UTILIZATION OF HAND-HELD PROGRAMMABLE CALCULATORS FOR RAPID BEDSIDE COMPUTATION OF PHYSIOLOGIC-PHARMACOLOGIC VARIABLES AND PROGNOSTIC INDICES DURING MECHANICAL CIRCULATORY SUPPORT

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This study describes five programs that may be used on compact, low-cost programmable calculators with adequate memory and sufficient numbers of program steps to compute cardiorespiratory variables. These short programs are especially useful in the operating room and at the bedside.

The use of serially determined quantitative hemodynamic and respiratory function data constitutes a sound physiologic basis for management of the critically ill patient.[1,2] With the introduction of the Swan-Ganz thermodilution catheter, reliable portable cardiac output computers, and a variety of transducers and pressure processors, rapid quantitation of cardiorespiratory variables is possible. Computation and comparison of these variables, with subsequent appropriate therapeutic manipulations, forms a basis for more precise patient care. Trajectories of derived cardiorespiratory data can also be used to formulate various prognostic indices predictive of survival or non-survival during pharmacologic and mechanical support of the failing circulation.[3]

Prior to the introduction of hand-held programmable calculators, manual derivation of relatively complex cardiorespiratory data was either too time-consuming for serial use or required expensive on-line computer monitoring systems. Smaller, less complex calculators have been in use for most of this decade. Because such devices still lack true portability, their use has been restricted mainly to laboratory applications.[4] Within the last two years, however, microelectronic technology has advanced to the point where compact low-cost programmable calculators with adequate memory and sufficient numbers of working program steps to compute cardiorespiratory variables are now available. Five programs for hand-held calculators are presented.

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MATERIALS AND METHODS

The SR-52 calculator* and the more recently available TI-59* use integrated magnetic card reader/writers for the development, storage, and execution of programs. Both calculators can be coupled to a desk top printer (PC-100 or PC-100A*), adding the capability of producing numeric or alpha-numeric printouts of programs or results. Both calculators utilize an Algebraic Operating System (AOS*), which allows mathematical expressions to be entered into the program in the same order that they would normally be written. This characteristic makes the SR-52 ideal for general clinical application, especially for those operators with little or no programming experience. The system incorporates 224 program storage locations, 20 addressable memory registers, ten user-definable keys, 72 identification labels, five program flags, and three program levels (one routine and two levels of subroutine).

Our initial programs for the SR-52 involved determination of prognostic classifications for post-cardiotomy and cardiogenic shock patients requiring mechanical circulatory support with either intra-aortic balloon pumping (IABP) or the abdominal left ventricular assist device (ALVAD).[5] Additional programs for calculating other prognostic indices and cardiorespiratory variables have subsequently been developed. Rapid calculation and comparison of serial hemodynamic and respiratory function data provide simple methods of evaluating the effectiveness of pharmacologic interventions. Dose response data can be rapidly reduced and used to establish guidelines for determining the appropriate concentration of a specific agent administered.[6]

It is possible through relatively complex programming techniques to calculate as many as 25 individual cardiorespiratory variables in one master program. Such a technique has been reported by Shabot et al.[7] While this approach indicates the absolute capabilities of the SR-52 on a grand scale, we believe that shorter, less complex programs for serial computation of small groups of closely related variables are more useful in the operating room or at the bedside. The following section details five programs developed and in routine use by the Circulatory Support Service of this institution.[8]

Program 1—Hemodynamic Indices for Post-Cardiotomy/Cardiogenic Shock

Low Output Syndrome

This program provides a rapid method for evaluating the hemodynamic effects of pharmacologic and/or mechanical circulatory support in the post-cardiotomy or post-myocardial infarction patient having left ventricular power failure/cardiogenic shock low output syndrome. The program calculates body surface area (BSA), average cardiac output ($\overline{CO}$), cardiac index (CI), pulmonary arteriolar resistance (PAR), systemic vascular resistance (SVR), and a prognostic classification (Class 1, 2 or 3) for survival or non-survival based on

*Texas Instruments, Dallas, Texas.

the relationship of cardiac index and systemic vascular resistance.[9] This program is designed for the hemodynamic characterization of critically ill patients, and is useful in determining the effect of clinical interventions, i.e., volume replacement, use of inotropic or vasoactive agents, and the need for mechanical circulatory support. It also provides an excellent means for indicating the extent of improvement or deterioration of the patient's circulatory status over time trajectories. The mathematical computations executed are outlined in Table I.

The method of prognostic classification is illustrated in Fig. 1 and can be defined as follows:

Class 1 patients have the most favorable hemodynamic responses, are at lowest risk, and may be considered as candidates for weaning from IABP.

Class 2 patients have less favorable hemodynamic responses, are at a higher risk, and may require continued IABP support.

Class 3 patients respond poorly to combined pharmacologic and mechanical circulatory support. These patients are at highest risk and should be considered as candidates for more profound circulatory support (i.e., left ventricular assist device) if clinical improvement is not observed in 6-12 hours.

In a recent study of 331 post-cardiotomy patients who required intra-aortic balloon pumping (IABP), all Class 1 IABP-supported patients survived; 80% of the patients in Class 2 survived, but only 7% of those who remained in Class 3 with IABP support for 12 or more hours postoperatively survived.[3]

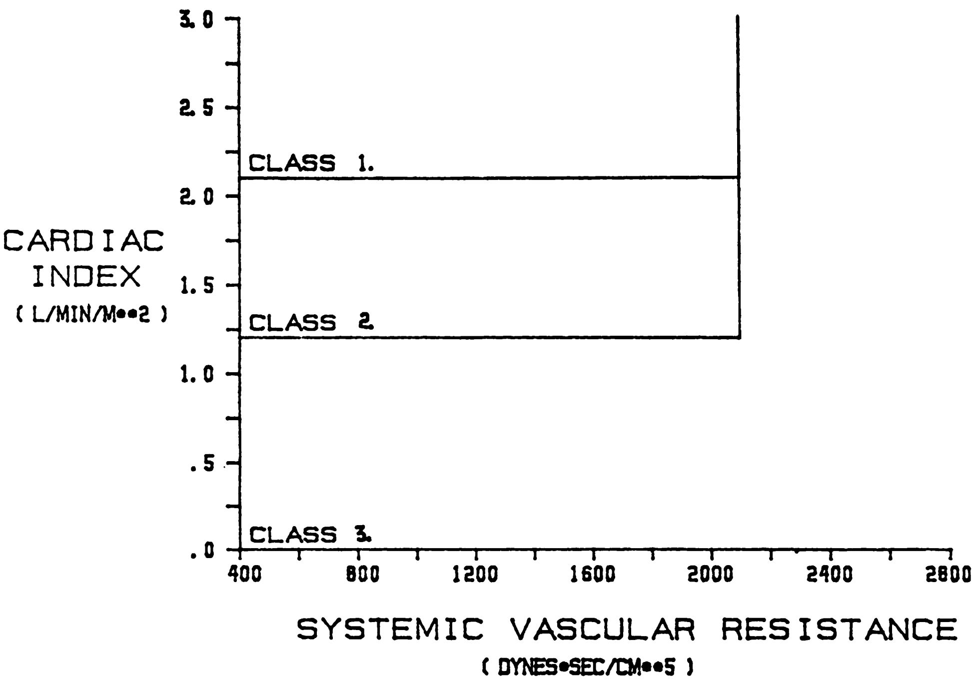

Fig. 1 Texas Heart Institute Mechanical Circulatory Support Prognostic Classification Matrix.

TABLE I. Mathematical Computations Executed by Program I.

$$BSA(M^2) = [Height(in) \times 2.54\ (\frac{cm}{in})]^{.725}\ (weight(lb) \times .4536\ (\frac{lb}{kg})]^{.425} \times .007184$$

$$\overline{CO}\ (L/min) = \frac{\sum_1^n CO\ (L/min)}{n} \qquad CI = \frac{\overline{CO}\ (L/min)}{BSA\ (M^2)}$$

$$SVR\ (dynes \cdot sec \cdot cm^{-5}) = \frac{[\overline{AoP} - \overline{RAP}\ (mmHg)]}{\overline{CO}} \times 80$$

$$PAR\ (dynes \cdot sec \cdot cm^{-5}) = \frac{[\overline{PAP} - \overline{PCW}\ (mmHg)]}{\overline{CO}} \times 80$$

Where:

CO = Cardiac Output

CI = Cardiac Index

$\overline{AoP}$ = Mean Aortic Pressure

$\overline{PCW}$ = Mean Pulmonary Wedge Pressure

$\overline{RAP}$ = Mean Right Atrial Pressure

SVR = Systemic Vascular Resistance

PAR = Pulmonary Arteriolar Resistance

BSA = Body Surface Area

Program Listing

The magnetic card can be programmed in accordance with manufacturer's instructions by entering the program steps in Table II.

User Instructions

After collection of input data, the program can be executed by following the sequence of keystrokes listed in Table III, after loading both sides of the programmed magnetic card.

Program 2—Biventricular Indices

This program provides a rapid method for computing and interpreting variables that reflect right and left ventricular function. We have reviewed the interrelationships of right and left ventricular performance during post-cardiotomy cardiogenic shock and assessed the role of biventricular function on IABP/ALVAD effectiveness. Serial hemodynamic data from 320 patients (302 requiring IABP and 18 requiring ALVAD implantation) were utilized to construct functional categorization matrices based on right and left ventricular minute work indices (RVMWI, LVMWI).[10,11] When these variables are used as the axes of a cartesian coordinate graph, plotted changes in biventricular minute work will divide patients into one of six functional categories (Fig. 2). The limits of the various categories are shown in Table IV. We have observed that these functional categories are representative of discrete levels of ventricular recovery or

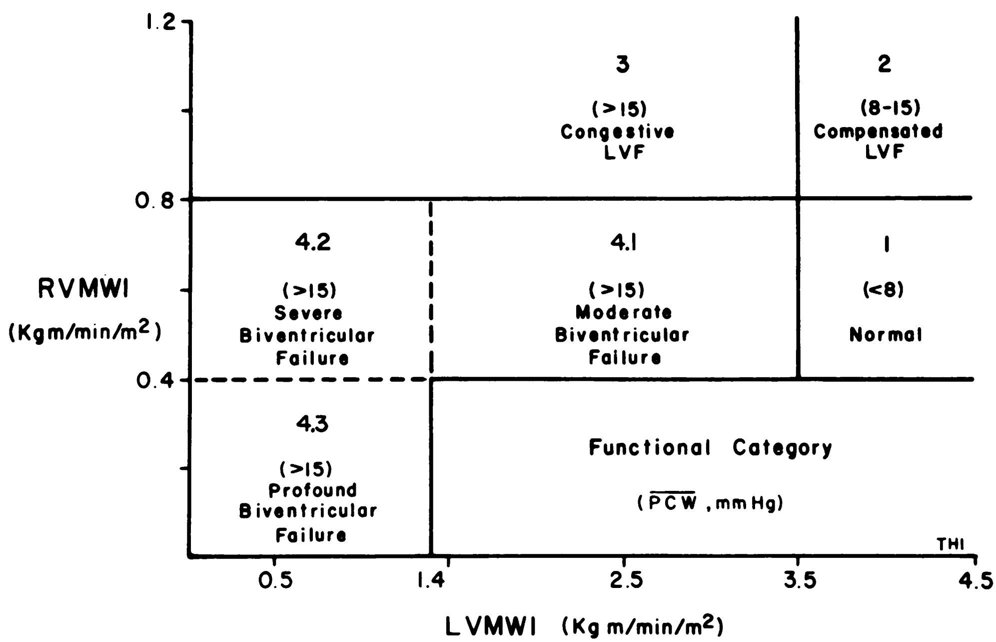

Fig. 2 Biventricular Minute Work Indices and Functional Categories.

deterioration during mechanical circulatory support. Category 1 patients are normal; category 2 patients respond to minimal pharmacologic support; category 3 patients will respond to more intensive pharmacologic therapy; category 4.1 patients require IABP support; category 4.2 patients do not show significant progress with combined intensive pharmacologic support and IABP, and therefore, require the use of a left ventricular assist device. Category 4.3 patients appear to be beyond help, short of cardiac transplantation.[12] Recognition of the correlation between this functional categorization and its corresponding clinical characterization (i.e., category 3 = congestive left ventricular failure, category 4.1 = moderate biventricular failure, etc.) is an important aid in the

TABLE II. Program Listing for Hemodynamic Indices for Post-Cardiotomy/Cardiogenic Shock Low Output Syndrome.

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
000	46	*LBL	038	00	0	076	44	SUM
001	11	A	039	02	2	077	00	0
002	65	X	040	45	Y^X	078	00	0
003	02	2	041	93	.	079	43	RCL
004	93	.	042	04	4	080	00	0
005	05	5	043	02	2	081	00	0
006	04	4	044	05	5	082	81	HLT
007	95	=	045	95	=	083	46	*LBL
008	42	STO	046	65	X	084	14	D
009	00	0	047	43	RCL	085	42	STO
010	01	1	048	00	0	086	00	0
011	98	*PRT	049	03	3	087	08	8
012	81	HLT	050	95	=	088	98	*PRT
013	46	*LBL	051	65	X	089	81	HLT
014	12	B	052	93	.	090	46	*LBL
015	65	X	053	00	0	091	15	E
016	93	.	054	00	0	092	42	STO
017	04	4	055	07	7	093	00	0
018	05	5	056	01	1	094	09	9
019	03	3	057	08	8	095	98	*PRT
020	06	6	058	04	4	096	81	HLT
021	95	=	059	95	=	097	46	*LBL
022	42	STO	060	57	*FIX	098	16	*A'
023	00	0	061	02	2	099	43	RCL
024	02	2	062	42	STO	100	00	0
025	43	RCL	063	00	0	101	04	4
026	00	0	064	04	4	102	98	*PRT
027	01	1	065	43	RCL	103	81	HLT
028	45	Y^X	066	00	0	104	46	*LBL
029	93	.	067	02	2	105	17	*B'
030	07	7	068	98	*PRT	106	43	RCL
031	02	2	069	81	HLT	107	00	0
032	05	5	070	46	*LBL	108	05	5
033	95	=	071	13	C	109	55	÷
034	42	STO	072	44	SUM	110	43	RCL
035	00	0	073	00	0	111	00	0
036	03	3	074	05	5			
037	43	RCL	075	01	1			

formulation of specific therapies. The mathematical computations executed by this program are outlined in Table V.

Program Listing

The magnetic card can be programmed in accordance with manufacturer's instructions by entering the program steps listed in Table VI.

User Instructions

After collection of input data, the program can be executed by following the sequence of keystrokes outlined in Table VII, after loading both sides of the programmed magnetic card.

TABLE. II. (Continued)

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
112	00	0	150	00	0	188	75	-
113	95	=	151	09	9	189	02	2
114	57	*FIX	152	54	)	190	93	.
115	02	2	153	55	÷	191	01	1
116	42	STO	154	43	RCL	192	95	=
117	00	0	155	00	0	193	80	*IFPOS
118	06	6	156	06	6	194	32	SIN
119	43	RCL	157	95	=	195	43	RCL
120	00	0	158	65	X	196	00	0
121	06	6	159	08	8	197	07	7
122	55	÷	160	00	0	198	75	-
123	43	RCL	161	95	=	199	01	1
124	00	0	162	57	*FIX	200	93	.
125	04	4	163	00	0	201	02	2
126	95	=	164	98	*PRT	202	95	=
127	42	STO	165	42	STO	203	80	*IFPOS
128	00	0	166	01	1	204	33	COS
129	07	7	167	00	0	205	03	3
130	43	RCL	168	81	HLT	206	98	*PRT
131	00	0	169	46	*LBL	207	99	*PAP
132	06	6	170	10	*E'	208	47	*CMS
133	98	*PRT	171	43	RCL	209	81	HLT
134	81	HLT	172	01	1	210	46	*LBL
135	46	*LBL	173	00	0	211	32	SIN
136	18	*C'	174	75	-	212	01	1
137	43	RCL	175	02	2	213	98	*PRT
138	00	0	176	01	1	214	99	*PAP
139	07	7	177	00	0	215	47	*CMS
140	98	*PRT	178	00	0	216	81	HLT
141	81	HLT	179	93	.	217	46	*LBL
142	46	*LBL	180	95	=	218	33	COS
143	19	*D'	181	80	*IFPOS	219	02	2
144	53	(	182	02	2	220	98	*PRT
145	43	RCL	183	00	0	221	99	*PAP
146	00	0	184	04	4	222	47	*CMS
147	08	8	185	43	RCL	223	81	HLT
148	75	-	186	00	0			
149	43	RCL	187	07	7			

Program 3—Cardiorespiratory Parameters I

This program provides a rapid method for calculating respiratory variables useful in monitoring patients with compromised pulmonary function. Required entry data include: arterial and mixed venous partial pressures of oxygen and oxygen saturations, partial pressure of arterial carbon dioxide and hemoglobin concentration. The program calculates the arterial and mixed venous contents (CaO_2, $C\bar{v}O_2$), arterial-mixed venous content difference ($a\text{-}\bar{v}DO_2$), alveolar-arterial oxygen tension difference ($A\text{-}aDO_2$), and intrapulmonary shunt fraction (Qs/Qt). Serial comparison of these derived respiratory variables provides considerably more insight into the patient's oxygen transport system than can be obtained from monitoring routine serial blood gases alone. The mathematical computations executed by Program 3 are outlined in Table VIII.

Program Listing

The magnetic card can be programmed in accordance with manufacturer's instructions by entering the program steps listed in Table IX.

TABLE III. User Instructions for Program I.

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1.	Enter height	Ht (in)	A	Ht (cm)
2.	Enter weight	Wt (lb)	B	Wt (kg)
3.	Enter cardiac output in liters/ min	CO (L/min)	C	1.00
4.	Enter any additional number of cardiac outputs and press C after each entry	CO (L/min)	C	Number of outputs entered
5.	Enter $\overline{PAP}$	$\overline{PAP}$ (mm Hg)	D	$\overline{PAP}$
6.	Enter $\overline{PCW}$	$\overline{PCW}$ (mm Hg)	E	$\overline{PCW}$
7.			A'	BSA
8.			B'	$\overline{CO}$
9.			C'	CI
10.			D'	PAR
11.	Enter $\overline{AoP}$		D	$\overline{AoP}$
12.	Enter $\overline{RAP}$		E	$\overline{RAP}$
13.			D'	SVR
14.			E'	Class
15.	Steps 7, 8, 9 and 10 should be performed in numerical sequence.			
16.	Class should be executed as the final step because all data memories are cleared during this program segment			
17.	BSA, CO, CI, PAR and SVR may be recalled at any time prior to calculation of class.			

TABLE IV. Limits of Texas Heart Institute Biventricular Classes.

FUNCTIONAL CLASS	CLINICAL CHARACTERIZATION	LVMWI	RVMWI	$\overline{PCW}$
1.	Normal	4.2 ± 0.7	0.6 ± 0.2	<8
2.	Compensated LVF	>3.5	>0.8	8-15
3.	Congestive LVF	<3.5	>0.8	>15
4.1	Biventricular Failure (IABP effective)	1.4 - 3.5	0.4 - 0.8	>15
4.2	Biventricular Failure (ALVAD effective)	<1.4	0.4 - 0.8	>15
4.3	Biventricular Failure (ALVAD ineffective)	<1.4	<0.4	>15
--	Hypovolemia	<3.5	<0.8	<15

TABLE V. Mathematical Computations Executed by Program II.

1. CI (L/min/M^2) = $\overline{CO}$ (L/min ÷ BSA (m^2)
2. LVMWI (kg•m/min/m^2) = $\overline{AoP}$ x CI x 0.0136
3. RVMWI (kg•m/min/m^2) = $\overline{PAP}$ x CI x 0.0136

Where:

CI = Cardiac Index

CO = Cardiac Output

BSA = Body Surface Area

$\overline{AoP}$ = Mean Aortic Pressure

$\overline{PAP}$ = Mean Pulmonary Artery Pressure

LVMWI = Left Ventricular Minute Work Index

RVMWI = Right Ventricular Minute Work Index

TABLE VI. Program Listing for Biventricular Indices.

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
000	46	LBL	038	04	4	076	06	6
001	11	A	039	98	PRT	077	98	PRT
002	47	CMS	040	81	HLT	078	81	HLT
003	93	.	041	46	LBL	079	46	LBL
004	00	0	042	16	A'	080	18	C'
005	01	1	043	43	RCL	081	43	RCL
006	03	3	044	00	0	082	00	0
007	06	6	045	02	2	083	05	5
008	42	STO	046	55	÷	084	65	X
009	00	0	047	43	RCL	085	53	RCL
010	00	0	048	00	0	086	00	0
011	25	CLR	049	01	1	087	04	4
012	81	HLT	050	95	=	088	65	X
013	46	LBL	051	57	FIX	089	43	RCL
014	12	B	052	02	2	090	00	0
015	42	STO	053	42	STO	091	00	0
016	00	0	054	00	0	092	95	=
017	01	1	055	05	5	093	57	FIX
018	98	PRT	056	98	PRT	094	02	2
019	81	HLT	057	81	HLT	095	42	STO
020	46	LBL	058	46	LBL	096	00	0
021	13	C	059	17	B'	097	07	7
022	42	STO	060	43	RCL	098	98	PRT
023	00	0	061	00	0	099	81	HLT
024	02	2	062	05	5	100	46	LBL
025	98	PRT	063	65	X	101	19	D'
026	81	HLT	064	43	RCL	102	43	RCL
027	46	LBL	065	00	0	103	00	0
028	14	D	066	03	3	104	07	7
029	42	STO	067	65	X	105	75	-
030	00	0	068	43	RCL	106	93	.
031	03	3	069	00	0	107	04	4
032	98	PRT	070	00	0	108	95	=
033	81	HLT	071	95	=	109	22	INV
034	46	LBL	072	57	FIX	110	80	IF POS
035	15	E	073	02	2	111	87	1'
036	42	STO	074	42	STO	112	75	-
037	00	0	075	00	0	113	93	.

User Instructions

After collection of input data, the program can be executed by following the sequence of keystrokes shown in Table X, after loading both sides of the programmed magnetic card.

Program 4—Cardiorespiratory Parameters II

This program uses values calculated in the Cardiorespiratory Parameters I program and is intended to follow in sequence. The variables of oxygen uptake,

TABLE VI. (Continued)

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
114	04	4	141	99	PAP	168	99	PAP
115	95	=	142	81	HLT	169	98	PRT
116	94	+/-	143	46	LBL	170	99	PAP
117	80	IF POS	144	88	2'	171	81	HLT
118	88	2'	145	43	RCL	172	46	LBL
119	43	RCL	146	00	0	173	89	3'
120	00	0	147	06	6	174	01	1
121	06	6	148	75	-	175	99	PAP
122	75	-	149	03	3	176	98	PRT
123	03	3	150	93	.	177	99	PAP
124	93	.	151	05	5	178	81	HLT
125	05	5	152	95	=	179	46	LBL
126	95	=	153	80	IF POS	180	77	4'
127	80	IF POS	154	89	3'	181	02	2
128	77	4'	155	43	RCL	182	99	PAP
129	03	3	156	00	0	183	98	PRT
130	99	PAP	157	06	6	184	99	PAP
131	98	PRT	158	75	-	185	81	HLT
132	99	PAP	159	01	1	186	46	LBL
133	81	HLT	160	93	.	187	78	5'
134	46	LBL	161	04	4	188	04	4
135	87	1'	162	95	=	189	93	.
136	04	4	163	80	IF POS	190	01	1
137	93	.	164	78	5'	191	99	PAP
138	03	3	165	04	4	192	98	PRT
139	99	PAP	166	93	.	193	99	PAP
140	98	PRT	167	02	2	194	81	HLT

TABLE VII. User Instructions for Program II.

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1.	Initialize program		A	0
2.	Enter BSA	BSA (M^2)	B	BSA (M^2)
3.	Enter CO	CO (L/min)	C	CO (L/min)
4.	Enter AoP	AoP (mm Hg)	D	AoP (mm Hg)
5.	Enter PAP	PAP	E	PAP (mm Hg)
6.			A'	CI (L/min/M^2)
7.			B'	LVMWI (kg·m/min/M^2)
8.			C'	RVMWI (kg·m/min/M^2)
9.			D'	Class

TABLE VIII. Mathematical Computations Executed by Program III.

$$CaO_2 = PaO_2 \times 0.0031 + SaO_2 \times Hgb \times 1.34/100$$

$$C\bar{v}O_2 = P\bar{v}O_2 \times 0.0031 + S\bar{v}O_2 \times Hgb \times 1.34/100$$

$$a\text{-}\bar{v}DO_2 = CaO_2 - C\bar{v}O_2$$

$$A\text{-}aDO_2 = [(P_{BAR} - P_{H_2O})(F_{IO_2}) - (PaCO_2)(1.25)] - PaO_2^*$$

$$Qs/Q_t = \frac{A\text{-}aDO_2 \times .0031}{(A\text{-}aDO_2 \times .0031) + a\text{-}\bar{v}DO_2}$$

Where:

CaO_2 = Arterial Oxygen Content

$C\bar{v}O_2$ = Mixed Venous Oxygen Content

$a\text{-}\bar{v}DO_2$ = Arterial-mixed Venous Content Difference

$A\text{-}aDO_2$ = Alveolar-arterial Oxygen Gradient

Qs/Qt = Intrapulmonary Shunt Fraction

PaO_2 = Partial Pressure of Arterial Oxygen

$P\bar{v}O_2$ = Partial Pressure of Mixed Venous Oxygen

$PaCO_2$ = Partial Pressure of Arterial Carbon Dioxide

SaO_2 = Arterial Oxygen Saturation

$S\bar{v}O_2$ = Mixed Venous Oxygen Saturation

Hgb = Hemoglobin Concentration

P_{BAR} = Barometric Pressure

P_{H_2O} = Water Vapor Pressure

F_{IO_2} = Fraction of Inspired O_2

*Note that for valid determination of $A\text{-}aDO_2$, the patient must be administered 100% oxygen for 15 minutes prior to drawing arterial and mixed venous blood samples. This is required since the calculations are based on the assumption that the hemoglobin is maximally saturated. Also note that the barometric pressure, water vapor pressure, and F_{IO_2} are set at 760 mm Hg, 47 mm Hg, and 1.0 automatically by default. Current daily barometric pressure may be inserted by entering an appropriate value and reprogramming steps 120-122 on the magnetic card.

TABLE IX. Program Listing for Cardiorespiratory Parameters I.

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
000	46	LBL*	038	46	LBL*	076	85	+
001	11	A	039	16	A*	077	43	RCL
002	42	STO	040	60	IF FLG*	078	00	0
003	00	0	041	01	1	079	08	8
004	01	1	042	34	TAN	080	54	)
005	22	INV	043	50	ST FLG*	081	42	STO
006	50	ST FLG*	044	01	1	082	00	0
007	01	1	045	42	STO	083	09	9
008	57	FIX*	046	00	0	084	53	(
009	02	2	047	06	6	085	43	RCL
010	43	RCL	048	93	.	086	00	0
011	00	0	049	00	0	087	04	4
012	01	1	050	01	1	088	65	X
013	81	HLT	051	03	3	089	43	RCL
014	46	LBL*	052	04	4	090	00	0
015	12	B	053	42	STO	091	06	6
016	42	STO	054	00	0	092	65	X
017	00	0	055	07	7	093	43	RCL
018	02	2	056	93	.	094	00	0
019	81	HLT	057	00	0	095	07	7
020	46	LBL*	058	00	0	096	85	+
021	13	C	059	03	3	097	43	RCL
022	42	STO	060	01	1	098	00	0
023	00	0	061	42	STO	099	02	2
024	03	3	062	00	0	100	65	X
025	81	HLT	063	08	8	101	43	RCL
026	46	LBL*	064	53	(	102	00	0
027	14	D	065	43	RCL	103	08	8
028	42	STO	066	00	0	104	54	)
029	00	0	067	03	3	105	42	STO
030	04	4	068	65	X	106	01	1
031	81	HLT	069	43	RCL	107	00	0
032	46	LBL*	070	00	0	108	43	RCL
033	15	E	071	06	6	109	00	0
034	42	STO	072	65	X	110	09	9
035	00	0	073	43	RCL	111	75	-
036	05	5	074	00	0	112	43	RCL
037	81	HLT	075	07	7	113	01	1

transport and utilization are calculated. Specifically, values for Minute Oxygen Consumption ($\dot{V}O_2$), Oxygen Availability (O_2AV) and Oxygen Extraction (O_2ER) are computed. Required entry data include 1) arterial mixed venous content difference; 2) arterial oxygen content, and 3) the average cardiac index. Much work has been detailed concerning the changes that occur in these variables during circulatory shock, resulting from various etiologies.[1,2] Each of these variables, when serially monitored, has been used as an early predictor of death or survival. Table XI outlines specific values for the oxygen transport variables that may be encountered during various stages of circulatory shock. The mathematical computations executed by Program 4 are outlined in Table XII.

TABLE IX. (Continued)

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
114	00	0	146	01	1	178	01	1
115	95	=	147	02	2	179	81	HLT
116	42	STO	148	65	X	180	46	LBL*
117	01	1	149	43	RCL	181	17	B*
118	01	1	150	00	0	182	43	RCL
119	53	(	151	08	8	183	01	1
120	07	7	152	54	)	184	02	2
121	01	1	153	55	÷	185	81	HLT
122	03	3	154	53	(	186	46	LBL*
123	75	-	155	53	(	187	18	C*
124	53	(	156	43	RCL	188	43	RCL
125	01	1	157	01	1	189	01	1
126	93	.	158	02	2	190	03	3
127	02	2	159	65	X	191	65	X
128	05	5	160	43	RCL	192	01	1
129	65	X	161	00	0	193	00	0
130	43	RCL	162	08	8	194	00	0
131	00	0	163	54	)	195	95	=
132	05	5	164	85	+	196	81	HLT
133	54	)	165	43	RCL	197	46	LBL*
134	54	)	166	01	1	198	19	D*
135	75	-	167	01	1	199	43	RCL
136	43	RCL	168	54	)	200	00	0
137	00	0	169	54	)	201	09	9
138	01	1	170	95	=	202	81	HLT
139	95	=	171	42	STO	203	46	LBL*
140	42	STO	172	01	1	204	10	E*
141	01	1	173	03	3	205	43	RCL
142	02	2	174	46	LBL*	206	01	1
143	53	(	175	34	TAN	207	00	0
144	53	(	176	43	RCL	208	81	HLT
145	43	RCL	177	01	1			

Program Listing

The magnetic card can be programmed in accordance with manufacturer's instructions by entering the program steps listed in Table XIII.

User Instructions

After collection of input data, the program can be executed by following the sequence of keystrokes shown in Table XIV, after loading Side A of the programmed magnetic card.

Program 5—Drug Concentration Calculations

The administration of potent vasoconstrictive and inotropic agents requires careful preparation and measured delivery. The calculation of dosage is often

TABLE X. User Instructions for Program III.

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1.	Enter PaO_2	PaO_2	A	PaO_2
2.	Enter $P\bar{v}O_2$	$P\bar{v}O_2$	B	$P\bar{v}O_2$
3.	Enter SaO_2	SaO_2	C	SaO_2
4.	Enter $S\bar{v}O_2$	$S\bar{v}O_2$	D	$S\bar{v}O_2$
5.	Enter $PaCO_2$	$PaCO_2$	E	$PaCO_2$
6.	Enter Hemoglobin*	Hgb	2nd A	$a\text{-}\bar{v}DO_2$
	*The program is immediately started after entry of hemoglobin value and 2nd A is pressed. Therefore the first resultant is seen in the display rather than the value entered for the hemoglobin.		2nd B	$A\text{-}aDO_2$
			2nd C	Qs/Qt
			2nd D	CaO_2
			2nd E	$C\bar{v}O_2$

TABLE XI. Optimal Values and Cut-off Points for Oxygen Transport Related Variables During Early, Middle, and Late Periods of Circulatory Shock*

	EARLY		MIDDLE		LATE		
	Survivor	Non-Survivor	Survivor	Non-Survivor	Survivor	Non-Survivor	
$\dot{V}_{O2}$ (ml/min/M²)	>210	< 79	--	--	>310	<130	140±25 (ml/min/M²)
O_{2AV} (ml/min/M²)	>460	<390	>830	<310	>820	<290	600±50 (ml/min/M²)
O_{2ER} (%)	< 27%	> 40%	< 28%	> 61%	--	--	26±2%

*Adapted from Shoemaker et al[2]

cumbersome and time-consuming. This program provides a rapid and reliable method for accurately determining the dose per unit volume of a solution and the dose delivered to the patient per unit time. By entering the patient's weight (either in pounds or kilograms), the volume of the intravenous solution bag,

TABLE XII. Mathematical Computations Executed by Program IV.

$$\dot{V}O_2 = a\text{-}\bar{v}DO_2 \times CI \times 10$$

$$O_{2AV} = CaO_2 \times CI \times 10$$

$$O_{2ER} = a\text{-}\bar{v}DO_2 \div CaO_2$$

TABLE XIII. Program Listing for Cardiorespiratory Parameters II.

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
000	46	LBL*	027	65	X	054	43	RCL
001	11	A	028	01	1	055	00	0
002	42	STO	029	00	0	056	03	3
003	00	0	030	95	=	057	95	=
004	01	1	031	57	FIX*	058	42	STO
005	81	HLT	032	02	2	059	00	0
006	46	LBL*	033	42	STO	060	06	6
007	12	B	034	00	0	061	46	LBL*
008	42	STO	035	04	4	062	16	A*
009	00	0	036	43	RCL	063	43	RCL
010	02	2	037	00	0	064	00	0
011	81	HLT	038	03	3	065	04	4
012	46	LBL*	039	65	X	066	81	HLT
013	13	C	040	43	RCL	067	46	LBL*
014	42	STO	041	00	0	068	17	B*
015	00	0	042	02	2	069	43	RCL
016	03	3	043	65	X	070	00	0
017	81	HLT	044	01	1	071	05	5
018	46	LBL*	045	00	0	072	81	HLT
019	16	A*	046	95	=	073	46	LBL*
020	43	RCL*	047	42	STO	074	18	C*
021	00	0	048	00	0	075	43	RCL
022	01	1	049	05	5	076	00	0
023	65	X	050	43	RCL	077	06	6
024	43	RCL	051	00	0	078	81	HLT
025	00	0	052	01	1			
026	02	2	053	55	÷			

the number of ampules added to the bag, and the number of milligrams of pharmacologic agent per ampule, this program calculates the strength of the solution in micrograms/ml and micrograms/kilograms/ml. From these intermediate values, the specific dose per unit time can be obtained in the following measurements: drops/min (based on a micro-drip infusion, i.e., 60 drops = 1 ml), micrograms/min., or micrograms/kg/min. By entering any one of the preceding time-dependent variables, the other two are calculated and displayed. The mathematical computations executed by this program are outlined in Table XV.

TABLE XIV. User Instructions for Program IV.

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1.	Enter $a\text{-}\bar{v}DO_2$	$a\text{-}\bar{v}DO_2$	A	$a\text{-}\bar{v}DO_2$
2.	Enter cardiac index	CI	B	CI
3.	Enter arterial oxygen content	CaO_2	C	CaO_2
4.	Display VO_2		2nd A	$\dot{V}O_2$
5.	Display O_{2AV}		2nd B	O_{2AV}
6.	Display O_{2ER}		2nd C	O_{2ER}

TABLE XV. Mathematical Computations Executed by Program V.

kg = LBSm/2.2

mg/BAG = AMP*/BAG x mg/AMP

μg/ml = mg/BAG ÷ ml/BAG x 1000

μg/min = gtts/min ÷ 60 gtts/ml x μg/ml

μg/kg/min = μg/min ÷ kg

μg/kg/cc = μg/cc ÷ kg

*AMP = Ampule

Program Listing

The magnetic card can be programmed in accordance with the manufacturer's instructions by entering the program steps listed in Table XVI.

User Instructions

After collection of input data, the program can be executed by following the sequence of keystrokes outlined in Table XVII, after loading both sides of the programmed card.

TABLE XVI. Program Listing for Dosages and Solutions Calculator.

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
000	46	LBL*	038	90	IF ZRO*	076	01	1
001	87	1*	039	88	2*	077	43	RCL
002	01	1	040	42	STO	078	00	0
003	05	5	041	00	0	079	06	6
004	04	4	042	03	3	080	81	HLT
005	46	LBL*	043	81	HLT	081	46	LBL*
006	16	A*	044	46	LBL*	082	12	B
007	90	IF ZRO*	045	19	D*	083	60	IF FLG*
008	87	1*	046	42	STO	084	01	1
009	47	CM's*	047	00	0	085	89	3*
010	57	FIX*	048	04	4	086	42	STO
011	02	2	049	81	HLT	087	00	0
012	42	STO	050	46	LBL*	088	07	7
013	00	0	051	10	E*	089	51	SBR
014	01	1	052	42	STO	090	32	SIN
015	55	÷	053	00	0	091	51	SBR
016	02	2	054	05	5	092	33	COS
017	93	.	055	65	x	093	50	ST FLG*
018	02	2	056	43	RCL	094	01	1
019	95	=	057	00	0	095	46	LBL*
020	42	STO	058	04	4	096	89	3*
021	00	0	059	55	÷	097	43	RCL
022	02	2	060	43	RCL	098	00	0
023	46	LBL*	061	00	0	099	07	7
024	17	B*	062	03	3	100	98	PRT*
025	90	IF ZRO*	063	65	x	101	81	HLT
026	87	1*	064	01	1	102	46	LBL*
027	42	STO	065	00	0	103	13	C
028	00	0	066	00	0	104	60	IF FLG*
029	02	2	067	00	0	105	01	1
030	25	CLR	068	95	=	106	77	4*
031	46	LBL*	069	42	STO	107	42	STO
032	88	2*	070	00	0	108	00	0
033	05	5	071	06	6	109	08	8
034	00	0	072	46	LBL*	110	51	SBR
035	00	0	073	11	A	111	33	COS
036	46	LBL*	074	22	INV			
037	18	C*	075	50	ST FLG			

SUMMARY

Over the last decade, considerable emphasis has been placed on the use of large computers in medicine, and many institutions have made major investments in systems for gathering, storing, retrieving and analyzing physiologic data. Despite the enormous capabilities of these systems, their actual usefulness has been limited because of increasing expense, rapid obsolescence, prolonged downtimes, and data retrieval lags that extend beyond the time available for therapeutic decision making. In comparison, the recent availability of inexpensive

TABLE XVI. (Continued)

LOC	CODE	KEY	LOC	CODE	KEY	LOC	CODE	KEY
112	51	SBR	150	43	RCL	188	00	0
113	34	TAN	151	00	0	189	09	9
114	50	ST FLG*	152	02	2	190	56	RTN*
115	01	1	153	95	=	191	46	LBL*
116	46	LBL*	154	42	STO	192	34	TAN
117	77	4*	155	01	1	193	53	(
118	43	RCL	156	00	0	194	43	RCL
119	00	0	157	81	HLT	195	00	0
120	08	8	158	46	LBL*	196	08	8
121	98	PRT*	159	32	SIN	197	65	x
122	81	HLT	160	53	(	198	06	6
123	46	LBL*	161	43	RCL	199	00	0
124	14	D	162	00	0	200	55	÷
125	60	IF FLG*	163	07	7	201	43	RCL
126	01	1	164	55	÷	202	00	0
127	78	5*	165	06	6	203	06	6
128	42	STO	166	00	0	204	54	)
129	00	0	167	65	x	205	42	STO
130	09	9	168	43	RCL	206	00	0
131	51	SBR	169	00	0	207	07	7
132	28	LOG*	170	06	6	208	56	RTN*
133	51	SBR	171	54	)	209	46	LBL*
134	34	TAN	172	42	STO	210	28	LOG*
135	50	ST FLG*	173	00	0	211	53	(
136	01	1	174	08	8	212	43	RCL
137	46	LBL*	175	56	RTN*	213	00	0
138	78	5*	176	46	LBL*	214	09	9
139	43	RCL	177	33	COS	215	65	x
140	00	0	178	53	(	216	43	RCL
141	09	9	179	43	RCL	217	00	0
142	98	PRT*	180	00	0	218	02	2
143	81	HLT*	181	08	8	219	54	)
144	46	LBL*	182	55	÷	220	42	STO
145	15	E	183	43	RCL	221	00	0
146	43	RCL	184	00	0	222	08	8
147	00	0	185	02	2	223	56	RTN
148	06	6	186	54	)			
149	55	÷	187	42	STO			

TABLE XVII. User Instructions for Dosages and Solutions Calculator—Program V

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1.	Enter patient weight (If 0 is entered in either A* or B*, program assumes wt = 70 kg)	if wt in lbs if wt in kg	A* B*	500† 500†
2.	OPTIONAL. Enter volume of bag (if specific bag vol is not entered, program assumes bag vol = 50 ml)	vol in ml	C*	vol of bag
3.	Enter no. of ampules/ bag	no. of amps	D*	no. of amps
4.	Enter mg/ampule	mg/amp	E*	μg/ml in bag
5.	Enter one of the following:	drops/min or μg/min or μg/kg/min	B C D	drops/min μg/min μg/kg/min
6.	Calculate the other two time-related variables by pressing the appropriate key*			
7.	To reset for new time-dependent variables for the same patient		A	μg/ml in bag
8.	Repeat Steps 5 & 6			
9.	OPTIONAL. After completing Step 4		E	μg/kg/cc

*Example: Enter drops/min, press B, then press C to display μg/min and D to display μg/kg/min.

($150-200) programmable hand-held calculators offers rapid analytic methods for immediate use at the bedside.

Five programs for the rapid determination of prognostic cardiocirculatory classifications, relevant indicators of respiratory function, and a useful method for accurate calculations of dosages and solutions have been developed. The use of hand-held programmable calculators and these programs offers the opportunity to improve critical care. Parameters pertaining to specific pathophysiologic states can be easily determined. Ease of operation encourages more quantitative methods of patient management.

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