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THE CAPNOGRAM IN THE STUDY OF CHRONIC OBSTRUCTIVE LUNG DISEASE

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INTRODUCTION

Study of the expiratory CO_2 curve is a useful means of investigation in chronic obstructive lung disease. It is well recognized that a non-homogeneous distribution of the inhaled air occurs in this condition.

Uneven ventilation is present by definition in bronchial asthma, chronic bronchitis, pulmonary emphysema, etc. In such diseases the lungs may be considered to be innumerable compartments arranged in parallel but differently ventilated. In other words there are properly ventilated alveoli alongside insufficiently ventilated alveoli. The latter, at least as far as the above-mentioned diseases are concerned, empty later and more slowly than well ventilated alveoli because of an increase in airway resistance and/or an increase in lung compliance. That is to say that alveoli with a normal time constant (the time constant being the product of airway resistance multiplied by lung compliance) empty first, whereas alveoli with a progressively higher time constant empty proportionally later. The abnormal shape of the capnographic curve observed in patients with chronic obstructive lung disease is due precisely to this mechanism.

The expiratory curve of CO_2 in subjects with chronic bronchitis, pulmonary emphysema, bronchial asthma, etc. has been studied by several authors [1, 2, 4, 5, 6, 7, 8, 9, 11, 13].

Different methods of mathematical analysis of the capnogram have also been suggested in order to quantify the changes in it [7, 10, 12, 13].

The purpose of this study is: 1) to emphasize the importance of the capnogram in the investigation of ventilatory troubles of the obstructive type; 2) to propose a numerical parameter representative of the capnogram; 3) to ascertain possible correlations between the changes in the capnogram and other tests of lung function.

PATIENTS AND METHODS

The study undertaken included all ambulatory patients with chronic bronchitis according to the criteria proposed by the European Coal and Steel Community [3] and showing the symptoms and the signs of bronchial obstruction (chronic obstructive lung disease). It was carried out without

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range of parameter B	capnogram type					
	1st	2nd	3rd	4th	5th	total
0-0.039	1	1	—	1	—	3
0.040-0.059	4	27	14	1	—	46
0.060-0.079	—	17	19	12	—	48
0.080-0.099	—	3	11	24	1	39
0.100-0.119	—	—	5	26	15	46
0.120-0.149	—	—	1	9	31	41
>0.150	—	—	—	1	21	22
total	5	48	50	74	68	245

Table 1 - 245 subjects with chronic obstructive lung disease subdivided according to capnogram type.

interruption between November 1972 and June 1973. In view of the fact that even in normal subjects the capnographic tracing is often abnormal in the presence of tachypnea, we excluded from our study all patients with a respiratory rate of over 20/min. We excluded also those patients whose tracings were irregular because of emotion, anxiety, etc.

Observing these limitations we examined 245 patients with chronic obstructive lung disease, their age being between 19 and 71 years; 210 were males, 35 were females.

All tests were performed on patients that had been rested and were seated. The capnogram was obtained by means of the Godart Capnograph; the expiratory curves of CO_2 were recorded from the tidal volume. A strip chart recorder, operating at a speed of 75 cm/min, traced the changing carbon dioxide concentration in the expired air.

Spirographic tests were carried out by means of the Godart Pulmotest and Pulmoanalyzer. To measure the dynamic lung volumes, the vital capacity (VC), the forced expiratory volume in 1 sec (FEV_1) and the FEV_1 as a % of the VC (FEV_1/VC) were calculated from the best of 3 attempts.

To determine the static lung volumes, the functional residual capacity (FRC) was measured in duplicate by the closed-circuit helium multiple-breath dilution method. An approximation of 250 ml or less was required from two successive determinations. From the FRC the total lung capacity (TLC), residual volume (RV) and the ratio RV/TLC were calculated. The values of dynamic and static lung volumes are expressed at BTPS.

Arterial blood samples were obtained in a heparin-lubricated syringe from the brachial artery when the patient was breathing air, and the Pa_{O_2}, Pa_{CO_2} and pH were measured in duplicate using electrodes (Radiometer, Copenhagen).

We investigated a parameter making it possible to express quantitatively the changes in the capnogram. In other words we attempted to substitute a numerical measure for the descriptive evaluation of the capnographic curve. The parameter was specifically proposed for the purpose of evaluating the significance of the capnogram in the study of obstructive ventilation disorders and to verify the existence of a correlation between changes in the capnogram and the commonest tests of lung function.

In normal and correctly breathing subjects the morphology of the capnogram is of the 'square' wave type (the first type of curve in tab. 2). When we examine the tracings of patients with chronic obstructive lung disease, we see that the capnographic curve shows increasingly greater changes until, in extremely uneven ventilation, it acquires the appearance of the 5th type of capnogram (tab. 2). The ascending part of the tracing is no longer vertical or *quasi*-vertical but becomes oblique. The *radius* of curvature of the segment between the ascending part and the '*plateau*' decreases more and more, the *plateau* itself disappears, and the tracing becomes steeper and steeper.

We, therefore, distinguished 5 types of capnographic tracing, from the normal type 1, with a 'square' wave, to type 5, which shows the greatest difference from normal. Types 2, 3 and 4 present intermediate characteristics with progressively more obvious changes.

When we examine the ascending phase of the capnogram (fig. 1), we note that, no matter what the type of tracing may be, it is a curve of the logistic type (fig. 2). In view of analogy between this curve and the capnogram, we can consider only the part rising from F, the flex point. As a matter of fact, the principal modifications of the tracing, as far as obstructive ventilation disorders are concerned, should be found just at this part of the capnographic curve.

A method to determine a parameter representing the capnogram has been considered in detail in a previous paper [13]. To determine this parameter in practice it is necessary to find the flex point F and the maximal point M on the capnogram (fig. 1), then to fix, as can be easily deduced from the figure, the point N, and measure the segment $\overline{MN}$ and find the point P so that $\overline{PQ} = 1/2\ \overline{MN}$.

If t_1 and t_2 be the points on the axis of abscissae corresponding respectively to the points F and P, then measurement of the segment $\overline{t_1t_2}$, which varies according to the capnogram changes, already gives us a value which may serve our purpose. However, as the capnographic curve presents a different period and therefore a different amplitude according to breathing frequency, it is advisable to divide the measure of the segment $\overline{t_1t_2}$ by a value (fig. 2), which can correctly represent the amplitude of the capnogram. Consequently the parameter

$$B = \frac{t_2 - t_1}{d}$$

has been considered as representative of the capnogram. The parameter B was calculated from at least 5 successive capnograms. Therefore the reported value of B was the average of 5 measurements. However, if even 1 of these 5 values showed a difference of more than 10 % in relation to the others, the case was excluded from the investigation.

RESULTS

In tab. 1 all 245 cases are subdivided according to the type of their capnogram and the value of parameter B. We can observe from this table that, with a few exceptions, as the capnogram changes become more evident, the parameter B also increases. This appears even more obvious in tab. 2, which gives the respective mean value of B and its coefficient of variation * for every group of patients. Even more

* Coefficient of variation = $\sigma/M \cdot 100$, where σ is the standard deviation and M the mean value of B in every group of patients.

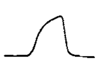
capnographic tracing	capnogram type	no. of patients	mean value of parameter B	variation coefficient
	1st	5	0.045	14.58
	2nd	48	0.058	19.86
	3rd	50	0.073	26.81
	4th	74	0.098	23.05
	5th	68	0.139	20.48

Table 2 - Mean values and variation coefficients of parameter B for the 5 groups of patients, subdivided according to the capnogram type.

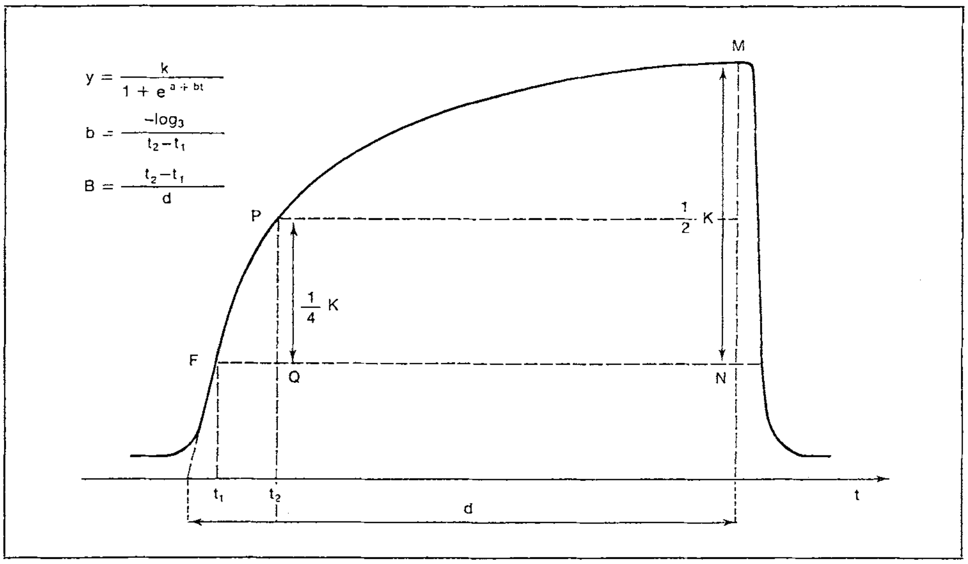


Fig. 1 - The capnogram as a logistic curve. (From: Vulterini et al. [13]).

than in tab. 1 this clearly shows, in fact, that the value of parameter B constitutes a measure of the changes in the capnogram. This measure is also statistically satisfactory inasmuch as the coefficients of variation are rather low.

The mean values of VC, RV, RV/TLC, FEV_1 and FEV_1/VC, expressed as % of the normal values, as well as the mean Pa_{O_2} and Pa_{CO_2} obtained in every group of patients, are shown in tab. 3. We can see that as the capnographic tracing becomes more and more abnormal, these parameters of respiratory function show a progressive deterioration.

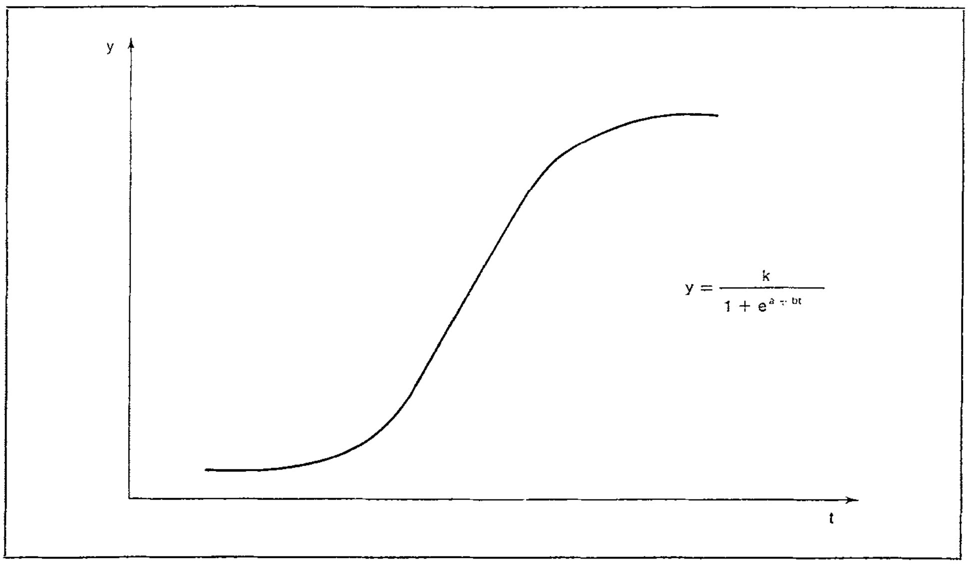


Fig. 2 - Logistic curve. (From: Vulterini et al. [13]).

capnogram type	no. of patients		VC*	RV*	RV/TLC*	FEV_1*	FEV_1/VC*	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)
1st	5	mean value	84.20	132.40	34.40	73.40	66.60	92.20	38.40
		variation coefficient	8.80	25.25	16.51	12.80	24.00	5.88	6.29
2nd	48	mean value	89.42	131.67	35.81	76.25	63.19	86.13	40.00
		variation coefficient	16.80	30.25	44.06	23.48	22.20	9.90	9.30
3rd	50	mean value	80.90	133.80	39.04	69.22	61.06	81.84	41.62
		variation coefficient	20.87	23.38	21.09	29.92	19.74	9.32	20.90
4th	74	mean value	77.11	156.46	45.78	51.95	47.01	76.32	40.42
		variation coefficient	19.40	30.04	19.67	33.53	22.18	9.80	9.74
5th	68	mean value	69.93	179.28	52.54	37.74	38.50	71.03	44.74
		variation coefficient	17.09	28.95	19.19	33.16	29.03	11.32	15.31
	245	* values expressed as % of the normal values							

Table 3 - Mean values of respiratory function tests obtained in the 5 groups of patients, subdivided according to the capnogram type.

In order to study the correlation between parameter B and the respiratory function tests, we calculated the binary correlation coefficient r between parameter B and the value of each of the above-mentioned tests. We also performed Student's t test for each coefficient to verify that it was significantly different from zero. We can note from tab. 4 that parameter B shows some correlation (positive or negative as the case may be) with the values of RV/TLC, FEV_1, FEV_1/VC, Pa_{O_2}.

We further calculated the multiple correlation coefficient R between parameter B and the values of the respiratory function tests considered as a whole. The value of F of Fischer-Snedecor was also determined to verify the significance of the coefficient R:

$$R_B\ (VC, RV, RV/TLC, FEV_1, FEV_1/VC, Pa_{O_2}, Pa_{CO_2}) = 0.77$$

where $F = 30.95$; $P < 0.001$.

It can thus be concluded that there is a good correlation between B and the values of the respiratory function tests considered as a whole.

DISCUSSION

KELSEY et al.[4] distinguished 4 types of capnographic curve, the 1st corresponding to the curve of normal subjects, whereas the 4th expresses maximal abnormality. On the basis of the study of 53 cases, they observed that all subjects with normal lung function tests (with 1 exception) showed capnograms of the 1st type, whereas subjects with very seriously impaired lung function showed a capnogram of the 4th type. These authors stated therefore that the capnographic tracing is useful for distinguishing those people with normal lung function from those with emphysema and, further, that this method, thanks to its extreme simplicity and facility of execution, constitutes an important lung function test. The same conclusions have been reached by CARDACI et al. [2] and PANUCCIO et al. [6]. SERRA et al. [8], on the other hand, propose the simultaneous recording of the expiratory curves of CO_2 and O_2 as a preliminary method to ascertain changes in the distribution of inspired air and the gaseous exchange.

In the 245 patients with chronic obstructive lung disease examined during the course of this research, we observed that subjects showing the greater changes in the capnographic curve also showed more marked abnormalities in the respiratory function tests. For example, in patients with capnograms of type 2, the RV showed a mean increase of only 25 % above normal; in patients with capnograms of type 5 the increase reached 89 %. In the same way the FEV_1/VC ratio in these 2 groups of patients was reduced by 37 % and 62 %, respectively. The mean Pa_{O_2} in patients with type 2 capnogram was about 85 mm Hg, whereas in those with a type 5 capnogram it was 70 mm Hg.

In order to verify whether there was any correlation between changes in the capnographic curve and abnormalities in the respiratory function tests, we introduced a parameter making it possible to substitute a quantitative for a descriptive criterion in the evaluation of the capnogram. This quantitative criterion consists essentially in calculating parameter B, which may be obtained for each capnogram in the way described above. The validity and the usefulness of this parameter is confirmed by the fact that its value increases with the deterioration in the capnogram. From a statistical point of view, the parameter B was significantly correlated with the values of RV/TLC, FEV_1, FEV_1/VC and Pa_{O_2}.

By calculating the multiple correlation coefficient we also demonstrated a good correlation between B and the whole of the respiratory function tests taken together. It therefore appears justified to assume that the capnogram gives us, naturally within certain limits, useful criteria for evaluating the extent of obstructive ventilatory disorders.

	r	Student's t test	P
VC	— 0.42	— 7.21	< 0.001
RV	0.42	7.21	< 0.001
RV/TLC	0.50	9.00	< 0.001
FEV_1	— 0.62	— 12.32	< 0.001
FEV_1/VC	— 0.59	— 11.39	< 0.001
Pa_{O_2}	— 0.53	— 9.74	< 0.001
Pa_{CO_2}	0.26	4.20	< 0.001

Table 4 - Coefficients of binary correlation (r) between parameter B and respiratory function tests.

CONCLUSIONS

By calculating the parameter B, which makes it possible to express the changes in the capnographic curve by a numerical measure, we have provided satisfactory evidence and statistical confirmation of the validity of the capnogram as a useful means to ascertain the existence of uneven ventilation.

In addition we have successfully used this method to demonstrate that a mere examination of the capnogram, even without calculating parameter B (which in any case is time-consuming and not always easily calculated) enables us, at least in most cases, to forecast and anticipate abnormal results in one or more respiratory function tests.

In conclusion the capnogram is really a ventilatory function test that is both rapid and reasonably error-free. It is also a fairly good method of evaluating the degree of uneven ventilation present in a given subject.

SUMMARY

The purpose of this study is: 1) to emphasize the importance of the capnogram in the investigation of ventilatory disorders of the obstructive type; 2) to propose a numerical parameter representative of the capnogram; 3) to ascertain, by means of this parameter, possible correlations between capnogram changes and other tests of lung function. This parameter enables a quantitative criterion to be substituted for a descriptive one in assessment of the capnogram. The study covered 245 patients with chronic obstructive lung disease. We observed that as the capnographic tracing becomes more and more pathological, the lung function tests show progressive deterioration.

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