Steady-State Cardiac Output Determination During Combined Right and Left Heart Catheterization

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Interpretation of the meaning of a mean diastolic atrioventricular gradient or a mean systolic ventricular-great vessel gradient requires simultaneous determination of the level of the gradient, the heart rate, and the cardiac output. The feasibility of steady-state Fick principle cardiac output determination during combined right and left heart catheterization is investigated.

LEFT heart catheterization[1-8] is a natural outgrowth of the development of mitral and aortic valve surgery and the resultant necessity for accurate preoperative evaluation of left-sided cardiac hemodynamics. Such evaluation requires simultaneous determination of valve gradient (systolic gradient for the aortic valve; diastolic gradient for the mitral valve), flow across the valve (cardiac output in the absence of valvular insufficiency), and heart rate. The first and third variables are readily determined during left heart catheterization. The purpose of this paper is to investigate the feasibility of steady-state cardiac output determination by the Fick principle, at rest and during exercise, in the course of combined right and left heart catheterization.

METHODS AND MATERIAL

Twenty-four comparisons of cardiac output at rest were performed in 23 patients, 11 women and 8 men with mitral valve disease, and 4 men with aortic valve disease. Right heart catheterization was performed, supine, in the usual manner, in the basal postabsorptive state, via a cutdown in the antecubital area. Brachial artery cannulation and open-circuit determination of oxygen consumption permitted calculation of cardiac output, generally in duplicate or triplicate. Left heart catheterization was then carried out in the prone position by a modification of the posterior percutaneous puncture technic of Fisher.[5] Two no.-17, thin-walled, 7-inch needles were inserted into the left atrium; polyethylene catheters were passed through the needles, one into the left atrium, and the other into the left ventricle. The needles were then removed over the catheters, leaving the latter in situ. The patient was then rotated back into the supine position. After a suitable rest period to permit restoration of the steady state, repeat cardiac output determinations were performed at rest, singly or in duplicate.

Ten comparisons of cardiac output during exercise were performed in 9 patients, 3 women and 5 men with mitral valve disease, and 1 man with aortic stenosis. All 9 are included in the above group of 23 patients. Exercise cardiac outputs during right heart catheterization alone were generally obtained in duplicate or triplicate before the commencement of left heart catheterization. Exercise cardiac outputs during combined right and left heart catheterization were carried out in the supine position, singly or in duplicate. A specially constructed bicycle wheel was employed in all exercise studies.

Blood gas analyses were performed on the Van Slyke manometric apparatus. Respiratory gas analyses were done on the micro-Scholander gas analyzer.

RESULTS

The over-all cardiac output data at rest and during exercise are listed in tables 1 and 2. Cardiac indices at rest during right and during combined heart catheterization are recorded in table 1. The average cardiac indices are 2.48 and 2.45 L. per minute per M^2 B.S.A. in the course of right and com-

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TABLE 1.—*Cardiac Output and Related Variables at Rest*

Subject	Cardiac index (L./min./M^2 B.S.A.)			O_2 consumption (ml./min./M^2 B.S.A.)			A-V difference (vol. %)			Respiratory quotient		
	Right	Combined	% deviation	Right	Combined	% deviation	Right	Combined	% deviation	Right	Combined	% deviation
1	2.59	2.79	+ 7	136	131	− 4	5.3	4.7	−12	.73	.74	+ 1
2	2.37	2.16	− 8	106	123	+16	4.5	5.7	+23	.77	.79	+ 3
3	2.12	1.94	− 9	123	111	−11	5.8	5.7	− 2	.73	.72	− 1
4	2.20	2.16	− 2	100	112	+11	4.6	5.2	+12	.97	.82	−17
5	1.76	1.78	+ 1	123	115	− 7	7.0	6.5	− 7	.80	.85	+ 6
6	2.51	2.72	+ 8	125	137	+ 9	5.0	5.1	+ 2	.92	.83	−10
7a	2.33	2.56	+ 9	118	119	+ 1	5.1	4.6	−10	.74	.80	+ 8
7b	2.43	2.24	− 8	125	112	−11	5.2	5.0	− 4	.81	.89	+ 9
8	1.29	1.24	− 4	100	87	−14	7.8	7.0	−11	.78	.85	+ 9
9	3.78	3.84	+ 1	123	119	− 3	3.3	3.2	− 3	.82	.87	+ 6
10	2.21	2.47	+11	120	128	+ 6	5.4	5.2	− 4	.69	.72	+ 4
11	2.46	2.47	0	106	114	+ 7	4.3	4.6	+ 7	.73	.89	+20
12	3.28	3.47	+ 6	113	125	+10	3.5	3.6	+ 3	.77	.78	+ 1
13	3.01	2.99	− 1	122	123	+ 1	4.1	4.1	0	.84	.90	+ 7
14	2.32	2.37	+ 2	136	138	+ 1	5.9	5.8	− 1	.82	.81	− 1
15	2.04	1.99	− 3	142	154	+ 8	7.0	7.7	+10	.89	.81	− 9
16	2.87	2.28	−23	139	128	− 8	4.9	5.6	+13	.78	.76	− 3
17	1.99	1.95	− 2	107	104	− 3	5.4	5.4	0	.81	.83	+ 2
18	1.91	1.77	− 7	102	102	0	5.4	5.8	+ 7	.83	.85	+ 2
19	1.76	1.93	+ 9	120	122	+ 2	6.8	6.4	− 6	.73	.83	+13
20	3.69	2.91	−24	155	162	+ 4	4.2	5.6	+28	.88	.87	− 1
21	3.96	3.93	− 1	161	151	− 6	4.1	3.9	− 5	.82	.87	+ 6
22	1.78	1.77	0	120	119	− 1	6.8	6.7	− 1	.81	.84	+ 4
23	2.79	3.19	+13	126	145	+14	4.5	4.6	+ 2	.81	.74	− 9
Average	2.48	2.45	7	123	124	7	5.2	5.3	7	.80	.82	6

TABLE 2.—*Cardiac Output and Related Variables during Exercise*

Subject	Cardiac index (L./min./M^2 B.S.A.)			O_2 consumption (ml./min./M^2 B.S.A.)			A-V difference (vol. %)			Respiratory quotient		
	Right	Combined	% deviation	Right	Combined	% deviation	Right	Combined	% deviation	Right	Combined	% deviation
5	2.23	1.95	−13	240	224	− 7	10.8	11.5	+ 7	.88	.99	+12
6	3.84	3.70	− 4	323	359	+11	8.4	9.7	+14	.90	1.03	+14
7a	3.59	3.26	−10	217	196	−10	6.1	6.0	− 1	.76	.79	+ 4
7b	3.04	2.77	−10	260	227	−14	8.6	8.2	− 5	.84	.85	+ 1
9	4.95	4.47	−10	272	259	− 5	5.5	5.8	+ 5	.97	.96	− 1
10	3.46	3.33	− 4	342	320	− 7	9.9	9.6	− 3	.80	.82	+ 2
12	4.66	4.78	+ 3	268	268	0	5.8	5.6	− 2	.87	.90	+ 3
13	3.32	3.06	− 8	193	208	+ 8	5.8	6.8	+16	.91	.90	− 1
14	2.68	2.70	+ 1	217	227	+ 5	8.1	8.4	+ 4	.85	.84	− 1
20	4.12	4.18	+ 1	270	293	+ 8	6.6	7.0	+ 6	.93	.90	− 3
Average	3.59	3.42	6	260	258	8	8.1	8.4	6	.87	.90	4

TABLE 3.—*Cardiac Output Data at Rest and during Exercise in Case 13 (Body Surface Area 1.60 M.²) on February 2, 1957*

Output number*	Cardiac output (L./min./ M.² B.S.A.)	Oxygen consumption (ml./min./ M.² B.S.A.)	A-V difference (vol. %)	R
1	3.08	126	4.1	.84
2	3.02	121	4.0	.85
3	2.93	120	4.1	.84
4 (3 min.)	2.92	178	6.1	.87 (exer.)
5 (6¾ min.)	3.39	203	6.0	.92 (exer.)
6 (8¾ min.)	3.25	182	5.6	.89 (exer.)
7	2.99	123	4.1	.90
8 (6½ min.)	3.06	208	6.8	.90 (exer.)

* The first 6 outputs were obtained during right heart catheterization alone; the last 2 outputs were obtained during combined heart catheterization.

TABLE 4.—*Cardiac Output Data at Rest and during Exercise in Case 14 (Body Surface Area 1.73 M.²) on November 29, 1956*

Output number*	Cardiac index (L./min./ M.² B.S.A.)	Oxygen consumption (ml./min./ M.² B.S.A.)	A-V difference (vol. %)	R
1	2.33	138	5.9	.77
2	2.30	136	5.9	.84
3	2.32	135	5.8	.84
4 (2½ min.)	2.49	192	7.7	.85 (exer.)
5 (6¾ min.)	2.68	217	8.1	.85 (exer.)
6	2.37	138	5.8	.81
7 (7 min.)	2.70	227	8.4	.84 (exer.)

* The first 5 outputs were obtained during right heart study; the last 2 during combined heart catheterization.

bined heart catheterization respectively. The average deviation, disregarding the sign of the deviation, is 7 per cent. In 20 of the 24 studies, the deviation was less than 10 per cent. There is no statistical difference between the mean values of 2.48 and 2.45 L. per minute per M.² noted above, $0.7 > p > 0.6$.

The oxygen consumption data are catalogued in table 1. The average oxygen consumption is 123 and 124 ml. per minute per M.² B.S.A., during right and combined heart catheterization respectively. There is no significant difference between these values, $0.5 > p > 0.4$. The average per cent deviation is 7 per cent.

The mean arteriovenous oxygen difference is also 7 per cent, table 1. The average values are 5.2 and 5.3 volumes per cent in the course of right and left heart catheterization respectively. These values again do not differ significantly, $0.6 > p > 0.5$.

The respiratory quotients (table 1) are virtually identical during right and combined heart study. The difference is not statistically significant, $0.3 > p > 0.2$.

The exercise data are portrayed in table 2. The average exercise cardiac index is 3.59 L. per minute per M.² B.S.A. during right heart catheterization and 3.42 L. per minute per M.² B.S.A. during combined cardiac catheterization. This difference is of questionable significance, $.05 > p > .02$. The 95 per cent confidence limits for the mean difference (0.17 L. per minute per M.² B.S.A.) are + 0.033 to + 0.305 L. per minute per M.² B.S.A. The average deviation is 6 per cent.

The agreement between levels of oxygen consumption (table 2) is excellent. The difference in mean values is not significant, $0.8 > p > 0.7$.

The mean exercise arteriovenous oxygen differences are 8.1 and 8.4 volumes per cent in the course of right and combined heart catheterization respectively, table 2. These values do not differ significantly, $0.2 > p > 0.1$. The mean per cent difference in arteriovenous difference is 6 per cent.

Table 2 lists the respiratory quotients during right and during combined heart catheterization. The mean values are 0.87 and 0.90 respectively, and are not significantly different, $0.2 > p > 0.1$.

Examples of the individual cardiac output data employed in construction of tables 1 and 2 are shown in tables 3 and 4. In table 3 outputs 5 and 6 were utilized to calculate the exercise outputs during right heart catheterization. Output 4 was obtained for another study, as was the fourth output in table 4.*

DISCUSSION

It is now generally agreed that interpretation of a mean diastolic atrioventricular and

*Outputs 4 in tables 3 and 4 were not used in calculating data of right heart exercise output.

of a mean systolic ventricular-great vessel gradient requires concurrent or simultaneous determination of flow across the valve. Use of the Fick principle to determine such flow requires demonstration that a steady state[10] may be achieved during combined right and left heart catheterization. Large errors in calculated flow may result otherwise.[11] There are as yet no published studies demonstrating that a steady state had been achieved either by the transbronchial or transthoracic technics, either at rest or during exercise. Such a demonstration requires correspondence of output data obtained by right heart catheterization with that obtained during combined heart catheterization in the course of the same study. If the Stewart-Hamilton technic is employed to determine cardiac output during left heart catheterization alone, relative constancy of flow during repeated determinations is required.

The data given in tables 1 to 4 indicate that determinations of steady-state Fick-principle cardiac output are feasible in the supine position, in the course of combined right and left heart catheterization, using the posterior percutaneous transthoracic puncture technic for left heart catheterization.

Summary

In 23 patients with rheumatic heart disease, comparison of cardiac output data during right heart catheterization alone and during combined right and left heart catheterization was made 24 times at rest and 10 times in the course of exercise studies. The results demonstrate that a steady state may be achieved during combined right and left heart catheterization.

Summario in Interlingua

In 23 patientes con rheumatic morbo cardiac, comparationes del datos de rendimento cardiac, obtenite in catheterismo dextro-cardiac sol e in catheterismo dextro- e sinistro-cardiac combinate, esseva completate 24 vices in stato de reposo e 10 vices durante exercitio. Le resultatos demonstra que un stato stabile pote esser effectuate in catheterismo dextero- e sinistro-cardiac combinate.

References

1. Facquet, J., Lemoine, J. M., Alhomme, P., and Le Febvre, J.: La measure de la pression auriculaire gauche par voie transbronchique. Arch. mal. coeur **45**: 741, 1952.
2. Allison, P. R., and Linden, R. J.: The bronchoscopic measurement of left auricular pressure. Circulation **7**: 669, 1953.
3. Radner, S.: Suprasternal puncture of the left atrium for flow studies. Acta med. scandinav. **148**: 57, 1954.
4. Björk, V. O., and Malmström, G.: Left auricular pressure measurements in man. Ann. Surg. **138**: 718, 1953.
5. Fisher, D. L.: The use of pressure recordings obtained at transthoracic left heart catheterization in the diagnosis of valvular disease. J. Thoracic Surg. **30**: 379, 1955.
6. Dickens, J., Villace, L., Woldow, A., and Goldberg, H.: The hemodynamics of mitral stenosis before and after commissurotomy. Brit. Heart J. **19**: 419, 1957.
7. Wood, E. H., Sutterer, W., Swan, H. J. C., and Helmholz, H. F.: The technic and special instrumentation problems associated with catherization of the left side of the heart. Proc. Staff Meet., Mayo Clin. **31**: 108, 1956.
8. Morrow, A. G., Braunwald, E., Haller, J. A., and Sharp, E. H.: Left heart catheterization by the transbronchial route: Technic and applications in physiologic and diagnostic investigations. Circulation **16**: 1033, 1957.
9. Litwak, R. S., Samet, P., Bernstein, W. H., Turkewitz, H., Silverman, L., and Lesser, M. E.: The effect of exercise upon the mean diastolic atrio-ventricular gradient in mitral stenosis. J. Thoracic Surg. **34**: 449, 1957.
10. Fishman, A. P., McClement, J., Himmelstein, A., and Cournaud, A.: Effects of acute anoxia on the circulation and respiration in patients with chronic pulmonary disease studied during the "steady state." J. Clin. Invest. **31**: 770, 1952.
11. Visscher, M. B., and Johnson, J. A.: The Fick principle: Analyses of potential errors in its conventional application. J. Appl. Physiol. **5**: 635, 1953.

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