Studies on the Pulmonary Diffusing Capacity and the Pulmonary Circulation with Special Reference to the Haemodynamic Aspects of the Average Contact Time

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THE SO-CALLED average contact time, which may have direct connection with the blood flow in the pulmonary capillary, is discussed in this presentation with special reference to the pulmonary circulation. The referring average contact time is defined to be the average time spent by the blood to pass through the pulmonary capillaries. This average contact time is, of course, considered to be also important to analyze the physiological mechanism of the gas exchange through the alveolar membrane. But, in this present investigations, the authors would like to refer to the dynamic aspects of the average contact time. Although some investigations on the problem through various methods have already been reported, the definite value of the referring average contact time, even in the healthy normal, has not yet been identified. The authors were interested to make it clear in cases with any impaired pulmonary circulation as well as in cases of normal healthy.

THEORETICAL BASIS

The principle of the present investigation is to perform the measurements of the pulmonary diffusing capacity of carbon monoxide simultaneously with the measurements of the effective pulmonary blood flow by the cardiac catheterization.

To estimate the red cell component of the apparent pulmonary diffusing capacity (D_B) it is necessary to repeat the same maneu-

vres of measurement of pulmonary diffusing capacity under the same steady state at any different alveolar oxygen tensions. In this presentation approximately 20 % and 60 % O_2 with 0.1 % carbon monoxide were preferred as for the breathing gas. For the calculation of this red cell component F_2 , introduced by Mochizuki and Fukuoka, was used. F_2 is the velocity constant of the oxygenation including the diffusing capacity inside the red blood cells. If the membrane component of the pulmonary diffusing capacity (D_m) and the pulmonary capillary blood volume (V_c) should not be changed under the referring two different alveolar oxygen tensions, D_B may be expressed by multiplying the effective pulmonary blood flow, F_2 and the average contact time.

$$D_B = [\text{eff. Pulmonary Blood Flow}] \times [F_2] \times [\text{contact time}]$$

In the original paper Mochizuki and Fukuoka did used the cardiac output for the calculation. But in our present paper the effective pulmonary blood flow is used instead of the cardiac output itself. The effective pulmonary blood flow at the same time may also be obtained by multiplying the cardiac output by Fick's method and the rate of the effective pulmonary blood flow. To calculate the rate of effective pulmonary blood flow, the following formula was used.

$$\text{effective pulmonary blood flow}$$

$$= \frac{Ca_{o_2} - C\bar{v}_{o_2}}{\text{ideal } C_{PC_{O_2}} - C\bar{v}_{O_2}} \times 100$$

In cases of normal healthy the rate of effective pulmonary blood flow was estimated to be about 90%.

Hence the so-called average contact time may be calculated if the pulmonary capillary blood volume, haematocrit, and the effective pulmonary blood flow are given by the following formula. The haematocrit of the mixed venous blood was used in this paper instead of the value of the pulmonary capillary blood.

$$\begin{aligned} &\text{average contact time} \\ &= \frac{[Vc] \times [60] \times [\text{haematocrit}]}{[\text{eff. pulmonary blood flow}]} \end{aligned}$$

METHODS AND MATERIALS

On the supine position the tip of the cardiac catheter is placed in the stem of the pulmonary artery under the fluoroscopy. The patients were requested to breathe the indicated gas mixtures for more than 6 minutes under the steady state. The specimens of the arterial- and of the mixed venous blood were taken simultaneously in the last 2 minutes of breathing the gas mixture. The expired gas was also collected during the same period to analyze the concentrations of oxygen, carbon dioxide and of carbon monoxide. The endtidal sampling of the expired gas was also done for the alveolar gas analysis. Then the apparent pulmonary diffusing capacity of the carbon monoxide by the Filley's steady state method may be calculated. The effective pulmonary blood flow at the time may also be obtained.

24 cases, out of which 5 cases were normal healthy, were studied in this present investigation. 13 cases with pulmonary tuberculosis, 2 kyphoscoliotics, 1 cases with giant bulla, with mitral stenosis, and with polycythemia vera were included. The cases without any impaired intrapulmonary distribution of inspired gas were preferred as for the materials because of the theoretical restriction. The impairment of the intrapulmonary distribution of the inspired gas was evaluated by the gas distribution curve.

RESULTS

The average contact time obtained in 5 normal healthy was ranged between 0.3–0.5 sec. In cases with any cardiopulmonary diseases the average contact time revealed various values below 0.5 sec. In some cases the

average contact time did shown the retarded average contact time longer than 0.5 sec. But the authors have excluded those data on the present discussion because it is quite suspicious on their reliability of the average contact time calculated because of their impaired intrapulmonary distribution of inspired gas.

The average contact time and the pulmonary capillary blood volume did shown any positive correlation as far as the present investigation concerns (Fig. 1). The relationship

Fig. 1. Pulmonary capillary blood volume and average contact time

abscissa: average contact time in seconds

vertical: pulmonary capillary blood volume in ml.

between the effective pulmonary blood flow and the average contact time were studied. In 3 cases with the increased effective pulmonary blood flow, significantly short average contact time was obtained. Any correlation between the mean circulation time and the average contact time could not be found. The ratio of average contact time vs. mean circulation time and the ratio of pulmonary

Fig. 2. Blood volume and circulation time

abscissa: ratio of average contact time vs. mean circulation time

vertical: ratio of pulmonary capillary blood volume vs. pulmonary blood volume

capillary blood volume vs. pulmonary blood volume did revealed somewhat positive correlation. The former value represents the circulation time and the latter does the blood volume as the ratio between the pulmonary capillary beds vs. the total pulmonary vascular beds (Fig. 2).

Next the relationship between the average contact time and the pulmonary arterial pressures was studied. Among 11 cases with the normal average contact time over 0.3sec, 9 cases did revealed their mean pulmonary arterial pressure below 15mmHg while only 2 did shown the pressure exceeding 15mmHg. But, 8 cases out of 10, which were accompanied by abnormally short average contact time below 0.3sec, did shown their mean pulmonary arterial pressure exceeding 15mmHg. It may be pointed out that cases with both slightly restricted cardiac output and slightly decreased average contact time between 0.2–0.3sec were accompanied by the pulmonary hypertensions (Fig. 3). It may be said that the cases with abnormally elevated mean pulmonary arterial pressures are often accompanied by abnormally short ave-

Fig. 3. Mean pulmonary arterial pressure and average contact time
abscissa: average contact time in seconds
vertical: mean pulmonary arterial pressure in mmHg

rage contact time. But any significant correlation of the average contact time neither with the systolic nor with the diastolic pulmonary arterial pressure could be found (Fig. 4).

As for the next step of the present investigation the average contact time at rest was studied in relation to the haemodynamic effects of slight exercise. There may be many physiological factors which may have any relation with the exercise tests. There are any restriction to discuss the effect of exercise on

Fig. 4. Pulmonary arterial pressure and average contact time
abscissa: average contact time in seconds
vertical: pulmonary arterial pressures, systolic and diastolic in mmHg. Black lines represent the pressures at the endexpiratory position and broken lines do the pressures at the endinspiratory position

the average contact time in this present paper because the average contact time was only measured at rest and was not measured on exercise. The authors would like to present two typical cases here to propose some problems on the points. Case No. 1 has revealed Dco of 8.2 ml/min/mmHg and case No. 2 did that of 7.4 ml/min/mmHg. Their pulmonary blood volume or their cardiac output at rest did not shown any significant difference with those during exercise respectively. The average contact time was found to be abnormally decreased in both cases, especially in case No. 1.

The response in the mean pulmonary arterial pressure through the exercise was shown significant difference as in Figs. 5 and 6 (Figs. 5, 6). The case No. 1 did not shown

Fig. 5. Effects of exercise. Case No. 1.

Fig. 6. Effects of exercise. Case No. 2.

any significant change in the mean pulmonary arterial pressure on exercise while, in case No. 2, the pressure did shown significant elevation during the exercise of the same degree. The referring reactions on the mean pulmonary arterial pressures through any changes in cardiac output were only seen in cases accompanied both with the restricted pulmonary

capillary blood volume and with the slightly short average contact time. This means the fact that the compensated impaired pulmonary circulation became significant through the exercise. In this present paper the average contact time during exercise was not measured. This would be one of the important problem on which any further investigations be needed.

CONSIDERATIONS AND CONCLUSION

The authors had presented our own methods to calculate the so-called average contact time done on the cases both of normal healthy and with the cardiopulmonary diseases through simultaneous measurements of the apparent pulmonary diffusing capacity and of the effective pulmonary blood flow. The methods presented here could only be applied on cases without any significant impaired intrapulmonary distribution of inspired gas. It has to be made clear that the effects of any unevenness of ventilation-perfusion relationships on the apparent pulmonary diffusing capacity before applying this methods on cases with impaired gas distribution.

The pulmonary capillary blood flow is now revealed to be pulsatile through various methods of investigations. Also in cases with some cardiopulmonary diseases any significant respiratory fluctuations in the pulmonary capillary blood flow may be existed. The average contact time is calculated by assuming the pulmonary capillary blood flow to be as the steady and constant ones. Therefore we have to know the limitation of the detailed discussions on the physiological evaluation of the average contact time. But the authors would like to insist the "raison de être" of our own method of investigation from the clinico-physiological standpoint as one method of approach for the pulmonary capillary haemodynamics.

Some investigators have reported that the average contact time has any physiological importance which represents the decreased pulmonary capillary beds to participate the gas exchange. It is also said that, in such cases with decreased reserved vascular system, the average contact time may reveal small values.

But, as shown in our case-presentation, the results obtained through the exercise tests tells us the existence of so complicated problem that it is difficult to present any definite conclusion in the present situation. As for the cause of the restriction of the average contact time, the authors would like to point out the following items, such as 1) increase in cardiac output, 2) decrease in effective- and/or reserved pulmonary capillary beds, 3) decrease in pulmonary blood volume, etc. Anyway we have to avoid in giving any definite conclusion on what factors may participate the most important role for the referring restriction of the average contact time.

SUMMARY

1) The method of estimating the average contact time through simultaneous measurements on the red cell component of the apparent pulmonary diffusing capacity and the effective pulmonary blood flow.

2) The physiological basis of the present method was introduced.

3) The average contact time in cases of normal healthy was ranged between 0.3–0.5 sec and that in cases of any cardiopulmonary diseases had revealed various degree of restriction.

4) The average contact time has been studied in relation with any haemodynamic factors of the pulmonary circulation and some physiological significance of the average contact time was reported.

5) As for the cause of the restriction of the average contact time, the authors have pointed out the following items: such as a)

increase in cardiac output, b) decrease in effective pulmonary capillary beds, c) decrease in pulmonary blood volume, etc.

6) The importance and necessity of further investigations to give any definite conclusion on the physiological mechanism to cause any restriction of the average contact time was emphasized.

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