Interrelationships between Cardiac Performance Measurements

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A comparison of cardiovascular performance measurements in current use was made in anesthetized dogs at rest and after administration of isoproterenol. The flow-related variables—stroke work, stroke power, stroke volume, cardiac output and mean ejection rate showed the best correlations, while the time tension index, ventricular pressure derivative, heart rate and mean systolic pressure showed no consistent correlations either with the stroke index or with each other. It was concluded that the effects of altered hemodynamics must be considered before using different cardiac performance measurements interchangeably.

THE most widely accepted methods for assessing the performance of the heart have been to examine its volume output, its work performed or power generated. These measurements have been used as standards for gauging cardiovascular stress.^{1), 2)} More recently, additional indices of cardiac performance have been described which include the tension time index,³⁾ mean ejection rate⁴⁾ and pressure derivative.⁵⁾ These have been considered to change in parallel with the standard cardiac performance measurements.^{6), 7)} This experimental study was undertaken to examine the interrelationships between measurements of cardiac performance at rest and after alteration of hemodynamics.

METHODS

Ten mongrel dogs ranging in weight from 15 to 24 Kg., anesthetized with intravenous pentobarbital, 60 mg./Kg. were used in the study. Mercury manometer calibrated catheters were passed to the aortic root and into the left ventricle via the right and left carotid arteries for the recording of aortic and left ventricular pressures. Cardiac output was determined by the dye dilution method using cardiogreen dye and an automatic computing device.* The first derivation of intraventricular pressure was obtained using a Dymec operational amplifier.** These parameters were recorded on an Electronics for Medicine photographic recorder*** using

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* Gilford Model 104

** Dymec Model 2460A

*** Electronics for Medicine Model DR-8

a paper speed of 200 mm./sec. From these recordings, calculations were made as follows :

<i>Measurement</i>	<i>Calculation</i>	<i>Units</i>
Mean Systolic Pressure (MSP)	$\frac{\text{Area under Aortic Curve}}{\text{Duration of Ejection} + \text{Diastolic Press.}}$	mm.Hg
Tension Time Index (TTI)	Area under Aortic Curve	mm.Hg-secs.
Maximum Ventricular Pressure Derivative (dP/dt)	By Differentiation**	mm.Hg/sec.
Stroke Volume Index (SVI)	$\frac{\text{Cardiac Index}}{\text{Heart Rate}}$	ml./Kg.
Stroke Work Index (SWI)	SVI times MSP	mm.Hg-ml./Kg.
Stroke Power Index (SPI)	$\frac{\text{SWI}}{\text{Ejection Time}}$	mm.Hg-ml./Kg. secs.
Mean Ejection Rate (MER)	$\frac{\text{Stroke Volume}}{\text{Ejection Time}}$	ml./sec.

Paired samples of the above measurements were made in resting states and with infusions of isoproterenol (Isuprel), given in a drip of dextrose and water (0.4 mg./L.) at a rate of 60 drops/min. for 5 to 10 min. This drug was chosen because it has been reported to simulate the effects of exercise.⁸⁾ The data were analyzed by performing linear regression analyses of each of these performance measurements on the stroke volume indices.⁹⁾ Independent analyses were performed for resting measurements and after isoproterenol exhibition.

RESULTS

The data obtained from the performance measurements are summarized in Table I. The ranges of the variables at rest were :

MSP : 83—136 mm.Hg
 TTI : 17.9—36.5 mm.Hg sec.
 SVI : 0.63—2.07 ml./Kg.
 SWI : 49—215 mm.Hg-ml./Kg.
 SPI : 393—1,319 mm.Hg-ml./Kg. sec.
 dP/dt : 1,000—2,700 mm.Hg/sec.
 HR : 96—170 beats/min.
 CO : 1.83—3.90 L./min.
 MER : 76—190 ml./sec.

After infusion of isoproterenol the ranges were :

MSP : 72—119 mm.Hg
 TTI : 17.3—43.8 mm.Hg-sec.
 SVI : 0.67—2.27 ml./Kg.

Table I

		MSP	TTI	SVI	SWI	SPI	dP/dt	HR	CO	MER
1.	C	104	20.4	2.07	215	1,319	2,700	125	3.9	190
		101	25.0	1.97	199	1,191	2,560	125	3.7	177
	I	82	32.1	2.27	186	1,148	2,430	115	4.0	214
		72	40.8	2.20	158	863	2,560	123	4.1	182
2.	C	96	19.1	0.63	60	408	1,450	170	2.02	81
		99	19.6	0.60	59	393	1,450	159	1.81	76
	I	101	20.9	0.67	68	503	1,740	175	2.25	95
		106	22.3	0.78	83	653	1,670	150	2.23	117
3.	C	117	17.9	0.99	116	928	2,000	140	2.39	137
		125	19.3	0.99	125	1,000	2,170	140	2.40	137
	I	101	21.6	1.16	117	936	2,350	168	3.32	158
		115	22.1	0.70	80	707	3,130	177	2.14	107
4.	C	115	29.2	1.52	175	994	2,100	110	2.57	133
		136	33.5	1.52	207	1,182	2,300	113	2.66	134
	I	106	30.1	1.65	175	1,190	2,500	141	3.59	173
		119	43.8	1.54	183	1,220	2,500	146	3.47	159
5.	C	112	19.3	1.21	135	865	2,000	119	2.16	116
		112	19.3	1.06	119	762	2,000	132	2.10	102
	I	109	17.3	1.43	156	1,040	2,000	125	2.69	143
		88	31.7	1.26	111	770	2,400	136	2.57	131
6.	C	83	26.7	1.10	91	478	1,880	108	1.84	89
		85	30.1	1.07	91	511	1,880	111	1.83	93
	I	77	38.7	1.14	88	507	2,070	113	1.99	102
		86	38.3	1.19	102	589	2,260	117	2.15	106
7.	C	91	34.2	1.15	105	460	2,940	114	2.15	83
		96	28.3	1.05	100	505	2,940	122	2.10	86
	I	96	41.7	1.37	132	640	3,420	120	2.70	107
		102	40.0	1.32	134	662	3,300	119	2.57	107
8.	C	115	36.5	1.44	144	702	2,050	131	3.17	118
		107	36.1	1.52	163	815	2,050	131	3.34	127
	I	96	33.2	1.46	146	793	2,370	154	3.77	133
		93	29.5	1.62	162	910	2,370	154	4.10	149
9.	C	126	27.7	0.74	93	492	2,540	137	2.12	82
		117	25.6	0.86	101	523	2,310	126	2.26	94
	I	94	27.8	0.99	93	540	2,890	146	3.06	121
		98	39.8	1.15	113	638	3,350	143	3.46	137
10.	C	93	30.5	1.07	99	556	1,000	96	2.42	141
		88	25.8	1.03	91	511	1,000	103	2.50	136
	I	101	32.7	1.24	125	748	1,750	139	4.08	175
		101	32.7	1.21	122	730	1,750	139	3.96	171

(Units described in text)

Key: C = control, I = immediate

SWI : 68—186 mm.Hg-ml./Kg.
 SPI : 503—1,220 mm.Hg-ml./Kg. sec.
 dP/dt : 1,670—3,420 mm.Hg/sec.
 HR : 113—177 beats/min.
 CO : 1.99—4.10 L./min.
 MER : 95—214 ml./sec.

Fig. 1. Comparison of stroke power and stroke volume indices against stroke work index. Note that slope of SPI is unaltered after Isuprel but SVI diminishes.

Fig. 2. Comparison of cardiac output (CO) with mean ejection rate (MER) at rest and after Isuprel. Note excellent correlation.

The regression analyses relating other cardiac performance measurements to SWI are presented in Tables II and III. These measurements are listed in their decreasing order of correlation. The highest correlation obtained in this study was between the SVI and SWI (Fig. 1). Under resting conditions the correlation coefficient was 0.93 and with infusion of isoproterenol 0.90. The slopes of these regressions, however, were altered with stress. The SPI also

Table II. Resting Data

SWI(± 17.6) = 108.8 (SVI) - 3.9	$r = 0.93$
SWI(± 18.2) = 0.146(SPI) + 17.8	$r = 0.92$
SWI(± 26.9) = 62.5 (CO) - 27.1	$r = 0.82$
SWI(± 29.1) = 1.12 (MER) - 8.8	$r = 0.79$
SWI(± 42.3) = 0.04 (dP/dt) + 47.1	$r = 0.44$
SWI(± 42.3) = 1.39 (MSP) - 22.6	$r = 0.44$
SWI(± 45.4) = -0.70 (HR) + 212.0	$r = 0.26$
SWI(± 46.0) = 1.68 (TTI) + 80.25	$r = 0.22$

Table III. Isoproterenol

SWI(± 16.6) = 76.4 (SVI) + 25.6	$r = 0.90$
SWI(± 18.3) = 0.144 (SPI) + 11.1	$r = 0.87$
SWI(± 26.0) = 34.8 (CO) + 16.2	$r = 0.72$
SWI(± 24.4) = 0.850 (MER) + 6.53	$r = 0.76$
SWI(± 28.8) = 0.0156 (dP/dt) + 85.3	$r = 0.26$
SWI(± 37.3) = -0.225 (MSP) + 144	$r = 0.08$
SWI(± 33.6) = -0.777 (HR) + 233	$r = 0.43$
SWI(± 34.1) = 1.87 (TTI) + 64.4	$r = 0.41$

Fig. 3. Comparison of maximum systolic pressure derivative (dP/dt) and tension time index (TTI) to the stroke work index. Note poor correlation.

Fig. 4. Comparison of mean systolic pressure (MSP) and heart rate to SWI. Note poor correlation.

showed an extremely high correlation with the SWI (Fig. 1) under resting conditions ($r=0.92$). The relationship as well as the slope of the correlation was maintained with infusion of isoproterenol ($r=0.87$).

Cardiac output under resting conditions showed a good correlation with the stroke work index ($r=0.82$) and this correlation was preserved after isoproterenol administration ($r=0.72$). These correlations are illustrated in Fig. 2.

The systolic pressure derivative was poorly related to SWI under resting conditions ($r=0.44$), but with administration of isoproterenol no correlation was found ($r=0.08$). The TTI was also poorly correlated with SWI both at rest ($r=0.22$) and after isoproterenol ($r=0.41$). These correlations are shown in Fig. 3. There were no significant relationships between SWI and HR or MSP under resting conditions or after isoproterenol infusion (Fig. 4).

DISCUSSION

Although the various parameters available for gauging cardiac performance are often used interchangeably, they do not define the same properties of myocardial contraction. Direct comparison of these measurements in either resting or stress states has not been quantitated critically. In the parameters studied here it was possible to compare resting values to those obtained after imposition of stress.

Regression analyses of these data indicate that these performance measure-

ments are not all directly related. Only the flow phenomena, SWI, SVI, SPI, CO and MER were closely correlated. Such correlations were not obtained with the other parameters of the study: dP/dt , MSP, HR and TTI.

An attempt was made to reclassify the data by grouping rate dependent functions (dP/dt , HR, MER, SPI) and pressure dependent functions (MSP, dP/dt , TTI). Of the rate dependent functions the only correlations which bordered on significance were dP/dt and MER; and of the pressure dependent functions, dP/dt and TTI.

Description of cardiac function curves classically has been accomplished by comparing stroke volume or stroke work to end diastolic ventricular pressure. More recently the time tension index,³⁾ mean ejection rate⁴⁾ and the ventricular pressure derivative⁵⁾ as performance measurements have been utilized. Braunwald^{6),7)} found that function curves could be constructed equally well with each of these parameters. The data presented here, however, indicate that these functions cannot always be used interchangeably and that the experimental conditions modify the interrelationships between cardiac performance measurements.

SUMMARY AND CONCLUSIONS

A comparison of the cardiovascular performance measurements in current use was investigated. Anesthetized animals were studied at rest, and after alteration of hemodynamics by administration of isoproterenol. The best correlations were obtained between the flow-related parameters: stroke work, stroke power, stroke volume, cardiac output and mean ejection rate, in that order. The tension time index, ventricular pressure derivative, heart rate and mean systolic pressure showed no consistent correlations either with the stroke index or between each other. It is concluded that the effects of altered hemodynamics must be considered before using different cardiac performance measurements interchangeably.

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