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Evaluation of Indicator Dilution Curve Areas

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ABSTRACT

In 24 patients with aortic or mitral valvular disease, 130 thermal dilution and 106 dye dilution curves were recorded for determination of cardiac output. This was in the range of 2–8 l/min. Each curve area was calculated using 3 different methods. The *first* method (Kinsman et al.) requires semilogarithmic extrapolation of the downslope of the curve and planimetry. The *second* method (Hepner et al.) differs from the first by a simplified extrapolation. The *third* method (Bradley & Barr) is more rapidly performed requiring only a few manual measurements and no planimetry. There was no significant difference between the results obtained by the first and second methods, either for thermal or for dye dilution curves. There was no significant difference between the values obtained by the third and the two other methods concerning dye dilution curves, but the difference was significant concerning thermal dilution curves. The third method was modified by replacing the original empirical factor derived from selected dye dilution curve areas by new ones derived from the present material and then became suited for the calculation of unselected thermal and dye dilution curve areas.

INTRODUCTION

Measurement of cardiac output using indicator dilution techniques according to the principle of Stewart (10) requires determination of the area under the indicator dilution curve. If a cardiac output computer is not used the area has to be evaluated separately by means of manual procedures such as extrapolation and planimetry or by the use of simpler measurements and mathematical formulae. The 'conventional' procedures including semilogarithmic extrapolation of the downslope of the curve as described by Kinsman et al. (7) and planimetry of the curve area are considerably time-consuming.

Several attempts to facilitate the evaluation of curve areas have been made. The procedure of extrapolation can be simplified by the method of Hepner et al. (5) or by other methods, cf. George et al. (4). The use of some landmarks on the curves for the calculation of the area by means of special mathematical formulae have been proposed by many authors e.g. Williams et al. (11), Jorfeldt & Wahren (6), Bradley & Barr (1). The mathematical method of Bradley & Barr (1) is especially appealing because of its simplicity but utilises an empirical factor derived from selected smooth dye dilution curves.

The aim of this work was to compare the 'conventional' method of Kinsman et al. (7), including semilogarithmic extrapolation and planimetry, with the method of Hepner et al. (5), using a simplified extrapolation, and with the simple pure mathematical method of Bradley & Barr (1). The material consisted of both thermal (3, 9) and dye dilution (2, 3) curves. It would be of value to investigate unselected curves from patients in order to adapt the methods for routine clinical use. New empirical correction factors derived from the present material were also to be determined when the method of Bradley & Barr (1) is used.

MATERIAL AND METHODS

The study is based upon 130 thermal and 106 dye dilution curves recorded during diagnostic heart catheterizations performed in 24 patients with aortic or mitral valvular diseases. The thermal dilution technique (3, 9) was used in 9 and the dye dilution technique (2, 3) in 15 of the patients. The cardiac output values were in the range of 2–8 l/min.

The *first method* used in the comparison was the 'conventional' technique described by Kinsman et al. (7). This technique comprises manual extrapolation of the downslope of the curve in order to avoid errors from recirculation. Points from the original exponential part of the curve are transferred onto a semilogarithmic paper and the coordinates for the extrapolated part of the curve so obtained are then replotted in order to complete the original curve (Fig. 1). The area of the curve is determined by planimetry.

The *second method* was that described by Hepner et al. (5) and has recently been used with good result in a material of thermal dilution curves from dogs by Pavek et al. (8). This method comprises a simplified extrapolation of the curve. Two vertical lines (Y_1 and Y_2) are drawn from the exponential part of the downslope of the curve (Fig. 1). Planimetry of the larger area (A_1), limited by the ascending and the first part of the descending slope of the curve and the first vertical line (Y_1) and the base line, is performed. Planimetry of the

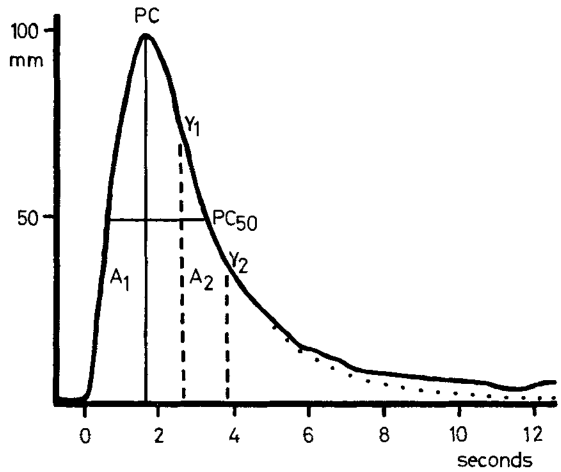

Fig. 1. A thermal dilution curve illustrating the methods used. Semilogarithmic extrapolation (Kinsman et al., 7) (......); modified extrapolation (Hepner et al., 5) (----); calculation from peak concentration (PC) and half the peak concentration (PC_{50}) (Bradley & Barr, 1) (——).

smaller area (A_2), limited by the two vertical lines (Y_1 and Y_2), the slope of the curve and the base line, is also performed. The total area (A) is obtained from the following formula: $A = A_1 + (Y_1/Y_1 - Y_2) \cdot A_2$. If Y_2 is chosen half the height of Y_1 the factor for the multiplication of A_2 will be 2.

The *third method* was that described by Bradley & Barr (1). This method does not require planimetry of the curve areas. Only the height of the curve (peak concentration, PC) and the width at half the peak concentration (PC_{50}) need to be determined and the area is obtained from the product of these values multiplied by an empirical factor (Fig. 1).

A modification of the method of Bradley & Barr (1) was also made by omitting their empirical factor and determining new empirical factors suited for the present material of unselected thermal and dye dilution curves.

In the present report the second and third methods were each compared with the first 'conventional' method.

Table I. *Comparisons between different methods for the evaluation of thermal dilution curve areas*

n signifies the number of thermal dilution curves, $\bar{d}$ mean difference, S.D.d standard deviation of the difference and P the significance

$n = 130$	I Kinsman et al. 1929	II Hepner et al. 1964	III Bradley & Barr 1969
Mean area, cm²	46.73	46.59	45.61
$\bar{d}$ to method I		0.14	1.12
S.D. d		2.62	3.31
P		>0.05	<0.001

Table II. *Comparisons between different methods for the evaluation of dye dilution curve areas*

n signifies the number of dye dilution curves, $\bar{d}$ mean difference, S.D.d standard deviation of the difference and P the significance

$n = 106$	I Kinsman et al. 1929	II Hepner et al. 1964	III Bradley & Barr 1969
Mean area, cm²	31.34	31.24	31.24
$\bar{d}$ to method I		0.10	0.10
S.D. d		1.17	1.62
P		>0.05	>0.05

RESULTS

The above mentioned methods were used for the calculation of 130 *thermal dilution* curve areas (Table I). They all gave fairly similar mean values. There was no significant difference betwen the values obtained by the first and second methods. A highly significant difference was, however, found between the third method and the first method. An even greater difference was found in the latter comparison when the empirical factor (1/0.856) of Bradley & Barr was omitted. The dispersion of the mean values of the areas was numerically relatively large due to the differences in the cardiac output levels of the patients. The order of magnitude of the dispersion for all the methods was the same. The coefficient of correlation between the second and first methods was 0.995 and between the third and first methods 0.992. The corresponding equations of the line were:

$Y = -0.124 + 1.000X$ and $Y = -0.325 + 0.983X$, respectively. The equation of the line obtained when the third method was used omitting the empirical factor found by Bradley and Barr (1) was: $Y = 0.032 + 0.838\,X$ (Fig. 2).

The same methods were used for the calculation of 106 *dye dilution* curve areas (Table II). There was with this technique no significant difference between the mean values of the curve areas calculated by any of the three methods. The dispersion of the mean values was also in this material of the same order of magnitude. The coefficient of correlation between the second and first methods was 0.995 and between the third and first methods 0.991.

The corresponding equations of the line were:

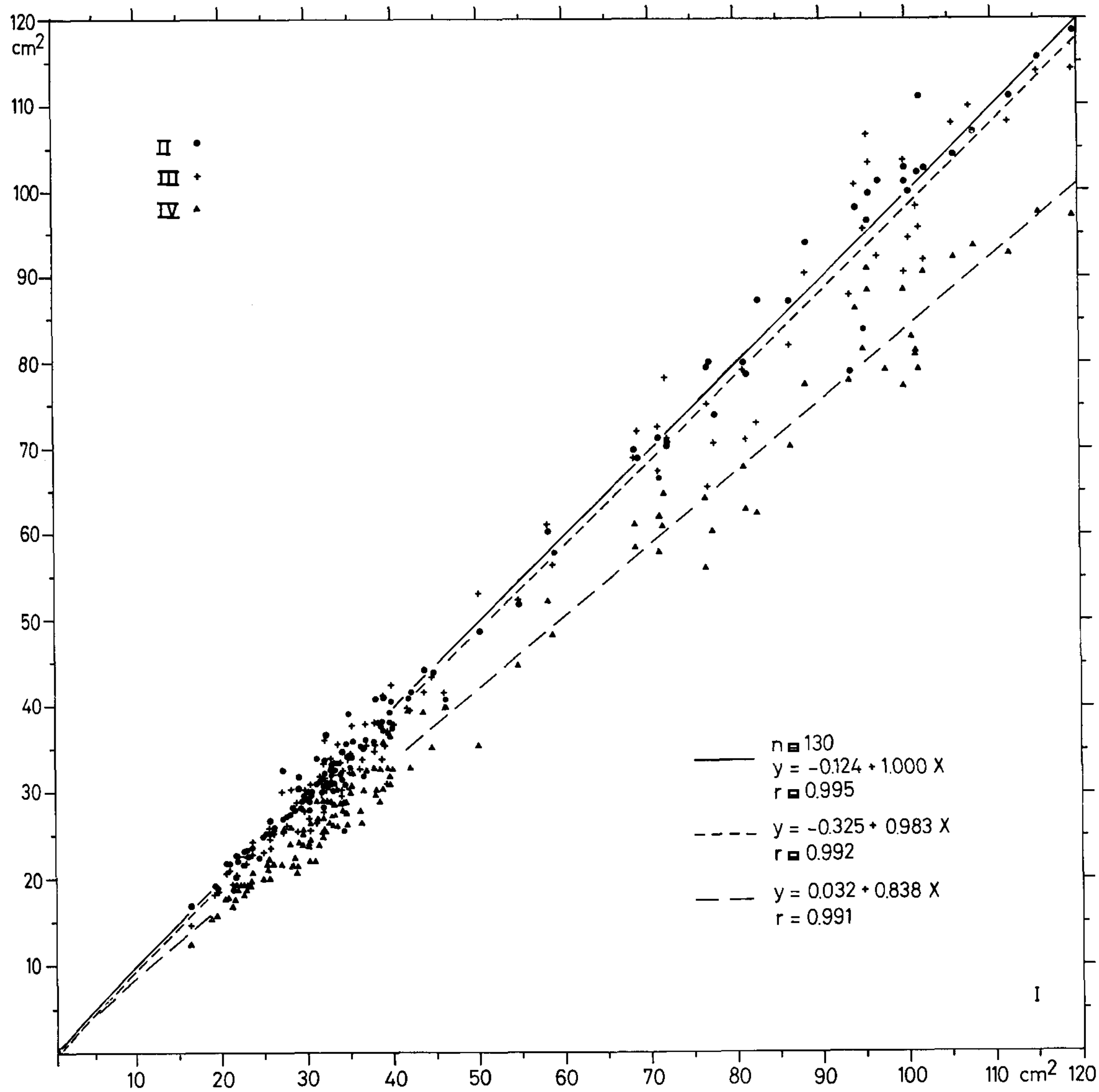

Fig. 2. Comparisons between different methods for the evaluation of thermal dilution curve areas according to: I Kinsman et al. (7), II Hepner et al. (5), III Bradley & Barr (1) and IV Bradley & Barr omitting their empirical factor. ● signifies values obtained in the comparison between II and I, + between III and I and ▲ between IV and I. The corresponding lines of regression are shown by ——, ----, and — —.

$Y = 0.098 + 0.994\ X$ and $Y = 0.391 + 0.984\ X$, respectively. The equation of the line obtained when the third method was used omitting the empirical factor found by Bradley and Barr (1) was:

$Y = 0.436 + 0.840\ X$ (Fig. 3).

A separate study was made on 18 out of the dye dilution curves which were extremely broad with a greatly prolonged disappearance slope. Even in this material there was no significant difference between the three methods.

CONCLUSIONS

In the present report of unselected *thermal dilution* curves from patients with valvular disease, there was no significant difference between the mean values of the curve areas obtained by the two methods which required planimetry. The dispersion

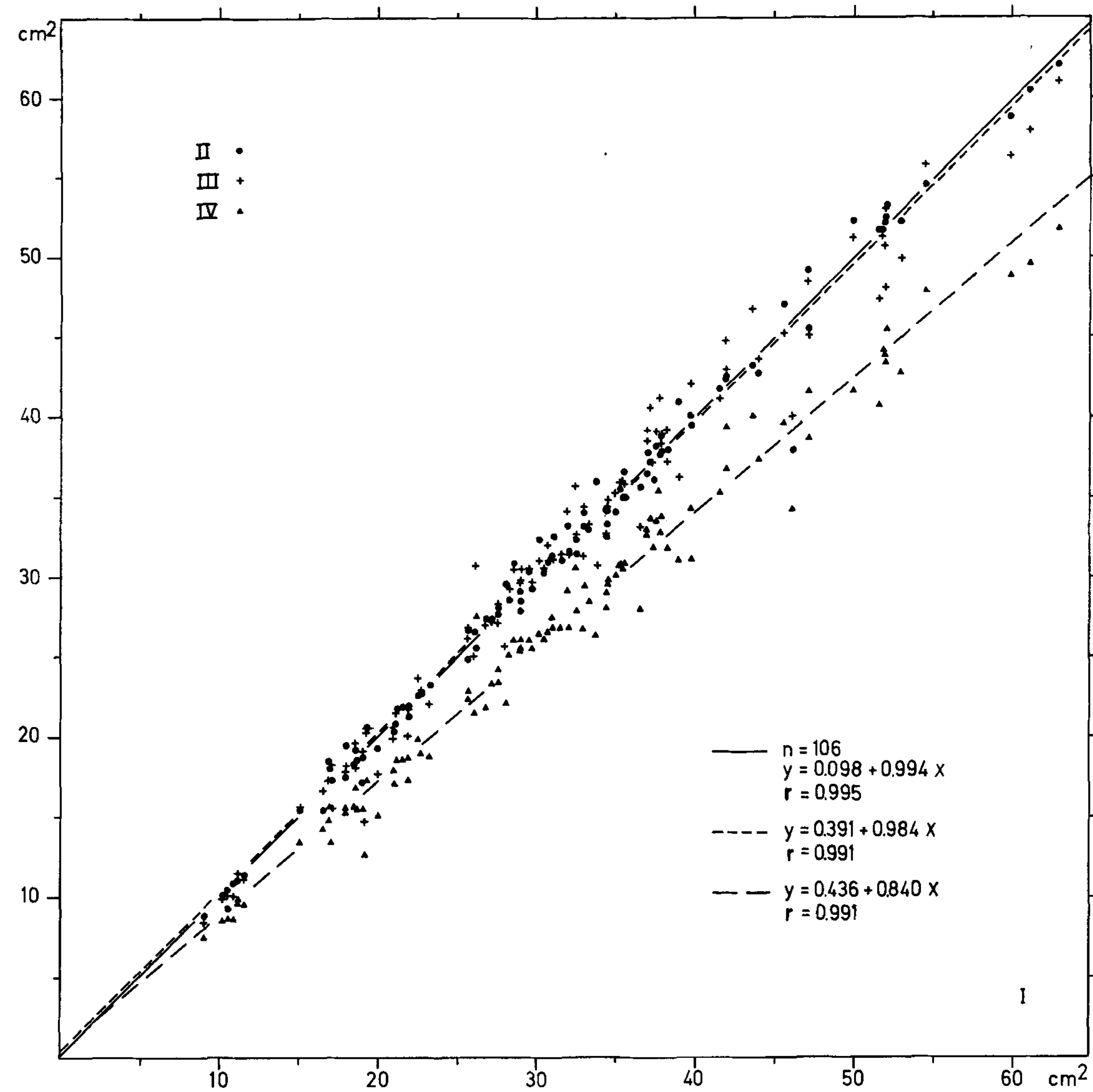

Fig. 3. Comparisons between different methods for the evaluation of dye dilution curve areas according to: I Kinsman et al. (7), II Hepner et al. (5), III Bradley & Barr (1) and IV Bradley & Barr omitting their empirical factor. ● signifies values obtained in the comparison between II and I, + between III and I and ▲ between IV and I. The corresponding lines of regression are shown by ——, ----, and — —.

of the mean values was also of the same order of magnitude. The more rapid method of Hepner et al. (5) which does not require semilogarithmic extrapolation of the curve was found to be reliable and suited for clinical use. The method of Bradley & Barr (1) with the empirical factor found from selected dye dilution curves did not give reliable values in the present material of thermal dilution curves. In order to use this simple method for the calculation of unselected thermal dilution curve areas, the values of the latter had to be multiplied by a correction factor of 1/0.838.

In the results of *dye dilution* curves from a similar group of patients there was also no significant difference between the first and second methods. Furthermore there was no significant difference between the third and the first methods. The empirical correction factor of 1/0.856 found by Bradley & Barr (1) from selected dye dilution curves was thus valid also for the calculation of areas in the present material of unselected curves. The correction factor found in the present work was 1/0.840 and this factor, however, would be more suited for the calculation of unselected dye dilution curve areas.

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