B. Bink (Netherlands Institute for Preventive Medicine, Leiden, Holland)

A simplified method for the determination of the oxygen diffusing capacity of the lungs.

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The oxygen diffusing capacity of the lungs represents the oxygen intake per unit time ($\dot{V}_{O_2}$) per pressure difference in mm Hg between the oxygen pressure in the alveolar air (P_A) and the mean alveolar capillary oxygen pressure ($P_{\bar{c}}$)(1). The diffusion capacity is given by the relationship

$$D_{O_2} = \frac{\dot{V}_{O_2}}{P_A - P_{\bar{c}}}.$$

The oxygen consumption ($\dot{V}_{O_2}$) is determined from volume measurement and continuous analysis of mixed expired air. The alveolar oxygen tension (P_A) is obtained from end-tidal air sampling.

The Bohr integral can be solved only if the end gradient $P_A - P_c$, is known (2). However this end-gradient is not measurable while air is being breathed and so the following simplification is proposed. On a standard dissociation curve $P_{\bar{c}}$ is always derived in the same way, graphically, from P_A and $S_{\bar{v}}$. Increase of P_A and decrease of $S_{\bar{v}}$ both result in an increase of $P_A - P_{\bar{c}}$.

If the oxygen intake is measured during exercise on a bicycle-ergometer, D_{O_2} can be calculated for each minute. Using an ergometer with progressively increasing load a curve is obtained of D_{O_2} against $\dot{V}_{O_2}$ for each minute of the exercise, $\dot{V}_{O_2}$ increasing from the resting value up to the maximal oxygen intake. If we compare this curve with the mean curve of normal subjects it becomes possible to compare the diffusion capacity curve of the patient with the normal value and to give the diffusion capacity as a percentage of normal.

Theoretical considerations:

For estimating $P_{\bar{c}}$ a method is developed which avoids catheterisation and arterial puncture.

We have used the close correlation of mixed venous saturation ($S_{\bar{v}}$) and the oxygen intake ($\dot{V}_{O_2}$) as found from the work of Donald, Bishop, Cumming and Wade (3).

Data have been obtained in catheterisations done by Donald, Bishop, Cumming and Wade in 16 normal subjects performing exercise up to an oxygen intake of more than 1000 ml/m^2. In their measurements the Spearman rank correlation between the values for mixed venous saturation and oxygen intake is 0.94. In our own experiments the correlation between $\dot{V}_{O_2}$ and pulse frequency is 0.96. Figure 1. shows the relation between $S_{\bar{v}}$ and the pulse frequency in the measurements of Donald et.al.

Since $C_{c'}$ scarcely changes as $\dot{V}_{O_2}$ increases, a close relation between $(C_{c'} - C_{\bar{v}})$ and the pulse frequency might be accepted and expressed in the formula $(C_{c'} - C_{\bar{v}}) = \frac{\text{pulse frequency}}{\text{basal frequency}} \times 4.3$ Vol % O_2.
Here 4.3 Vol.% O_2 is the basal arterial-venous difference according to measurements of Cournand (5). This seems to be a reasonable supposition because the quotient $\frac{C_{c'} - C_{\bar{v}}}{\text{pulse frequency}}$ is constant both at basal condition and at maximal performance. Under basal conditions the quotient $\frac{(C_{c'} - C_{\bar{v}})\text{bas.}}{\text{basal pulse freq.}} = \frac{4.3}{62} = 0.07$

At maximal effort the quotient $\frac{(C_{c'} - C_{\bar{v}})\text{max.}}{\text{max. pulse freq.}} = \frac{14}{200} = 0.07$

According to Christensen 14 Vol.% O_2 is the maximal av difference found at maximal physical performance.
$S_{\bar{v}}$ is calculated from $(C_{c'} - C_{\bar{v}})$ and the haemoglobin content of the blood. Here again $C_{c'}$ is derived from P_A.

For a subject breathing air the end gradient $(P_A - P_{c'})$ is unmeasurable and hence the Bohr integration cannot be performed. Therefore a simple artifice is used by which $P_{\bar{c}}$ is derived graphically from P_A and $S_{\bar{v}}$. This method is always the same, and is described in the next section.

Methods:

The oxygen consumption $\dot{V}_{O_2}$ is calculated from ventilation and difference in oxygen concentration of inspired and expired air. The ventilation is measured by the Lilly flowmeter with a summator (by which it is possible to determine the ventilation in l/min with a standard deviation of 1.1% of the mean). This difference in oxygen concentration is measured according to the principle of Noyons which uses the differences in thermal conductivity of different gases (The standard deviation of the measurements of the oxygen concentration difference is 1.8% of the mean).

Outside air passes through the Lilly flowmeter. The pressure difference (which is only a few mm H_2O) at both sides of the gauze in the Lilly flowmeter is transmitted to a condenser-manometer, which is part of an oscillating circuit. After detection and modulation the signal is led to an ordinary electric meter. After calibration we can read the ventilation in l/min. with a standard deviation of 1.1% of the mean.

An electronic apparatus uses (the quick changes in potential of) the R peaks as a signal for counting the pulse frequency.

The alveolar oxygen tension P_A is obtained by end tidal air sampling by the method of Rahn and Otis. About 120 ml is sampled through a Pauling oxygenmeter. Before and after each experiment the Pauling oxygen meter is calibrated with nitrogen for the baseline and with outdoor air for the 20.94% line. The Pauling oxygen meter is linear between these two points. The oxygen fraction in the end tidal air is read off and we assume the alveolar oxygen pressure corresponding to the oxygen fraction in the end tidal air. If the sampled air is dried before passing through the oxygen meter $P_A = F_A(B - 47)$. (P_A and B in mm of Hg.) For estimating end capillary saturation it is assumed that capillary oxygen pressure equals alveolar oxygen pressure, the dissociation curve being nearly horizontal in this part.

The P_A value found by end tidal air sampling and the value of the saturation of the mixed venous blood, $S_{\bar{v}}$, calculated as described above are plotted on the standard dissociation curve of Riley and Cournand (fig. 2). The point P_A on the dissociation curve is joined by a straight line to the zero point of the dissociation curve. Through the point of intersection of $S_{\bar{v}}$ and P_A a perpendicular is drawn to this line. Where this perpendicular crosses the dissociation curve is the point $P_{\bar{c}}$. We can read off $P_A - P_{\bar{c}}$ directly. The distance from 0 to 100% saturation must equal the distance 0 to 100 mm Hg.

Curves of the oxygen fraction in the end tidal air during exercise with continously increasing load show that P_A, calculated from end tidal air sampling, decreases with increasing load, which argues against an increase of the dead space ventilation in the end tidal air during higher ventilation.

Results:

When this method is used during a 45 minutes exercise on a bicycle ergometer with progressively increasing load, the relationship between D_{O_2} and $\dot{V}_{O_2}$ can be obtained for all values of $\dot{V}_{O_2}$.

The curve of fig. 3 is obtained from eight experiments by the same moderately trained subject. D_{O_2} has been calculated in the way described, and plotted against $\dot{V}_{O_2}$. The subject performed an exercise on the bicycle ergometer with a load that increased continuously by ten Watts per minute. Each experiment went from zero to 250 Watts. The standard deviation of the D_{O_2} values for each minute is 9.3% of the mean.

When we use the same test in patients with pure mitralstenosis or patients with emphysema or pulmonary tuberculosis we obtain much lower curves.

We have compared the method described in this paper for the calculation of D_{O_2} with the D_{CO} method. In the table below, are given the D_{O_2} values found by this method, and the D_{CO} values measured by Dr D.V. Bates in the St. Bartholomew Hospital, London, both in subject B.B.

$\dot{V}_{O_2}$	D_{CO}	D_{CO} x 1.23	D_{O_2}
rest	12.8	15.7	16.1
1.25 l/min.	26.2	32.2	49.0
2.08 l/min.	56.5	69.5	66.6

The method described appears useful in the clinical study of a number of cardiac and pulmonary diseases, such as mitral and pulmonary stenosis, emphysema, pneumoconiosis, lung cysts and pulmonary fibrosis.

Fig. 1

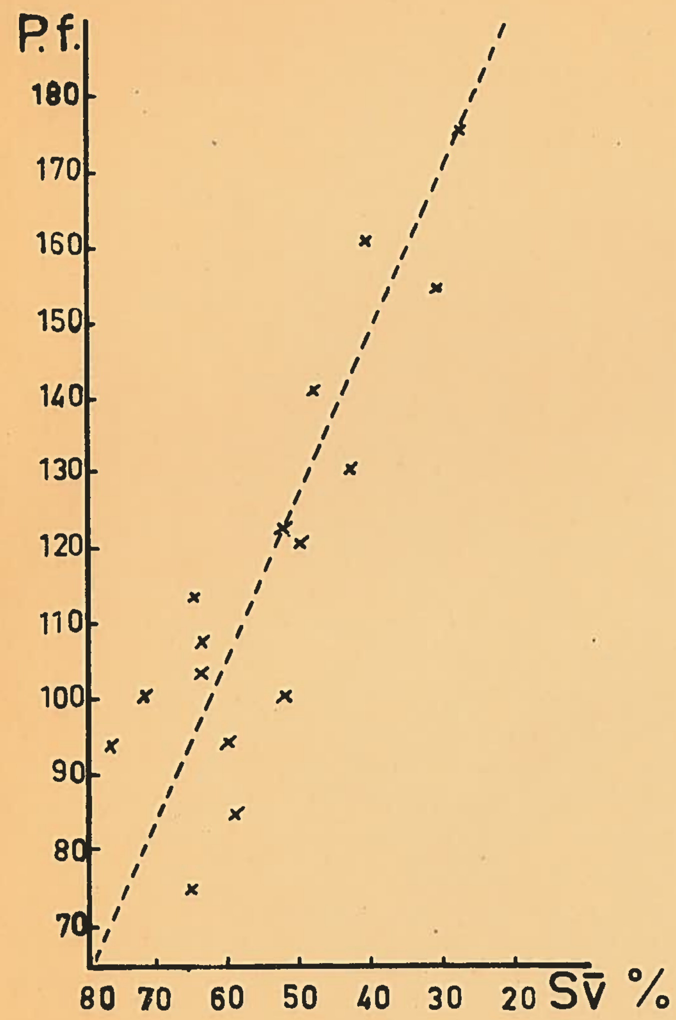

P.f.
180
170
160
150
140
130
120
110
100
90
80
70
80 70 60 50 40 30 20 Sv̄ %

Fig. 2

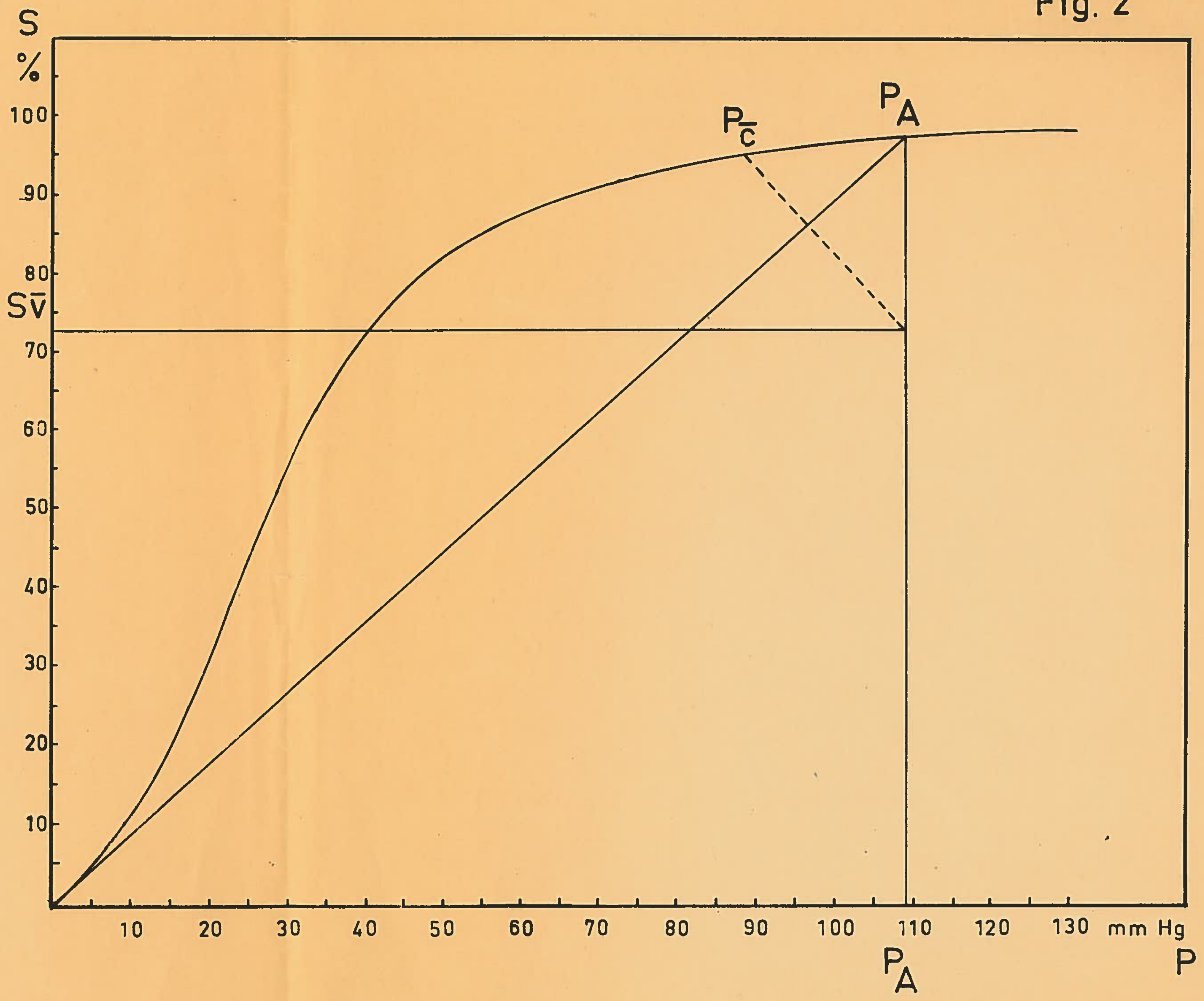
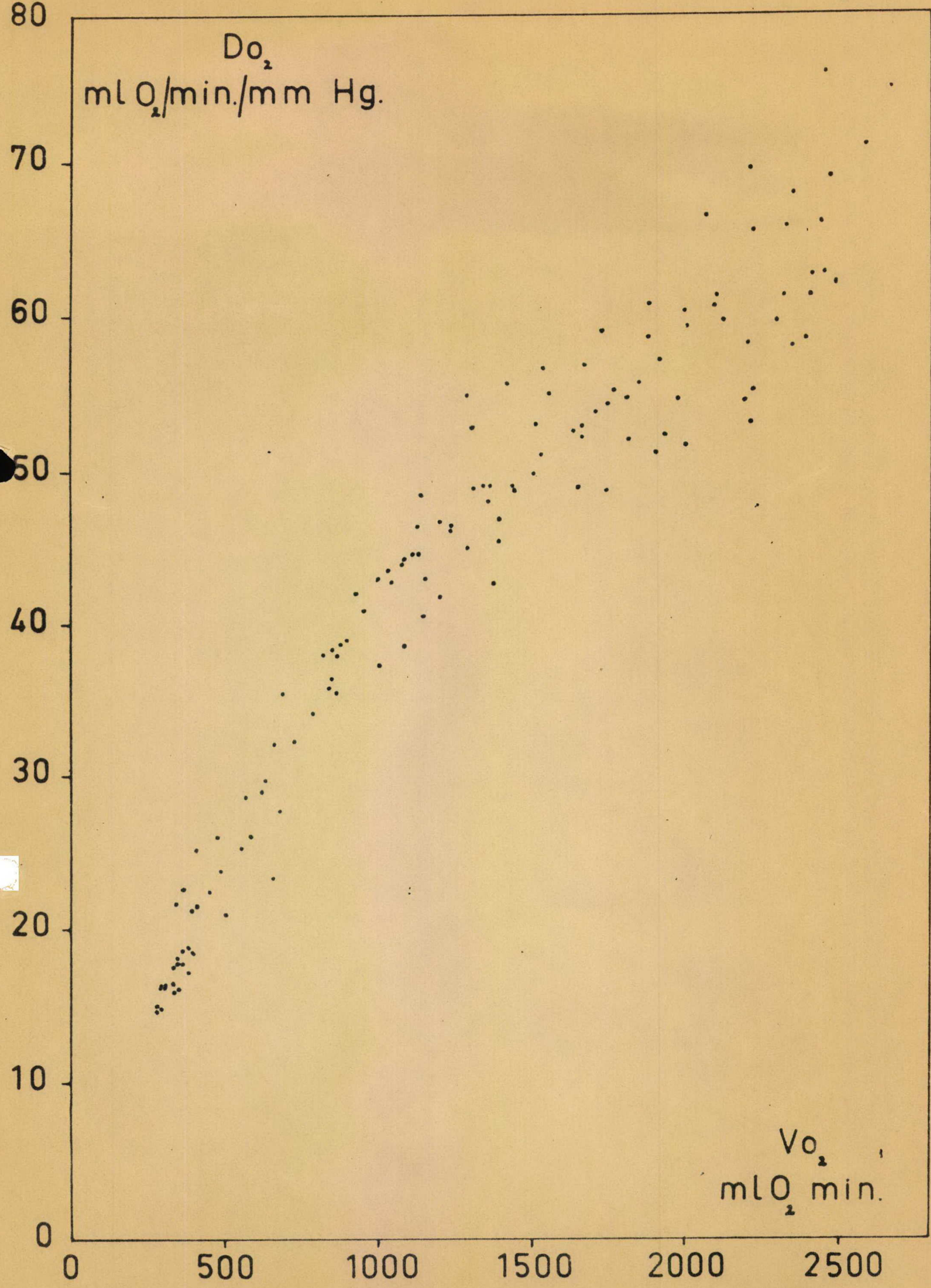

S
%
100
90
80
Sv̄
70
60
50
40
30
20
10
$P_{\bar{c}}$
P_A
10 20 30 40 50 60 70 80 90 100 110 120 130 mm Hg
P_A
P

Fig. 3


80
70
60
50
40
30
20
10
0
D_{O_2}
ml O_2/min./mm Hg.
V_{O_2}
ml O_2 min.
0
500
1000
1500
2000
2500

Kamer Prof. Polman.

Bink, B (Leiden, The Netherlands). A simplified method for the determination of the oxygen diffusing capacity of the lungs.

Modifications have been applied to the standard method for determining the oxygen diffusing capacity of the lung (1) to avoid arterial and mixed venous blood sampling and to simplify the Bohr integration (2). The diffusing capacity is obtained from the relationship $DO_2 = \dfrac{\dot{V}_{O_2}}{PA - P_{\bar{c}}}$

the oxygen consumption is obtained from the continuous analysis of mixed expired air ($\dot{V}O_2$).
The alveolar oxygen tension (PA) is obtained from end tidal air samples fed through a Pauling oxygen-meter. The mean alveolar capillary oxygen pressure ($P_{\bar{c}}$) is found by a graphical solution of the Bohr integration from the alveolar oxygen tension (PA) and the saturation of the mixed venous blood ($S_{\bar{v}}$). $S_{\bar{v}}$ may be expressed in the form

$$S'_c - (S'_c - S_{\bar{v}}), \text{ where } (S'_c - S_{\bar{v}}) = \frac{C'_c - C_{\bar{v}}}{O_2 \text{ capacity}},$$

using the International Terminology (PAPPENHEIMER, 3).
We have found empirically, using the data of DONALD, BISHOP, CUMMING and WADE (4), that the concentration difference between end capillary and mixed venous blood

$$(C'_c - C_{\bar{v}}) = \frac{\text{Pulse fr.}}{\text{Basal pulse fr.}} \times 4.3, \text{ where } 4.3 \text{ is the}$$

assumed value for $(C'_c - C_{\bar{v}})$ under basal conditions (COURNAND, 5).
When this method is used during a 3/4 hour exercise period on a bicycle ergometer with progressively increasing load, the relationship between D_{O_2} and $\dot{V}_{O_2}$ can be obtained for all values of $\dot{V}_{O_2}$.

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4. - Donald, K.W., Bishop, J.M., Cumming, G., Wade, O.L. Clinical Science, 1955, 14, 37.
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