METHOD OF CALCULATING THE MEAN DEPTH OF RESPIRATION FROM SPIROGRAMS

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A method of calculating the mean depth of respiration by means of a planimeter from spirographic and bronchospirographic data is described. The mean depth of respiration (a_m) is determined by the formula: $a_m = \frac{S}{l}$, where S represents the area of a figure bounded by a broken line obtained by joining the upper and lower ends of neighboring segments expressing the amplitude of individual inspirations on the investigated portion of the spirogram, measured by a planimeter; and l is the distance between cuts representing the amplitudes of the first and last inspiration.

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The combined and differential spirograms provide complete information on the functional state of each lung. However, their analysis requires many calculations, a large proportion of which is concerned with determining the mean value of the depth of inspiration in order to obtain the minute respiratory volume (MRV).

In many diseases requiring investigation of pulmonary ventilation, variations among individual respiratory cycles are observed, making it impossible to take any one of them as the mean amplitude of inspiration or to average these cycles over a period of 1 min, because this would lead to considerable distortion of the indices of external respiration. Accordingly, in order to obtain reliable data for pulmonary ventilation it is necessary to measure some hundreds of lines of inspirations on the spirogram, thereby wasting much time and effort in calculation.

The suggested method of determination of the mean depth of respiration by means of a planimeter considerably reduces the time spent in calculation.

According to the general rules for use of a planimeter, the area (S) of a segment of the spirogram is measured in square millimeters by tracing the outline of the figure $A_0, A_1, \ldots, A_n, \ldots B_1, B_0$ (Fig. 1), bounded by a closed lined obtained as a result of joining the upper and lower ends of neighboring segments $A_0B_0, A_1B_1, \ldots, A_nB_n$, reflecting the amplitude of individual inspirations, successively. The distance (l) between the segments A_0B_0 and A_nB_n, which are the amplitudes of the first and last inspirations, is then measured in millimeters. To obtain the mean value of the depth of respiration (a_m), S must be divided by l:

$$a_m = \frac{S}{l}. \tag{1}$$

The linear value a_m thus obtained is converted into milliliters by multiplying it by 2, the scale value of the spirograph. This gives the required mean depth of respiration.

The example given below shows the order of the calculations and also their simplicity. Before outlining the spirogram, the counting mechanism shows the number 4535. After outlining the segment of the spirogram recorded over 3 min, the counter indicates 4947. The difference between these two numbers is 412. Multiplying this by the scale value of the PP-2K planimeter gives 4120 mm^2.

In our example the value of l is 150 mm. The area obtained (4120 mm^2) is divided by 150, giving 24.1 mm, which must be multiplied by the scale value of the spirograph (20). The mean depth of respiration is accordingly 432 ml.

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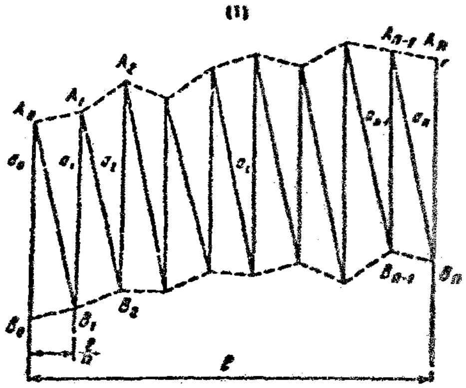

Fig. 1. Scheme of a segment of a spirogram. A_0B_0, A_1B_1, A_2B_2, A_{n-1}, B_{n-1}, $A_n B_n$ represent the limits of inspiration and expiration; a_0, a_1, a_2, a_{n-1} the values of the depth of respiration; $n+1$ the total number of respiratory cycles; l the distance between the first and last inspirations along the horizontal axis; a_i the depth of an individual respiration.

Proof of the validity of equation (1) is given below. The value of S of the figure $A_0A_1 \ldots A_nB_n \ldots B_1B_0$ depicted above can be obtained as the sum of the areas of the trapezia $A_0A_1B_1B_0$, $A_1A_2B_2B_1 \ldots$, $A_{n-1}A_nB_nB_{n-1}$. The area of trapezium $A_iA_{i+1}B_{i+1}B_i$ is given by:

$$S_{A_iA_{i+1}B_{i+1}B_i} = \frac{a_i + a_{i+1}}{2n} l.$$

Therefore

$$S = \frac{1}{n} l \left(\frac{a_0 + a_n}{2} + a_1 + \ldots + a_{n-1} \right).$$

Hence it follows that

$$a = \frac{S}{l} = \frac{1}{n} \left(\frac{a_0 + a_n}{2} + a_1 + \ldots + a_{n-1} \right). \tag{2}$$

The right-hand side of equation (2) differs only slightly from the sampling mean value (a_{sm})

$$a_{sm} = \frac{1}{n+1} (a_0 + \ldots + a_n). \tag{2*}$$

In fact we can estimate the difference between a_{sm} and a_m. By substituting in (2) and (2*), after transformation we obtain:

$$a_{sm} - a_m = \frac{(n-1)(a_0 + a_n) - 2a_1 - \ldots - 2a_{n-1}}{2n(n+1)}. \tag{3}$$

It follows from equation (2) that the difference between a_{sm} and a_m, with a high level of probability, can be taken as close to 0; furthermore,

$$|a_{sm} - a_m| \leqslant \frac{(n-1)(a_0 + a_n) + 2a_1 + \ldots + 2a_{n-1}}{2n(n+1)} \leqslant \frac{a_0 + a_n + \frac{2}{n}(a_0 + a_n)}{2(n+1)} + \frac{a_{sm}}{n+1}.$$

For high values of n, the first term of the last inequality can be disregarded; in any case

$$\frac{a_0 + a_n + \frac{2}{n}(a_0 + a_n)}{2(n+1)} < \frac{a_0 + a_n}{n} \text{ when } n \geqslant 2,$$

so that the absolute value of the difference $a_{sm} - a_m$ can be estimated by means of the inequality

$$|a_{sm} - a_m| < \frac{a_0 + a_n}{n} + \frac{a_{sm}}{n+1}.$$

If, therefore, $n \geq 50$, the roughest overestimate can hardly exceed 2%. For practical considerations, for calculating the sampling mean value it is essential that $n \geq 30$; even in the case $n = 30$, however, the error does not exceed 5%.

In parallel calculations we determined the mean depth of respiration by the usual method and by means of a planimeter from 34 spirogram cuts. Identical results were obtained during the measurement of 16 cuts. In the other 18 cases differences of 15 and 16 ml were found only when measuring two cuts, corresponding to calculated values of the MRV of 0.2 and 0.3 liter. In all other cases the difference was so small that in practice it could be disregarded.

The suggested method of calculation of the mean depth of respiration can be used in any medical department where the spirographic method of investigation of external respiration is used.