A SIMPLIFIED METHOD OF DETERMINING THE DEGREE OF REGURGITATION OF BLOOD THROUGH INCOMPETENT VALVES FROM DYE-DILUTION CURVES

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Investigations have recently been published [11, 12, 13, 14, 15, 19] in which dye dilution curves have been used for the qualitative and quantitative determination of the degree of regurgitation associated with lesions especially of the mitral valve.

Later, in experiments on dogs with experimental mitral incompetence, it was shown that the regurgitation of blood could be determined quantitatively and accurately [10]. In these investigations a complicated method of double cardiac catherization (of the atrium and ventricle) or puncture of the left ventricle and atrium and also of a peripheral artery was used. This method has been applied in clinical practice [9, 17] to evaluate the degree of regurgitation of blood in mitral incompetence. Obviously such an investigation is not only technically complicated, but also hazardous for the patient.

It has been reported [7, 18] that regurgitation (or a shunt from left to right in congenital defects) may be detected qualitatively by intravenous injection of dye. The presence of regurgitation of blood or a shunt from left to right increases the time taken to clear the dye. The ratio between the time taken to clear the dye and the time taken for its concentration to reach the maximum increases; the higher this ratio, the greater the shunt from left to right [6].

We have attempted to simplify the technique and the calculation of the degree of regurgitation of blood in cases of incompetence of the heart valves.

To record the dye dilution curves we used a modified ear oxyhemograph manufactured by the "Krasnogvardeets" factory, with a paper speed of 2.5 mm/sec. The dye (a 1% solution of methylene blue; 0.5 mg/kg) was injected into the cubital vein; a preliminary injection of 2.4 ml of physiological saline or of a 40% solution of glucose was given into the vein. The choice of methylene blue as dye was based on the fact that this substance is readily available and harmless. According to our findings [2-4], in close agreement with those in the literature [1, 5], on the curves obtained with healthy persons the time of clearance of the dye was 1.7 times longer than the time taken for the concentration to rise to a maximum (segments MO and EM in Fig. 1), i.e., the ratio MO : EM has the value of 1.7. In the presence of regurgitation, the time for clearance of the dye rose considerably, and the ratio MO : EM became greater than 1.7 (Fig. 2). From Hamilton's formula [10], the minute volume of the heart Q is given by:

$$Q = \frac{I \cdot 60}{\Sigma c(t)}, \qquad (1)$$

where I is the quantity of dye injected (in mg), and $\Sigma c(t)$ is the sum of the concentrations of dye (c) during its first passage over a period of time t, obtained by extrapolation of the dye clearance curve as far as zero concentration. $\Sigma c(t)$ corresponds to the area enveloped by the curve. According to this formula, the area occupied by the figure EM'O' (see Fig. 2) is inversely proportional to the volume of the forward blood flow.

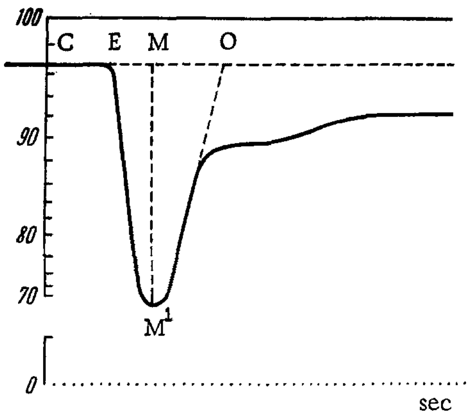

Fig. 1. Dye dilution curve of healthy person. Along the axis of ordinates—logarithmic scale of oxyhemograph, along the axis of abscissas —time (in sec): C) moment of injection of dye into cubital vein; E) appearance of dye in vessels of lobe of ear; M) Projection of moment of maximal concentration of dye along the axis of abscissas; O) extrapolated moment of complete clearance of dye. Ratio between time intervals MO : EM = 1.67.

Because of the fact that with a normal blood flow, uncomplicated by regurgitation, the clearance time of the dye (MO) is 1.7 times greater than the time taken for its concentration to rise to a maximum (EM), we assumed that we could distinguish from the area enveloped by the curve EMO' the ideally correct curve EM'O which is shown shaded. To do this, we plot from the point E a segment EO, equal to 2.7 EM, and we join the apex of the curve M' with the point O. The area EM'O corresponds to the sum of the concentrations of dye diluted in the total minute volume of the blood flow.

The area enveloped by the true curve EM'O' corresponds to the sum of the concentrations of dye diluted in the forward flowing volume. Since the area EM'O' is greater than the area occupied by the ideal curve EM'O, the forward volume is less than the total volume.

$$\frac{Q_{\text{forward}}}{Q_{\text{total}}} = \frac{I \cdot 60}{\Sigma c'(t')} : \frac{I \cdot 60}{\Sigma c(t)} = \frac{\Sigma c(t)}{\Sigma c'(t')}, \qquad (2)$$

where $Q_{forward}$ is the minute volume of blood entering the aorta; Q_{total} is the minute volume of blood entering the aorta plus the volume of blood regurgitating through the valves.

The oxyhemogram is a semilogarithmic graph in which the time is plotted against a linear scale and the changes in optical density, corresponds to the changes in the concentration of dye, against a logarithmic scale.

A curve plotted in a semilogarithmic system of coordinates has the advantage [10] that the branch representing the clearance of the dye is converted into a straight line. It therefore becomes possible to extrapolate this branch to the zero line, i.e., to calculate accurately the time for the first passage of dye. However, before the sum of the concentrations can be calculated, the true values of the concentrations and not their logarithms must be plotted.

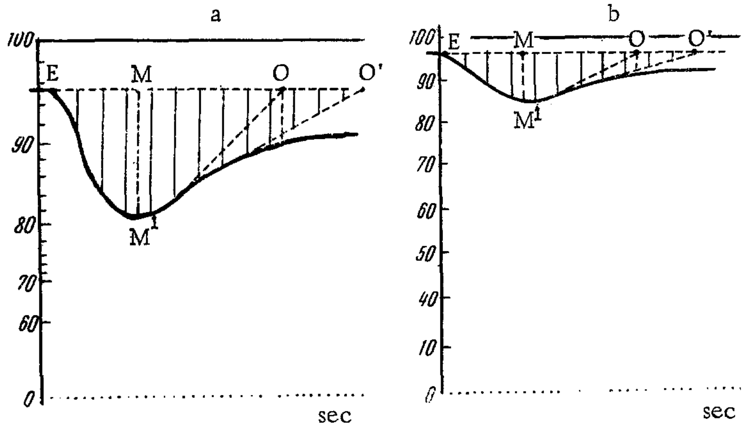

Fig. 2. Dye dilution curve during regurgitation of blood (patient Ch.; diagnosis: combined rheumatic heart lesion with predominance of mitral incompetence). a) Tracing of ear oxyhemograph. Along the axis of ordinates—logarithmic scale of oxyhemograph, along the axis of abscissas—time (in sec); b) curve A plotted against a linear system of coordinates. Along the axis of ordinates—linear scale of conventional units from 0 to 100. Significance of points E and M the same as in Fig. 1. O) point plotted in accordance with the ratio MO : EM = 1.7; O') extrapolated time of clearance of dye in the presence of regurgitation; ratio MO':EM = 2.6.

It had to be established that the ratios between the summed concentrations $\frac{\Sigma c(t)}{\Sigma c'(i')}$ and between the areas of the figures $\frac{EM'O}{EM'O'}$ traced on the oxyhemograph were equal. To do this, we transferred the figures traced on the oxyhemograph to a linear system of coordinates and by calculating the area planimetrically and also by the method of geometrical integration, we found that the values agreed for practical purposes; the differences amounted only to a fraction of 1% (see Fig. 2a and b) and could be disregarded. It can therefore be assumed with sufficient accuracy that:

$$\frac{Q_{forward}}{Q_{total}} = \frac{S_{EM'O}}{S_{EM'O'}}, \tag{3}$$

where S represents the areas of the figures EM'O and EM'O', respectively. This ratio can be obtained by measuring with the planimeter the areas formed by the oxyhemometric curves. However, since the figures described by the curves EM'O and EM'O' are almost triangular in shape, this ratio can be simplified still further by substituting in it the values of the areas of triangles with the same altitude h.

After transformation we obtain:

$$\frac{Q_{forward}}{Q_{total}} = \frac{EO}{EO'}, \tag{4}$$

Substituting, as mentioned above, 2.7 EM for EO, we obtain:

$$\frac{Q_{forward}}{Q_{total}} = \frac{2.7\,EM}{EO'}. \tag{5}$$

If the volume of the reflux blood flow is expressed as a percentage of the total volume of the heart, taken as 100%, then:

$$Q_{forward} = \frac{2.7\,EM}{EO'} \times 100\% \tag{6}$$

$$Q_{regurg} = 100 - Q_{forward} = \frac{EO' - 2.7\,EM}{EO'} \times 100\% \tag{7}$$

The equation thus obtained for calculating the regurgitation on the basis of analysis of the dye dilution curve alone has been applied only to the evaluation of the total regurgitation and not to that through any one valve. According to our observations, in cases when the ratio EM : CE is greater than 0.9, the simplified form of the calculation cannot be used.

The simplified formula given above has been used by the author to determine the regurgitated blood flow in patients with combined defects of the heart valves. The results obtained have shown satisfactory agreement with the clinical findings.

SUMMARY

A formula has been derived for the simplified estimation of blood regurgitation through incompetent heart valves from the dye-dilution curve (methylene blue injected intravenously) recorded by an auricular oxyhemograph. The degree of regurgitation as a percentage of the total blood-flow is expressed as a relation of the "ideal" curve area to an area limited by the actual curve. The "ideal" curve may be plotted on the assumption that with normal hemodynamics the time on the stain curve form its appearance in the ear to the extrapolated moment of complete disappearance is on the average 2.7 times longer than that from the appearance of the stain to the maximum concentration.

With a small risk of error, the figure delineated by the stain dilution curve may be assumed to be a triangle. This renders the calculation simpler, and as a result the percentage of the blood black flow is determined from the formula $\frac{OE^1 - 2.7\,EM}{EO^1} \cdot 100\%$; where, EO^1 is the actual time on the entire curve from appearance to extrapolated moment of disappearance of the dye and 2.7 EM is the "ideal" curve time.

LITERATURE CITED

1. L. V. Vesel'nikov, Kardiologiya, 5, 74 (1962).
2. R. S. Vinitskaya, Éksper. khir., 2, 19 (1962).
3. R. S. Vinitskaya, Abstracts of Proceedings of the 14th Scientific Session of the Institute of Surgery of the AMN SSSR [in Russian], (Moscow, 1962), p. 77.
4. R. S. Vinitskaya and B. M. Kostyuchenok, Kardiologiya, 2, 25 (1964).
5. V. I. Struchkov, A. V. Vinogradov, V. A. Sakharov, et al., Grudnaya khir., 5, 46 (1960).
6. I. Kamaras, A. Gemeri, and L. Pataki, Cor et Vasa (Praha), 4, 65 (1962).
7. C. B. Chapman, J. H. Mitchell, J. F. Glover et al., Am. Heart, J., 1957, Vol. 53, p. 519.
8. P. Dow, J. appl. Physiol., 1955, Vol. 7, p. 399.
9. M. M. Gorelick, S. C. Lenkei, R. O. Heimbecker et al., Am. J. Cardiol., 1962, Vol. 10, p. 62.
10. W. F. Hamilton, J. Moore, J. M. Kinsman et al., Am. J. Physiol., 1928, Vol. 84, p. 338.
11. P. S. Hetzel, H. J. C. Swan, A. A. Ramires de Arellano et al., J. appl. Physiol., 1958, Vol. 13, p. 92.
12. U. Isler and R. Hegglin, Cardiologia (Basel), 1958, Vol. 33, p. 69.
13. J. R. Keys, E. Woodward Jr., H. J. C. Swan et al., Circulation, 1956, Vol. 14, p. 960.
14. P. I. Korner and J. P. Shillingford, Clin. Sci., 1956, Vol. 15, p. 417.
15. W. Rutishauser, E. Luthy, and R. Hegglin, Cardiologia (Basel), 1960, Vol. 36, p. 242.
16. H. R. Warner, Circulat. Res., 1962, Vol. 10, p. 519.
17. E. H. Wood and E. Woodward Jr., Proc. Mayo Clin., 1957, Vol. 32, p. 536.
18. E. H. Wood, Circulat. Res., 1962, Vol. 10, p. 531; 569.
19. E. Woodward Jr., H. B. Burchell, and E. H. Wood, Proc. Mayo Clin., 1957, Vol. 32, p. 518.
20. E. Woodward Jr., H. J. C. Swan, and E. H. Wood, Proc. Mayo Clin., 1957, Vol. 32, p. 525.

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