Methodology of Indicator Dilution Cardiac Output Determination*

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A previous study from this laboratory analyzed the methodology of true pulmonary blood volume determination. Three methods were described. The first consisted of pulmonary artery and left atrial indicator dilution injection with systemic arterial sampling, method A, the second pulmonary artery injection with left atrial sampling, method B, and the third right atrial injection with pulmonary artery and left atrial sampling, method C.

It was observed that the first and third methods gave approximately the same results; but the second method, despite its apparent simplicity, grossly overestimated the true pulmonary blood volume as defined by the first and third techniques.1 The purpose of the present report is to analyze the simultaneously obtained cardiac index data to determine whether any systematic deviations in flow were present. Ninety-six patients were studied in all.

METHODS AND MATERIALS

The patients ranged from 17-64 years in age; they were studied in the fasting state. Rheumatic heart disease with mitral and/
or aortic valve disease was the most common diagnosis. Congenital heart disease without a right-to-left or left-to-right shunt was present in some patients. A few subjects were found to be free of heart disease after complete study. Indocyanine green in doses of 2-3.5 mg. together with saline flushes were utilized to inscribe the indicator dilution curves from the various sites. A No. 5, 80 cm. long Lehman catheter was passed into the superior vena cava or right atrium. A No. 6, 100 cm. long Lehman catheter was passed into the pulmonary artery. The left atrium was entered with a Teflon Brockenbrough catheter via the percutaneous right femoral vein transseptal left atrial puncture technic. A systemic artery was cannulated with a No. 18T Cournand needle. The indicator dilution curves were recorded via Gilford densitometers on an 8 channel photographic recorder, (DR-8, Electronics for Medicine, Inc.). Blood was withdrawn from the patient via the systemic arterial needle or the cardiac catheter with a Harvard constant infusion-withdrawal unit. The delay times were determined for each system employed. All blood was returned to the patient after dye curve inscription. The dye curves were calibrated by three dye-in-blood concentration levels. During the calibration procedure the two densitometers were connected in series and the same blank blood and dye-in-blood samples were passed through the densitometers. Cardiac output was calculated by the Hamilton-Stewart semi-logarithmic replot method.53 In each of the 96 patients studied, all cardiac index determinations were made in duplicate—that is in the first method (A) paired pulmonary artery and paired left atrial injection site outputs were averaged to give each of the two cardiac index values. In method B, pulmonary artery injection with left atrial sampling, two dilution curves were inscribed and the results averaged. In method C, right atrial injection, the two pulmonary artery and the two left atrial dye dilution curves were averaged to

**Figure 2:** Comparison of cardiac index data by methods A and C.
**METHOD**

**FIGURE 3:** Comparison of cardiac index data by methods B and C.

**METHOD A**

Run 1 vs Run 2

**FIGURE 4:** Reproducibility of duplicate averaged cardiac index data by method A.
FIGURE 5: Reproducibility of cardiac index data by method B.

FIGURE 6: Reproducibility of duplicate averaged cardiac index data by method C.
give each of the two cardiac index levels. We thus analyzed 960 dye dilution curves.¹

RESULTS

In this group of 96 subjects, the mean cardiac index by method A was 2.65 L./min./M², 2.80 by method B, and 2.79 by method C. The differences between the means for methods A and B are significant, P<0.001. The differences between the means for methods A and B are significant, P<0.001. However these overall differences are quite small, about 5 per cent in all, and are of little physiologic significance. There is no difference between the means for methods B and C. The data are illustrated in Fig. 1-3 and Table 1.

Analysis of the reproducibility of each of the three methods reveals the following. The mean for the first average of the pulmonary artery and left atrial injection sites was 2.62 compared to 2.68 for the second average; the difference is significantly different, P<0.001, but the difference is of little physiologic import. For method B, the first average is 2.78 while the second is 2.83, P=0.05. For method C, the mean for the first average of the pulmonary artery and left atrial sampling sites is 2.79 compared to 2.78 for the second mean; there is no significant difference between this two latter means. These data reveal good reproducibility for each of the three methods and are illustrated in Fig. 4-6.

DISCUSSION

It is of considerable interest that the cardiac indices by all three methods are very similar despite the gross overestimation of the true pulmonary blood volume by the pulmonary artery injection left atrial sampling site technique. These findings must mean that the error in method B (pulmonary artery to left atrium) is caused by overestimation of the mean transit times. The reason for the erroneously prolonged mean transit time is not certain but is probably caused by uneven indicator distribution in the pulmonary vascular bed with consequent uneven left atrial indicator sampling. There are many different mean circulation times in the pulmonary vascular bed. Equal dye-in-blood concentrations in vascular sections with different mean circulation times could also prolong the overall mean circulation time with overcalculation of the true pulmonary blood volume by method B.

These output data are noteworthy for another reason. In patients with severe mitral and aortic regurgitation, in whom the downstroke of the systemic arterial indicator dilution curve is marked off prolonged so as to obviate the possibility of calculation of cardiac output, the latter may be determined by right atrial indicator injection with pulmonary artery sampling. In patients with severe aortic regurgitation, right atrial or pulmonary artery injection sites with left atrial sampling sites may be utilized for determination of cardiac output. A ventricular mixing chamber is apparently not required between the pulmonary artery injection site and the left atrial sampling site to permit valid cardiac output determination.

SUMMARY

Several methods of indicator cardiac output determination have been utilized. Despite differences in true pulmonary blood volumes by these methods, all three approaches result in similar cardiac output data. The reasons for this are discussed.

RESUMEN

La evaluación del rendimiento cardiaco por diversos métodos basados en la dilución de un indicador arroja resultados similares, a pesar de ciertas diferencias en el volumen sanguíneo pulmonar efectivo.

<table>
<thead>
<tr>
<th>Table 1—Summary of Cardiac Index Determination (ml./min./M²): Mean and Standard Deviations</th>
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<tr>
<td>Method A</td>
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<tr>
<td>First Determination</td>
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<td>Second Determination</td>
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INDICATOR DILUTION CARDIAC OUTPUT DETERMINATION

RESUMÉ
Plusieurs méthodes de détermination du débit cardiaque par la technique des dilutions ont été utilisées. Malgré les différences dans les volumes sanguins pulmonaires par ces méthodes, toutes les trois méthodes donnent des résultats semblables sur le débit cardiaque. Les raisons de ce fait sont discutées.

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REFERENCES

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DISTURBANCES OF BRONCHIAL PATENCY AFTER PULMONARY RESECTION
The use of lateral roentgenograms during the first days after the operative intervention is conducive to the recognition of this complication, whereas tomography performed five to 12 days after the operation reveals atelectasis.


ADULT HEART DISEASE DUE TO COXSACKIE VIRUS GROUP B
A series of ten adult patients, believed to have heart disease due to Coxsackie B virus infection is reported. There were nine men, aged 37 to 56 years, and one woman aged 30 years. All patients had evidence of myocardial involvement, and six, in addition, had pericarditis and presented with pericardial pain. In the majority of patients, the erythrocyte sedimentation rate was moderately accelerated and the white blood cell count showed a moderate leukocytosis with a preponderance of neutrophil leukocytes. Serologic tests implicated Coxsackies B5 in four, B4 in three, B2 in three and B1 in one. Seven patients, including a patient who was desperately ill with heart failure and nephritis, made a complete clinical recovery, though one of these patients has residual changes in the electrocardiogram. A further patient had four recurrences of pericarditis in the two years after the initial illness, but so far shows no evidence of permanent heart damage. One patient has mitral incompetence due to chronic myocardial damage or possible endocarditis. One patient died, possibly due to a summation of Coxsackie myocarditis with coronary heart disease.
The heart disease may be associated with other features of Coxsackie infection, such as myalgia, orchitis, pleurisy, aseptic meningitis, and rarely hepatitis, pancreatitis, encephalitis, and nephritis. Myocarditis may occur alone, but pericarditis is almost always associated with a degree of myocarditis. Coxsackie virus infection should be considered in patients with acute myocarditis, idiopathic cardiomyopathy, "murmurless heart disease," Fiedler's myocarditis, and otherwise unexplained cardiographic changes. Coxsackie virus endocarditis should be considered in the diagnosis of obscure valve lesions in man.