Cardiac Output Measurement: A Comparison of Direct Fick, Dye Dilution and Thermodilution Methods in Stable and Acutely Ill Patients*†

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THE estimation measurement of cardiac output (CO) has now become a readily available clinical tool enabling better management of patients with cardiovascular disease. Commonly employed procedures for measuring CO include the direct Fick method (CO_F) indocyanine green dye dilution and thermodilution techniques.[1-3] We compared these techniques in the catheterization laboratory and in the Coronary Care Unit, and the results of these studies form the basis of this report.

METHODS

CO was determined in 57 patients undergoing cardiac catheterization six weeks to six months following acute myocardial infarction (AMI). During catheterization, No. 7F pigtail catheters were placed in the pulmonary artery (PA) and ascending aorta (AO). CO was determined in duplicate by the Fick principle in 19 patients and duplicate results did not differ by more than 7%. Oxygen consumption was determined by measuring ventilation with a Tissot spirometer and analyzing the expired gas with a Micro-Scholander apparatus. Two tonometers were used for the gas samples and the results of the two gas samples had to agree by 0.04%. Mixed venous blood samples were obtained from PA and arterial blood from AO. Arterial and mixed venous oxygen contents were determined by the method of Van Slyke and Neill. The blood samples were analyzed in two different machines and the results did not differ by more than 0.2 vol.%. CO was obtained by dividing oxygen consumption by the arterio-venous oxygen difference.

In 38 additional patients undergoing cardiac catheterization, CO was measured by the indocyanine green dye dilution method (CO_{DD}) in duplicate. A Lyons densitometer (model DCC0-02), a Harvard withdrawal pump and a strip chart recorder were used. Injection was made into PA and sampling done from AO. CO was calculated on-line by a computer incorporated into the densitometer. Periodically, dye-dilution curves were extrapolated on semilogrithmic paper and the Stewart-Hamilton method was used for computation of CO. The values thus obtained agreed closely with those of the computer.

In nine patients of the catheterization groups, both CO_F and CO_{DD} were obtained, the one following the other immediately.

*Supported in part by U.S.P.H.S. Grant #HMS00106 and U.S.P.H.S. Grant #5 R01 MB00146.
†Presented in part at the Annual Meeting, Biomedical Engineering Society, New Orleans, La., April 12, 1975.

Table 1. CARDIAC OUTPUTS IN PATIENTS UNDERGOING CATHETERIZATION

	<3.0 L/Min.			*3.0 – 4.5 L/Min.*			*>4.5 L/Min.*		
	No.	*Mean*	*Range*	*No.*	*Mean*	*Range*	*No.*	*Mean*	*Range*
Fick Principle (19)	2	2.7	—	6	4.0	3.0–4.5	11	5.7	4.7–6.8
Dye Dilution (38)	4	2.3	1.6–2.9	8	4.0	3.0–4.2	26	6.4	4.6–9.1

Forty-nine patients with acute myocardial infarction complicated by heart failure, pulmonary edema, hypotension or shock underwent bedside hemodynamic studies. In 19 patients, CO_{DD} was obtained by the technique described earlier. In 30 patients, CO was measured on 47 occasions by the ther-

Table 2. COMPARISON OF FICK AND DYE DILUTION TECHNIQUES (TOTAL — 9 PATIENTS)

No.	*Fick (L/Min.)*	*Dye Dilution (L/Min.)*	*Differences (L/Min.)*
1	7.8	6.3	+ 1.5
2	4.7	5.0	− 0.3
3	6.3	6.7	− 0.4
4	4.4	4.6	− 0.2
5	5.8	5.4	+ 0.4
6	2.6	4.2	− 1.6
7	6.0	7.6	− 1.6
8	6.3	6.1	+ 0.2
9	4.0	4.1	− 0.1
*M±SEM	5.3±0.5	5.6±0.4	

*Mean ± standard error of the mean.

modilution technique (CO_{TD}) using a No. 7F quadruple-lumen Swan-Ganz catheter placed in the PA. The injectate was prepared by drawing 10 ml. of 5% dextrose in water into a syringe and capping it under sterile conditions. The syringes were immersed in an ice water bath for at least 30 minutes. CO was calculated on-line by a computer (Edward's Lab. Model 9500 cardiac output computer). Periodically, the thermodilution curves were recorded on a strip chart recorder and calculations of CO from these curves agreed closely with those of the computer. The Swan-Ganz catheter was usually left in place for a period of three to five days, permitting repeated estimations of CO.

In 15 patients of the bedside study group, both CO_{DD} and CO_{TD} were obtained in rapid succession.

RESULTS

The results of CO estimations in 57 patients obtained during cardiac catheterizations are shown in Table 1. Fick principle was used in 19 patients and dye-dilution in 38. Two in the Fick group and four in the dye group had a CO of less than 3 L/min. The rest of the patients had COs ranging between 3.0 and 9.1 L/min.

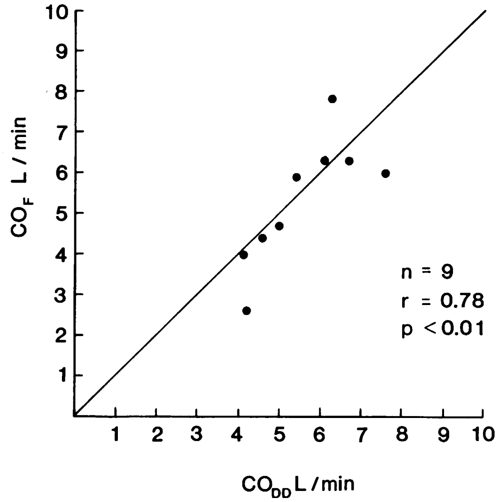

Fig. 1. Nine almost simultaneous measurements of cardiac output using direct Fick methods (CO_F) and dye dilution technique showing good correlation (n — number of patients; r — correlation coefficient; p — significance).

The data from nine patients in whom both CO_F and CO_{DD} were done in rapid succession are shown in Table 2. The M±SEM for the Fick group was 5.3±0.5 L/min. and that for the dye group was 5.6±0.4 L/min. Patients 1, 6 and 7 show a greater discrepancy between CO_F and CO_{DD}. In patient 1, during measurement of CO_{DD}, the sampling rate was not constant due to malfunction of the withdrawal pump. In patient 6, the amount of gas collected was felt to be abnormally low during CO_F and a leak was suspected. In patient

Table 3. CARDIAC OUTPUTS IN PATIENTS WITH ACUTE MYOCARDIAL INFARCTION

	<3 L/Min.			*3.0 – 4.5 L/Min.*			*>4.5 L/Min.*		
	No.	*Mean*	*Range*	*No.*	*Mean*	*Range*	*No.*	*Mean*	*Range*
Thermodilution (47)	14	2.3	1.8–2.8	18	3.7	3.2–4.5	15	5.3	4.6–7.2
Dye Dilution (19)	8	2.4	1.8–2.9	10	3.6	3.0–4.5	1	5.3	

7, there was no obvious problem recognized at the time of the study.

Statistical analysis revealed a good correlation ($r=0.78$; $p<0.01$) between the two methods (Fig. 1).

The results of COs obtained in 49 patients with AMI are shown in Table 3. In 30 patients, CO_{TD} was obtained on 47 occasions; in 19 patients, CO_{DD} was measured. A significant number of patients had COs below 3 L/min. In 15 patients, immediately sequential measurement of CO_{TD} and CO_{DD} were obtained. The M±SEM was 3.27±0.22 L/min. for the CO_{DD} group and 3.51±0.24 for the CO_{TD} group. Statistical analysis revealed a high correlation ($r=0.85$; $p<0.005$), between the two methods (Fig. 2).

Table 4. COMPARISON OF DYE DILUTION AND THERMODILUTION METHODS

	Green Dye Output L/Min.	*Thermodilution Output L/Min.*	*Differences L/Min.*
1	1.92	2.43	− 0.51
2	5.30	5.48	− 0.18
3	4.17	3.85	+ 0.32
4	3.69	4.15	− 0.46
5	4.13	3.98	+ 0.15
6	3.46	3.96	− 0.50
7	2.70	3.23	− 0.53
8	3.10	4.68	− 1.58
9	2.50	2.10	+ 0.40
10	2.95	3.29	− 0.34
11	3.65	4.04	− 0.39
12	3.42	3.32	+ 0.10
13	2.45	2.64	− 0.19
14	2.56	2.67	− 0.11
15	2.98	2.84	+ 0.14
MEAN:	3.27	3.51	
*SEM:	.22	.24	

*Standard error of the mean.

DISCUSSION

The present study revealed a good correlation between the direct Fick and the dye dilution methods. This compares favorably with the observations of previous workers.[2,4,5] Our previous work has demonstrated the reliability of repeated estimations of CO_{TD} in our hands.[6] Again, the correlations between our dye dilution and thermodilution measurements were significantly high. Similar results were obtained by Ganz et al.[7,8] and Weisel and associates.[9] Although there were no systematic differences, the dye dilution results tended to be somewhat lower than the thermodilution values (Table 4). It is known that the dye dilution technique may give erroneous cardiac output results in patients with low output states.[10] In this context, it is noteworthy that a significant number of our patients were either in severe congestive heart failure or cardiogenic shock.

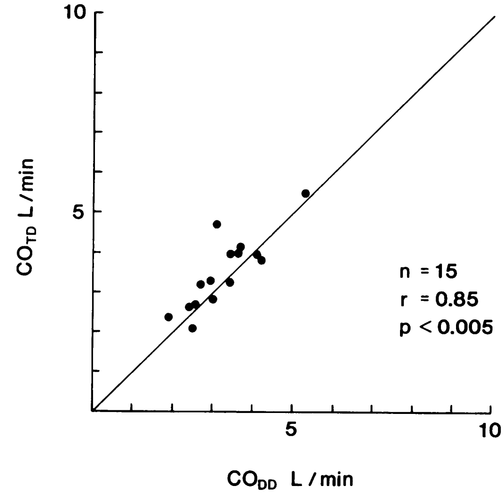

Fig. 2. Comparison of cardiac outputs determined by thermodilution (CO_{TD}) and dye dilution (CO_{DD}) methods revealing a high correlation.

The advantages of the thermodilution technique have been previously commented upon.[7,8] They include its easy repeatability,

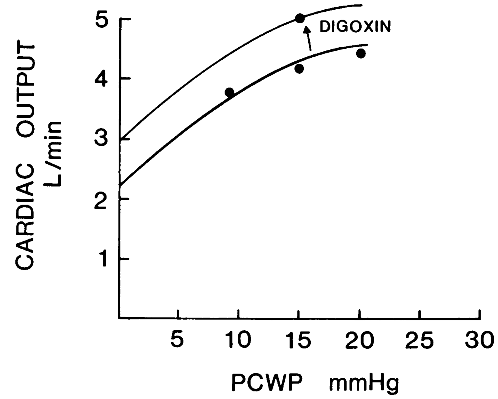

Fig. 3. Serial determinations of cardiac outputs and pulmonary capillary wedge pressure (PCWP) obtained in a 45-year-old man with acute myocardial infarction complicated by hypotension. Initially, PCWP was 9 mmHg. and cardiac output (CO) was 3.8 L/min. Volume expansion resulted in some increase in CO but the PCWP rose to 20 mmHg. Digitalization at this time resulted in reduction in PCWP with further increase in cardiac output.

simple and reproducible calibration and the elimination of the need for an arterial catheter. In addition, the introduction of flow directed balloon-tipped catheters, has made pulmonary artery catheterization a simple and safe bedside procedure.

Knowledge of the CO together with the measurement of pulmonary arterial and capillary wedge pressure (PCWP) enable the clinician to construct ventricular function curves and choose appropriate therapy logically. Figure 3 shows results from a patient in whom serial measurements were made using thermodilution.

SUMMARY

In summary, these data demonstrate a good correlation between the direct Fick and dye dilution methods, and between the dye dilution and the thermodilution techniques. The advantages of the thermodilution technique make it eminently suitable as a bedside procedure in intensive care units. The ability to measure serially both cardiac output and PAWP at the bedside enables the clinician to closely follow the hemodynamic status of acutely ill patients, choose therapy appropriately, and follow the results of therapy with greater accuracy.

ACKNOWLEDGEMENTS

We are grateful to Dr. Robert Barndt for assistance with methodology and to Mrs. Arleen Olson and Mr. Gerard Willey for expert technical assistance.

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