Automation of Cardiopulmonary Bypass Data Collection

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Abstract

A computer assisted data collection system is presented. The system is comprised of a microprocessor with permanent memory, a general purpose interface board capable of analog to digital conversion, and communication ports to collect data from other microprocessors.

Continuous in-line blood gas values and ventilation control parameter values are passed to the microprocessor for storage in an addressable memory location. Analog signals for blood flow, patient temperatures and pressures are also stored and referenced to real time.

This system provides the perfusionist with the following capabilities in the in vivo laboratory and OH surgical suite; minute-by-minute trending of the progress of perfusion, documentation of device and perfusionist performance and patient response to dynamic changes. Physiological transformations and calculations are automatically performed and the microprocessor notifies the perfusionist of user defined alarm situations.

Analysis of the data base created on-line by this system leads to learning situations that improve open heart surgical teamwork, the consistency of patient care, and provides a possible defense against medical legal complication.

Introduction

The primary function of the perfusionist is to maintain the patient in an acceptable physiological state during bypass. Often, documentation of this effort becomes secondary. A rapid proliferation of cardiopulmonary bypass (CPB) data sources, both external and on-line during bypass, has created a need for more efficient collection and interpretation of many physiological and mechanical parameters.[1-28] Traditional methods applied to these processes are cumbersome, time consuming, and frequently produce errors by omission.[1,5,11,16,17,25,28] Additionally, the lack, or misinterpretation, of important perfusion documentation reviewed retrospectively may have disastrous implications to a legal defense of clinical activity.

The availability of transducers which directly measure physiologic events during CPB has made automatic data collection feasible for CPB procedures.[7-9,15,16]

Intraoperative application of computer technology can increase the accuracy, frequency, and efficiency of the data collection process and has become a useful ally to the surgical team.[2-6,11,14,17-19,25,28]

The system described is designed to assimilate in useful form all of the existing algorithms used to calculate perfusion management parameters.[1-28] The need for program loading into less powerful microprocessing units and keystroke entry of data has been eliminated. Simultaneously, expanded memory capacity and flexible programmability is achieved.

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Method

Figure One presents the pattern of information flow through the CPB automatic data collection system.

AUTOMATIC DATA COLLECTION SYSTEM INFORMATION FLOW

Transducers / Sensors → Measurement Systems / Amplifiers → Recorder Output / Analog Signal → Multiplexer → Computer Software → Memory → Output Devices / Display / Printout → Modem → Data Base / Mainframe

FIGURE 1

Graphically illustrates the flow of input data through the system from initial physiologic or mechanical signal to link with remote mainframe memory.

TABLE 1

Lists sources of data input, abbreviation for parameters, units of measure, and supplier of direct measurement devices.

ANALOG SIGNAL INPUT

Directly Measured Parameter	Abbreviation	Unit of Measure	Manufacturer
Blood Flow	BQ	$liter \cdot minute^{-1}$	Carolina Medical Electronics, Inc., King, NC, 27201
Gas Flow	GQ	$liter \cdot minute^{-1}$	Teledyne Hastings-Raydist, Hampton, VA, 23661
Percent Oxygen	FiO_2	fraction (%)	Ohio Medical Products, Madison, WS 53707
Gaseous pCO_2	$PinCO_2$, $PexCO_2$	mmHg	Biochem International, Inc., Milwaukee, WI, 53213
Hemoglobin O_2 Saturation	SaO_2, SvO_2	%	American Bentley, Irvine, CA, 92714
Arterial and venous pH, pCO_2, pO_2 and temperature	PaO_2,$PaCO_2$,PaH, PvO_2,$PvCO_2$,PvH, T_{art} and T_{ven}	mmHg, °C	Cardiovascular Devices, Inc., Irvine, CA, 92714
ECC Blood Reservoir Level	RL	milliliters	Cardiovascular Perfusion Resources, Inc., Troy, MI, 48098
Hematocrit	HCT	%	American Bentley, Irvine, CA, 92714
ECC Arterial Line Pressure	ALP	mmHg	Electromedics, Inc., Inverness, CO, 80112
Arterial and Venous Blood Pressure	mABP,CVP	mmHg	Hewlett-Packard, Inc., Loveland, CO, 80537
Real Time	HR:MN	hour:minute	Otrona Advanced Systems Corp., Boulder, CO, 80301

Physiologic parameters are measured directly by the transducers and sensors listed in Table 1.

An analog or digitalized signal is obtained by the computer through external multiplexing or a communication port respectively. An event programmed into the software, or a single key stroke by the user, initiates the collection of directly measured parameters. The parameter values are saved, referenced to elapsed bypass time, and employed to calculate the parameters listed in Table 2. The directly measured parameters and software calculated parameters include well documented CPB patient management aids. The units of measure and references for the algorithm to calculate each parameter from the directly measured parameters are found in Table 2.

The calculated parameters are consistent with the indices of patient and device function currently found in the cardiopulmonary bypass literature and in documentation of cardiovascular device performance from manufacturers. The directly measured and calculated parameters may be displayed by output devices in formats that are acceptable for entry into the medical record, and that are useful to the user, in real time, during cardiopulmonary bypass.[2,5,18,19] The most useful formats for presentation of single calculated parameters will evolve as users study and learn the signficance of monitoring the parameters in Tables 1 and 2.

At the termination of cardiopulmonary bypass, the computer generated perfusion record may be entered into the medical record. The sampling frequency and the ability to reproduce cardiopulmonary bypass minute by minute is evident.

Results

Two examples of the continuous monitoring of CPB parameters and calculation of perfusion management parameters are found in Print-Outs 1 and 2. Print-Out 1 is the cardiopulmonary bypass record from a one and one-half year old male undergoing repair of atrioventricular canal. Print-Out 2 is the record of a test oxygenator run for an in vitro equilibrium deoxygenator evaluation circuit. These Print-Outs represent extremes of clinical and in vitro perfusion. Measured and calculated parameters may be presented to the computer monitor or output devices in any manner that the perfusionist finds acceptable to support the management of a particular perfusion technique.

TABLE 2

Lists measurement categories (topics), parameters abbreviations, units of measure for each parameter, and reference source from medical literature.

COMPUTER SOFTWARE CALCULATED PARAMETERS

Topic/Parameter	Abbre-viation	Unit of Measure	Reference
TIME			
Elapsed Time	ET	minute	
HEMODYNAMICS			
Cardiac Index	CI	liter.minute$^{-1}\cdot(M^2)^{-1}$	1
Systemic Vascular Resistance Index	SVRI	dyne.sec.cm$^{-5}\cdot(M^2)^{-1}$	
Viscosity	CPS	centipoise	20, 21
Geometric Component	GC	cm^{-4}	20, 21
OXYGEN TRANSPORT			
Gas: Blood Flow	GBQR		
Oxygen Delivery	0_2DEL	0_2 Vol%.liter.minute^{-1}	18
Oxygen Transfer	$V0_2$	milliliter 0_2.minute^{-1}	
% Expected $V0_2$	$V0_2$Exp	%	11, 24
Hemoglobin P_{50}	P_{50}	mmHg	10, 14
CARBON DIOXIDE TRANSPORT			
Bicarbonate	$[HC0_3^-]$	milliequivalent.liter^{-1}	13
Base Excess	B.E.	milliequivalent.liter^{-1}	13
$PC0_2$ Forcing Function	LMdp$C0_2$	mmHg	26
$C0_2$ Transfer	$VC0_2$	milliliter $C0_2$.minute^{-1}	8, 12
Respiratory Quotient	R.Q.		
Venous $C0_2$ Content	$[C0_2]_V$	milliliter $C0_2$.deciliter^{-1}	28
Fraction Inspired $C0_2$	$FiC0_2$	fraction (%)	8
HEAT TRANSPORT			
Coefficient of Heat Exchange	CHE	fraction	27
Water in—Blood in Temperature	Twi-Tbi	°C	27
Heat Flow	HQ	kilocalories.minute^{-1}	27
Net Heat Transfer	KCAL	+/- kilocalories	27

Samp Time	CO L/M	mABP mmHg	02 L/M	C02 mL/M	Pa02 mmHg	PaC02 mmHg	PaH	Hct %	Pv02 mmHg	B.E. mEq/L	TNP °C	FiO2 %
4	1.25	48	2	30	192				21		32	66
5.5	1.6	45	1	30	129				23		27.5	34
10	.75	50	1	40	217				17		22.8	40
13	1	50	1.5	55	116	24	7.33	17.6	21	-11.8	20.9	48
26	.75	35	1.5	80	196				22		16.5	33
36	.9	45	1.5	80	194		Patient		22		18	33
132	1.8	40	1.5	50	105		Exsanguinated		14		19.1	49
135	1.65	43	1.5	40	134				28		24	61
139	1.7	80	1.5	20	120	30	7.34	22.6	31	- 8.2	27.1	71
144	1.95	61	1.5	20	144				39		30	73
148	1.75	58	1.5	0	192				37		34	82
152	1.75	56	1.75	0	172				34		37	84
159	1.8	63	1.4	0	202				34		37.5	99
170	1.75	75	1.3	20	227	31	7.4	30.5	41	- 4.8	37.6	99
180	1.3	73	1.3	20	231				30		37.7	97

VENTILATION PARAMETERS

Samp Time	GBQR	FIC02 %	Sv02 %	C02V mL %	C0 L/M	Hct %	V02 mL/M	RQ	TBI °C
4	1.62	1.5	61.4		1.25		39.4		26.9
5.5	.64	2.9	63.4		1.6		48.2		24.7
10	1.39	3.8	77.6		.75		13.1		20.6
13	1.56	3.5	82.6	44.5	1	17.6	14.8	6.61	19.1
26	2.11	5.1	89		.75		4.9		16.5
36	1.76	5.1	80.6	Patient	.9		11.5		19.3
132	.86	3.2	54.2	Exsanguinated	1.8		63.5		19.7
135	.93	2.6	72.4		1.65		33.4		25.6
139	.89	1.3	75	47.2	1.7	22.6	43.9	2.97	30.1
144	.78	1.3	68.3		1.95		56.2		33.5
148	.86		60.8		1.75		64.5		36.4
152	1		58.1		1.75		67.5		37.8
159	.78		64.1		1.8		60.7		37.5
170	.75	1.5	66.8	43.8	1.75	30.5	82.2	.98	37.8
180	1.02	1.5	54.2		1.3		76.6		38.2

PERFUSION ADEQUACY PARAMETERS

Samp Time	C.I. /M2	Sv02 %	P50 mmHg	SVRI /M2	Geom Comp	%Id V02	TBI °C	Kcal /M	Tr °C
4	3	61.4		7273	7.66	63.8	26.9	-8.6	33
5.5	3.8	63.4		5327	5.42	105.6	24.7	-8.8	29.2
10	1.8	77.6		12627	10.73	41.7	20.6	-3.6	26.2
13	2.4	82.6	32.4	9470	7.91	56	19.1	-3.7	24.2
26	1.8	89		8839	6.87	29.6	16.5	-1.8	18.5
36	2.1	80.6	Patient	9470	10.06	58.8	19.3	.4	18.2
132	4.3	54.2	Exsanguinated	4209	4.26	288.3	19.7	-1.5	20.5
135	3.9	72.4		4936	7.65	96.1	25.6	7	22.5
139	4	75	24.9	8913	15.56	99.1	30.1	7.6	24.2
144	4.6	68.3		5925	10.9	103.4	33.5	7	24.5
148	4.1	60.8		6277	12.04	92.5	36.4	5.1	26.2
152	4.1	58.1		6061	11.69	81.8	37.8	3.3	28.7
159	4.3	64.1		6629	12.62	71.6	37.5	2.7	32.5
170	4.1	66.8	29.5	8117	15.43	96.4	37.8	2	35
180	3.1	54.2		10636	20.37	89.3	38.2	1.5	36

PRINTOUT 1

Computer generated Cardiopulmonary Bypass Record which lists directly measured and calculated parameter values in mechanical, ventilation, and perfusion adequacy categories.

SAMP NO	BLD L/H	GAS L/H	GAS: BLD	HGB GM%	SVO_2 %	LM PCO_2	TEMP DC	$PVCO_2$ mmHg
8	3	1.5	.5	13	78.5	11.8	36.5	45
9	3	3	1	13	80.4	10.9	36.5	44
10	3	.75	.25	13	81	12.3	36.5	44.5
11	4	2	.5	13	81	12.3	36.5	45
12	4	1	.25	13	78	12.1	36.5	44
13	2	2	1	13	74.7	10.4	36.5	41
14	2	1	.5	13	75.9	10.9	36.5	42
15	2	.5	.25	13	73.8	11.4	36.5	44.5
16	1	1	1	13	74.6	9.3	36.5	43.5
17	1	.5	.5	13	73	7.3	36.5	44.5
18	2	2	1	13	78.8	9.9	36.5	40.5
19	2	2	1	13	77.6	10.4	36.5	39.5
20	2	2	1	13	76.9	10.7	36.5	39.5
21	2	2	1	13	77.4	10.5	36.5	39
22	2	2	1	13	77.4	10.5	36.5	40.5

SAMP NO	PAO_2 MMHG	$PACO_2$ MMHG	PAH UNIT	B.E. MEQ/L	HCT %	PVO_2 MMHG	PVH UNIT	P50 MMHG
8	171	30	7.29	-10.7	37	14	7.37	7.5
9	227	27.5	7.27	-12.7	37	14	7.35	7
10	48	33.5	7.23	-12.1	37	8	7.34	4.2
11	214	30.5	7.23	-13	37	17	7.35	8
12	75	32.5	7.2	-13.6	37	12	7.33	5.7
13	235	26	7.26	-13.7	37	6	7.35	3.3
14	114	28.5	7.23	-13.9	37	7	7.36	3.6
15	42	32.5	7.2	-13.7	37	6	7.33	3
16	82	23	7.25	-15.3	37	6	7.33	3.2
17	32	31.5	7.22	-13.4	37	4	7.33	2.1
18	187	25	7.22	-15.6	37	7	7.36	3.3
19	346	23.5	7.24	-15.4	37	7	7.36	3.5
20	373	22	7.24	-16.1	37	6	7.37	3
21	379	22.5	7.25	-15.5	37	5	7.37	2.5
22	326	24.5	7.24	-15	37	5	7.36	2.5

SAMP NO	SAO_2 %	$PEXCO_2$ MMHG	AVO_2 VOL%	VO_2 ML/M	VCO_2 ML/M	R.Q. UNIT
8	95.5	30	3.42	102.6	64.9	.63
9	96.1	24	3.36	100.8	103.8	1.03
10	91	33	3.06	91.8	35.7	.39
11	96.5	33	3.28	131.2	95.1	.72
12	93.5	35	2.88	115.2	50.4	.44
13	96.8	23	4.52	90.4	66.3	.73
14	95.8	27	3.78	75.6	38.9	.51
15	91.7	31	3.22	64.4	22.3	.35
16	96	12	3.95	39.5	17.3	.44
17	88.1	10	2.71	27.1	7.2	.27
18	96.5	20	3.61	72.2	57.6	.8
19	96.7	22	4.32	86.4	63.4	.73
20	96.7	22	4.52	90.4	63.4	.7
21	96.7	22	4.45	89	63.4	.71
22	96.8	19	4.39	87.8	54.8	.62

PRINTOUT 2

Depicts a computer generated example of software program functions from an IN VITRO deoxygenator test circuit

Discussion

It is evident that the integration of microprocessor technology with the extracorporeal circuit provides the perfusionist with a powerful and useful diagnostic and interpretive tool. Automation of the data collection process permits the perfusionist to focus attention on more substantive tasks which are essential to the effective management and safety of CPB.

A number of investigators have developed computer algorithms which are capable of rapid collection, interpretation, and presentation of specific categories of patient data.[1,6,11,14,16-19,21,24,28] The assimilation of these algorithms, coupled with the direct measurement, calculation, and expanded memory capabilities of the system presented, has significantly broadened the indication for routine use of this technology.

The numerous in-line monitoring systems (for blood gases, pH, hemoglobin saturation, temperature, microemboli and blood flow) which provide accurate and useful information to the perfusionist during CPB have, of necessity, created a potentially dangerous level of distraction to the user. The values of these directly measured parameters may be applied in computer assisted calculation of a large number of derived parameters. The system presented has reduced the cumbersome, time-consuming task of calculation and useful presentation of data previously considered academic to a benign, "user friendly" computer software package. As perfusionists discover and define the use and usefulness of sophisticated perfusion parameters in clinical practice, the inherent value of the automated data collection process will become measurable.

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