}{10000} \]

Drug dosages are determined using our modification of the Bull protocol. This calculation utilizes a linear regression formula and the patient's ACT at any particular moment to calculate the amount of heparin needed to increase the ACT to 480 seconds, or, in the case of protamine, to return the ACT to its initial (control) value. The linear regression is derived from the relation:

\[ QS = \frac{200}{WT} \]

\[ QS = \frac{210}{WT} \]

Total body surface area (BSA) is calculated using the formula:

\[ BSA = \sqrt{\frac{HT \cdot WT}{80}} \]

Drugs and fluids may be entered at any time during pump flow calculations.

![Figure 2: Listing of the program used in Cardiopulmonary Bypass.](image)
tion of ACT to heparin administered in three steps during initial heparinization for cardiopulmonary bypass. The microcomputer saves time and minimizes error.

An optional feature of the computer program determines the predicted hematocrit on cardiopulmonary bypass. The estimated HCT is the quotient of the red blood cell volume (RBC) and the combined volumes of the circulating blood (CBV), PV, and IF:

$$\text{Est. HCT} = \frac{\text{RBC}}{\text{CBV} + \text{PV} + \text{IF}}$$

RBC is calculated as the product of the preoperative HCT and the CBV. The CBV is derived from the formula(e):

$$\text{CBV} = \text{WT} \times 80$$

BSA < 1.09; CBV = WT × 80

BSA > = 1.1; CBV = WT × 70

In addition, if the perfusionist elects to add blood to the priming volume, the program requests the number of units (U) of red blood cells given to the patient and makes the distinction as to whether the units are whole or packed. The RBC is then calculated with the formula(e):

whole; RBC = (HCT × CBV) + (175 × U)
packed; RBC = (HCT × CBV) + (190 × U)

All of the input and calculated data are printed out onto a data slip, utilizing the built-in printer.

Results

The sample data slip (Figure 3) illustrates the patient's preoperative hematocrit, estimated hematocrit on cardiopulmonary bypass, expected pump flow (liters/min.), body surface area, height (in inches) and weight (in pounds). Dosages of heparin and protamine are also displayed when inputted. Additional doses of heparin and protamine administered are shown with their corresponding ACT and the running tally of the total dosages given. While this information is being placed on a permanent record using a replaceable pen, it is also being displayed on the computer's screen. When the program has finished, a table listing the final ACT, total heparin given, and total protamine given is printed.

Although the data slip contains the crux of the information computed by the program, the screen is the actual link between operator and computer. Whether a particular statement is printed depends upon the BASIC command used. Thus, to fully visualize the requirements needed to operate the program, one must look first at the program listing (Figure 2) and the commands utilized. In so doing, one realizes that all of the questions regarding data input are shown on the screen, not the printer. Additionally, all data printed is dually displayed on the screen. Hence, the screen is primarily used for quick visual reference during program operation, whereas the data slip can be viewed at a later point in time.

The program (Figure 2) takes up 3,324 bytes of memory and is programmed in a form of BASIC, that is compatible with the ROM of the Sharp PC-2500. Other BASIC programs might need altering in accordance to the ROM of their system; such alterations could possibly change the total number of kilobytes used.

The calculations done by the program assist the perfusionist by eliminating the need to work out tedious and lengthy computations, thus providing him with time to devote elsewhere. Storage of data on paper negates the need to record items by hand, thus increasing efficiency and facilitating later review of data (Fig-
Discussion

The present communication describes the evolution of a computerized technique to aid perfusionists and surgeons in doing rapid calculations relevant to cardiopulmonary bypass. Microcomputers are a rapidly developing part of operating room technology. Computing power becomes increasingly economical as component microcircuits are mass produced and developmental costs are absorbed. The capabilities of the microcomputer described here represent a dramatic advance in almost every respect over the programmable calculator described in our previous paper. Furthermore, the PC-2500 is less expensive than the calculator we used previously. It is likely that computing equipment will be increasingly relied upon during cardiopulmonary bypass and other forms of surgery to do complex calculations.

In this instance, our new equipment has eased the process of rapidly introducing changes into the program. The options that have been made available due to the increased memory and flexibility of microcomputers in comparison to calculators are many. Maintenance of the equipment also appears simplified, but the durability of the computer, especially the printer, remains to be proven.

Computer manufacturers appear reluctant to become involved in the custom manufacturing of devices for bypass computations because of low profit margins, wide individual variation in protocols for heart surgery, and potential product liability. For these reasons, we have utilized standard equipment to fit our needs; the flexibility of programmable microcomputers makes this possible.

Our previous experience with computing equipment has influenced our requirements for computing equipment to be used in the operating room. In the event of loss of power, battery power becomes a necessity; it is also helpful in eliminating clutter.

In our prior system, the process of reprogramming a calculator before every case with a magnetic card proved a tiresome chore that was subject to error, wear, and mechanical malfunction. Permanent storage of the program within the memory of the computer, maintained by low level battery power when the computer is turned off, eliminates this problem. A fully charged battery will function for approximately 15 hours (slightly less with extensive printer usage). The battery is routinely recharged overnight, and we maintain three computers in the event of two simultaneous cases.

A permanent recording of the program on cassette tape is also an important element of the system because it allows the program to be restored quickly in the event of damage, which eliminates the need to retype and debug a new program. The audio tapes also simplify the process of exchanging programs with users in other institutions.

We wish to emphasize that any computer programmed for intraoperative use should be carefully debugged. The program should be fully tested before use with a variety of data to assure proper function.

The program must also be tested to be certain that it is immune to the personal idiosyncrasies of perfusionists and any others who are not intuitively computer-oriented. In addition, the users should be thoroughly trained in the operation of both the computer and the program. Operators must also be alert to the appearance of erroneous computed data and should be familiar with the procedures at hand in order to prevent mishaps from occurring.

We conclude that microcomputers are becoming an increasingly valuable adjunct to the conduct of cardiopulmonary bypass. The availability of increasing computer power intraoperatively will also permit the use of other computation-intensive procedures yet to be defined.

References