A New Pumpside Aid For Decision Making: The Pocket Programmable Calculator

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Introduction

The pocket programmable calculator represents a new generation of information processing devices. It can take real-time information such as pressures, gas tensions, cardiac outputs, and other directly measured parameters and make extremely complex numerical calculations providing valuable physiological information to physicians, perfusionists, nurses, or technicians. This information is obtainable as quickly as from computer systems but at a much lower cost. The portability of the calculator permits immediate data access in either the operating room or intensive care unit.

The application of the programmable calculator can be particularly helpful during cardiopulmonary bypass. It permits rapid yet effective calculation of oxygen consumption, arterial-venous oxygen content differences, body vascular resistance, base excess, and drug dosages. These variables provide added information for improved decision-making during extracorporeal perfusion.

Materials and Methods

Texas Instruments Model 59 (TI-59) programmable calculator was used in the development of the following presentation. The TI-59 represents advanced technology in electronics by providing versatility. This versatility is particularly applicable to cardiopulmonary perfusion, where improved patient care standards are still maturing. The TI-59 is compact and power supply-independent with its own nickel-cadmium rechargeable batteries. The calculator offers complete electronic construction with variable functions ranging from 100 memories to 960 program steps, depending on keyboard controlled partitioning. Programs may be stored on magnetic cards allowing future rapid programming on demand. The cost of the TI-59 is about $200, which is not considered to be a major capital investment.

The TI-59 is easy to learn and simple to operate and/or program. No diverse education in computer science is required, only a few hours with the calculator at hand while reading the simple instruction booklet.

Although the author's data is based on the TI-59, the principles can be applied to other programmable calculators, with some modification, depending on the calculator's machine language.

Sources of input data include oxygen tension sensors placed in the arterial and venous lines of the extracorporeal circuit providing continuous analysis.* Temperatures near the oxygen sensors need to be measured. Frequent blood gas and hematocrit determinations provide the remaining blood chemistry information.

* Critikon, Oxytrode Model 630, Div. McNeil Lab., Irvine, CA 92714.

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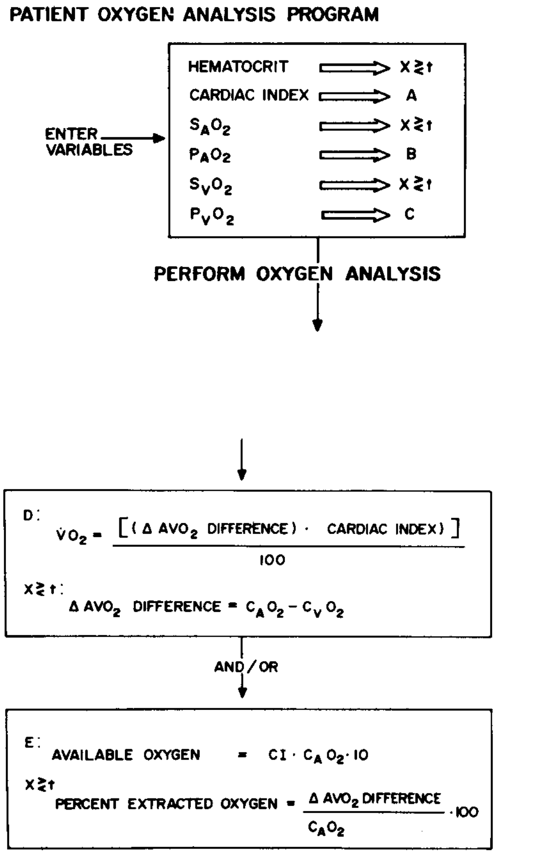

FIGURE 1. Flow-diagram demonstrating the application of the Patient Oxygen Analysis program. After the calculator is programmed, the respective variables are entered into the specific keys as directed by the arrows. Oxygen consumption index ($\dot{V}O_2/m^2$) is found by pressing D, using the formula shown with the entered variables. Key X ≷ t gives the $Ca\text{-}C_{\bar{v}}O_2$). The oxygen available to the patient is determined in ml/min/m^2 by pressing E, and X ≷ t gives the percent oxygen extracted.

Pressures are obtainable from the monitoring and the pump flows from the pump calibration chart.

The development of programs for application to perfusion and other health care areas is dependent on reliable formula determinations. The success in development of useful programs is dependent on the programmer's skill. Currently, the authors have developed programs for determination of body surface area, blood volume, oxygen consumption and AV content differences, body vascular resistances, base excess, tissue oxygen extraction, oxygen saturation, cardiac index, and many others. This information can be generated within a matter of seconds upon entry into the calculator.

Discussion

Today's parameters in determining perfusion adequacy, i.e. pressures, flows, and urine output may be poor indices given the conditions of physiological compensation. One author proposes the use of oxygen consumption plateauing as an indicator for future perfusion standards.[1] Oxygen consumption, for example, is easily calculated with the TI-59, as illustrated in Figure 1. Simply by entering the hematocrit, cardiac index (or pump flow) and arterial-venous oxygen tensions, the oxygen consumption of the patient is obtained upon pressing a single key. As an option, the available oxygen is discernable, along with the percent of extracted oxygen. Currently, the arterial and venous hemoglobin saturations need to be manually determined and entered, however, modification of the program may eliminate this entry.

Analysis of perfusion adequacy in Case Example # 1 can be determined using the oxygen consumption program. On appearance, the conventional bypass parameters appear sufficiently adequate. The pre-bypass parameters are completely normal. Pre-bypass oxygen consumption index ($\dot{V}O_2/m^2$) is determined to be 155 ml/min/m^2, arterial-venous content differences ($Ca\text{-}C_{\bar{v}}O_2$) was found to be 5.8 vol%. The available

TABLE I
Example of Actual Clinical Data Collected for Evaluation in Perfusion Adequacy

Case Example # 1	
Pre-Bypass	Bypass
HCT = 45	HCT = 32
CI = 2.64 L/min/Kg	CI = 2.64 L/min/Kg
P_AO_2 = 200 mmHg	P_AO_2 = 400 mmHg
S_AO_2 = 0.99	S_AO_2 = 0.99
P_VO_2 = 35 mmHg	P_VO_2 = 62 mmHg
S_VO_2 = 0.70	S_VO_2 = 0.92
MAP = 100 mmHg	MAP = 85 mmHg
CVP = 4 mmHg	CVP = 1 mmHg
Urine Output = 2 cc/min	Urine Output = 4 cc/min

TABLE II
Clinical Representation of Pressures and Flows for Evaluation of Vascular Resistance

Case Example #2	
Pre-Bypass	Bypass (normothermia)
MAP = 75 mmHg	MAP = 105 mmHg
CVP = 7 mmHg	CVP = 0 mmHg
CI = 3 L/min/m^2	CI = 3 L/min/m^2

oxygen (O_{2av}) was 501 ml/min/m^2. The percent oxygen extracted (O_{2e}) was 31%. According to Table 3, all parameters are normal. However, oxygen analysis on bypass found $\dot{V}O_2$ = 51 ml/min/m^2, ($Ca\text{-}C_{\bar{v}}O_2$) = 1.93 vol%, O_{2av} = 377 ml/min/m^2 and O_{2e} = 13.58%. All oxygen parameters are abnormal, from Table 3, with the most significant being $\dot{V}O_2$. Since the $\dot{V}O_2$ is obviously so low, inadequate perfusion is occurring. The use of a vasodilator will improve peripheral circulation and thus increase tissue perfusion and oxygen consumption. The significance of the oxygen analysis determination lies in that, from the time of programming the calculator to the time of retrieval of the information, less than sixty seconds would elapse. Use of the calculator does not distract the perfusionist from the mechanics of perfusion.

Body vascular resistance is another very useful but seldom used index of perfusion adequacy. It is also as easily determined as oxygen consumption. Figure 2 demonstrates the application of Pouisielle's Law for the determination. Either systemic vascular resistance, pulmonary vascular resistance, or total peripheral resistance may be calculated in about thirty seconds from time of programming to data retrieval.

TABLE III
Normal Values for Important Hemodynamic Parameters That Are Easily Determined with a Programmable Calculator

Variable	Abbreviation	Units	Normal Adult Value
Body surface area	BSA	m^2	1.2–2.2
Blood volume	BV	L	50–100 cc/Kg
Cardiac index	CI	L/min/m^2	3.2 ± 0.2
Mixed venous oxygen content	$C_{\bar{v}}O_2$	vol %	14–15
Arterial-venous oxygen content difference	$Ca\text{-}C_{\bar{v}}O_2$	vol %	4.25–5.25
Arterial oxygen content	CaO_2	vol %	18–20
Capillary oxygen content	CcO_2	vol %	20
Physiological shunt	$\dot{Q}s/\dot{Q}t$	%	4–8
Alveolar-arterial oxygen difference	A-a difference	mmHg	11–15
Oxygen extracted	O_{2e}	%	26 ± 1
INDICES			
Oxygen consumption	VO_2/m^2	ml/min/m^2	142 ± 8
Oxygen availability	O_{2av}	ml/min/m^2	560 ± 43
Systemic vascular resistance	SVR	dyne·sec·cm^{-5}·m^{-2}	2090 ± 112
Total peripheral resistance	TPR	mm·sec·cc^{-1}	1.0 ± 0.25
Pulmonary vascular resistance	PVR	dyne·sec·cm^{-5}·m^{-2}	270 ± 43
Left ventricular stroke work	LVSW	g·m·m^2	50 ± 5.0
Right ventricular stroke work	RVSW	g·m·m^2	8.8 ± 0.9
Left cardiac work	LCW	Kg·min·m^2	3.8 ± 0.4
Right cardiac work	RCW	Kg·min·m^2	0.6 ± 0.06

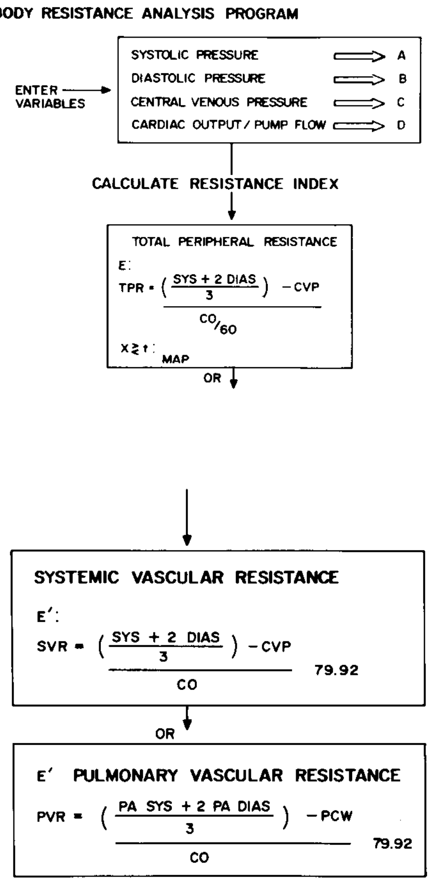

FIGURE 2. Flow-diagram demonstrating the body vascular resistance analysis. After programming, the pressures and flows are entered in the respective keys. Pressing E calculates the total peripheral resistance. If pulmonary vascular resistance is desired, then pulmonary systolic and diastolic pressures, as well as pulmonary artery wedge pressures should be entered as variables. E′ gives PVR. In each case of resistance calculation, the mean arterial pressure, or mean pulmonary artery pressure, can be found by depressing the X ≷ t key.

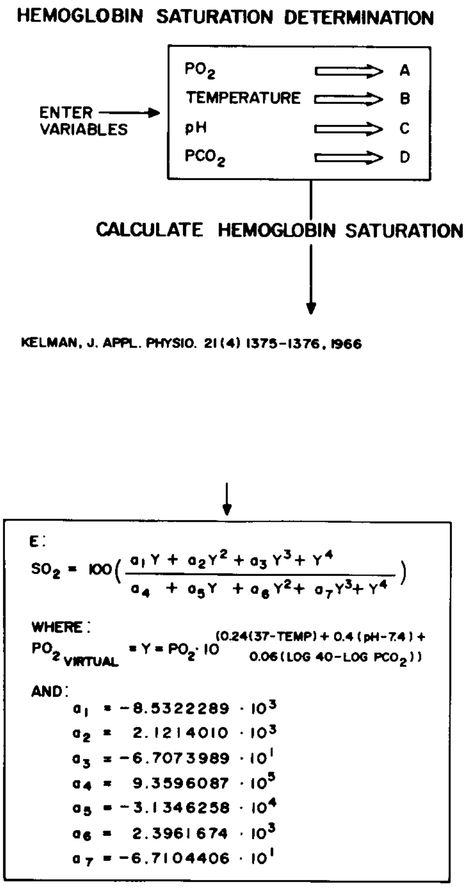

FIGURE 3. Flow-diagram demonstrating the application of the Hemoglobin Saturation Determination. After programming, the variables are entered into the respective keys on the calculator, indicated by the arrows. By simply pressing E, the saturation of the hemoglobin is displayed.

In Case Example #2 (Table 2), a perfusionist might elect to decrease the flow in order to control the pressure. However, the program reveals that the bypass systemic vascular resistance is about 2800 dynes·sec·cm^{-5}·m^2 which is significantly higher than normal (see Table 3). Thus, a peripheral vasodilator should be administered to decrease the resistance and increase the peripheral perfusion. With the TI-59 this evaluation can be made in a matter of seconds, thus providing an aid in decision making.

Obviously, the data processed can better improve the decisions made during bypass and, thus, can be a valuable tool. The rapidity of the information generation is necessary so that instant alterations may be made. Improved patient care is the ultimate goal and the TI-59 can definitely provide new parameters to help decide how to improve the patient status.

The TI-59 can also be applied in the elimination of perfusion nomograms. Hemoglobin saturation programs,[2] body surface area programs,[3,4,5] temperature correction programs,[6,7,2] and body fat programs[8] have all been developed by the author. Figure 3 is an example of the hemoglobin saturation program. The percent hemoglobin oxygen saturation will be determined in % by simply entering the pO_2, pCO_2, temperature, and pH. Moreover, the time of data entry and calculation generally will be less than that using nomograms.

Another perfusion program application is base excess (BE) determination using the Siggard-Anderson equation:[9]

$$(-0.0143\ Hb)(HCO_3^- - 24) + (9.5 + 1.63\ Hb)(pH - 7.4) = BE$$

where Hb is the hemoglobin concentration in gm/dl and HCO_3^- is the bicarbonate concentration, which is derived from the Henderson-Hasselbach equation:

$$(0.0301 \cdot P_aCO_2 \cdot (\text{antilog}(pH\text{-}6.10)) = HCO_3^- \text{ (mEq/L)}$$

Another program application in perfusion is in the calculation of blood volume by the Allen method[10] where:

$$\frac{\text{blood volume}}{\text{(liters)}} = 0.415(\text{ht in m})^3 + 0.039(\text{wt in Kg}) - 0.03$$

In addition to application in perfusion, patient hemodynamic or respiratory analysis data from the operating room or intensive care unit is also easily obtainable. The hemodynamic status may be determined given various cardiac work parameters and resistance indices upon entry of certain real-time information.[11] The respiratory analysis of the patient calculates arterio-venous oxygen contents and differences, oxygen availability, oxygen extracted, oxygen consumed, the physiological shunt, and/or the A-a difference.[12]

The TI-59 is essential for research, as well as for patient status maintenance and/or determination. Many parameters may be statistically compared with the use of the optional soft-ware module, since primary statistical tests may be performed.

The author encourages the use of the imagination in formulating new ideas for programs. However, certain programs are available upon request from the author as a demonstration of the rapid usefulness of the programmable calculator.

Conclusion

The programmable calculator provides immediate real-time determinations of necessary hemodynamic information to improve patient care standards during cardiopulmonary bypass, in the operating room or in the intensive care unit. It also eliminates nomograms, and is a valuable, but inexpensive, investment.

References

1. Mandl, J. P. and J. R. Motley, Oxygen consumption plateauing: A better method of achieving optimum perfusion. 17th Internat'l Con. Amer. Soc. Extracorp. Tech., Houston, 1979.
2. Kellman, G. R., Digital computer subroutine for the conversion of oxygen tension into saturation. *J. Appl. Physiol.* *21*(4):1375, 1966.
3. Dubois, E. R., *Basal metabolism in health and disease.* Philadelphia, 1927.
4. Stretczyn, Michael, Personal Communication.
5. Galletti, P. M. and G. A. Brecher. Heart-Lung Bypass: *Principle and Technique of Extracorporeal Circulation,* New York, 1962, Grune and Stratton, p. 217.
6. Greenburg, A. G. and P. V. Moulder; Temperature coefficients for pCO_2 and pH in whole blood. *Arch. Surg.* 91:867, 1965.
7. Kelman, G. R. and J. F. Nunn, Nomograms for the correction of blood pO_2, pCO_2, pH and Base Excess for time and temperature. *J. Appl. Physiol.* *21*(5):1484–90, 1966.
8. Pierson, W. R. and E. L. Eagle, Nomogram for estimating body fat, specific gravity and lean body weight from height and weight. *Aerospace Med.* *40*(2):161, 1969.
9. Siggard-Anderson, O. E., Titratable acid or base. *Ann. N.Y. Acad. Sci.* *133,* 1966.
10. Allen, T. H. *et al., Metabolism 5*:328, 1956.
11. Mattar, J. A. *et al.,* Measurement of hemodynamic and oxygen transport in critically ill patients. *Cur. Top. Crit. Care Med.* 3:43, 1977.