Unequal ventilation of different parts of the lung and the determination of cardiac output
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Summary.

This thesis should be considered as an attempt to contribute to the knowledge of the nature of the ventilation of the lungs (Chapters I - XI). At the same time some problems have been examined regarding the determination of the cardiac output with the aid of acetylene. (see Chapter XII).

In Chapter I a summary has been given of the principal publications which are of importance for the study of the character of the ventilation of the lungs. One may find anatomical, pathological and roentgenographic investigations besides publications dealing with the elasticity of the lung tissue and the "negative" intra-thoracic pressure.

In a second group most of the investigations have been mentioned referring to the examination of the composition of the alveolar air.

The third group comprises practically all investigations concerning the mixing in a lung-bag system. The last mentioned publications are for a greater part connected with the determination of the cardiac output. Several conclusions which are to be found in these publications, could be criticized.

Chapter II. In order to obtain a good idea of the different possibilities of the ventilation of the lungs, four diagrams were drawn up, each showing a certain type of ventilation. These diagrams illustrate partly the problem the experiments are referring to; they show successively:

1. a perfectly uniform ventilation of the lungs.
2. an unequal ventilation of the lungs with a consequent stratified inhomogeneity in the alveolar air.
3. an unequal ventilation of the lungs causing a regional inhomogeneity in the alveolar air.
4. an unequal ventilation of the lungs giving cause to a combination of a stratified and a regional inhomogeneity in the alveolar air.

With the aid of these diagrams it was possible to indicate a new criterion of mixing for the lung-bag system fit for practical use. This criterion is suitable for the determination of the cardiac output with Grollmann's method (criterion No. A).

Chapter III. Preparatory experiments. In this chapter it has been demonstrated that the irregularities in the graphs, which represent the course of the gaseous concentrations in the bag and in the alveolar air during the mixing in a lung-bag system, must be due to inhomogeneous composition of the contents of the bag and to the fact that the alveolar samples have not always been taken with the same depth of expiration (see also Chapter X). Therefore it is necessary to choose the bags not larger than is necessary for the depth of respiration. Bulb-shaped bags of rubber dam have been indicated, with which the depth of inspiration and expiration can be made wholly constant. Further a description of three experimental arrangements has been given.

The apparatus shown in Fig. 5 is suitable for the determination of the cardiac output and the residual air and for the investigation of the character of the ventilation of the lungs. This arrangement is based on the principle, used by Grollmann and others.

The apparatus of Fig. 5 enables us to record the depth of the mixing respirations and to eliminate the dead space of the respiratory passages and the apparatus.

The apparatus shown in Fig. 9 forms the transition to the apparatus of figures 11 and 12. Four model experiments were made with the apparatus shown in Fig. 9. These model experiments aimed to prevent a wrong construction of the apparatus shown in Figs 11 and 12.
Chapter IV. An apparatus is described (see Figs. 11 and 12) with which it is possible by means of bulb-shaped bags of rubber dam to make a rebreathing experiment in a lung-bag system, in which the depth of respiration is constant and the alveolar samples are always taken accurately at the end of the expirations. With the aid of mixing experiments made with the apparatus shown in Fig. 11 three original proofs of an unequal ventilation of the lungs are furnished. The lungs are ventilated in principle according to the scheme of mixing nr. 3, that is to say unequally, but without stratified inhomogeneity in the alveolar ducts. The inhomogeneity observed in the alveolar air is of regional nature. The course of the concentration of oxygen in the alveolar air is traced while the subject hyperventilates from a mixture of oxygen of a composition which remains constant.

Chapter V. The influence of the elimination of the dead space on the form of the mixing graphs in the alveolar air and in the bag is ascertained. The smaller the dead space, the more the oxygen graphs in the alveolar air and in the bag approach each other; the sooner the alveolar oxygen graph shows an upward concavity, the more pronounced is this concavity and the less pronounced is the upward concavity in the O₂ curve of the bag.

Chapter VI. An experimental arrangement has been described, with the aid of which it has been possible for the first time to trace the diffusion process in the alveolar air during 45 to 60 seconds (breath-holding experiments). There are parts of lungs which have, and others which have not a demonstrable diffusion contact with each other. The structure of the lung tissue is described with the aid of data from the literature. With the aid of a calculation it has been proved that the inhomogeneity observed in the experiments described, must be of a regional nature. Furthermore it has been proved by means of a calculation that in the alveolar air no stratified inhomogeneity worth mentioning can exist.

Chapter VII. During the expiration the ventilation ratio changes in favour of the less well-ventilated parts of lungs. After a deep expiration the poorly ventilated parts of all parts of lungs are filled best at the beginning of the inspiration. In the further course of the inspiration the better ventilated parts of lungs predominate. During this further course a modification in the ventilation ratio in favour of the less well-ventilated parts takes place. The modification of the ventilation ratio becomes very irregular at the end of a deep expiration.

Chapter VIII. The inequality of the ventilation of the lungs decreases in our experiments according as the value of the ratio depth of respiration / lung volume increases, and vice-versa. So, it is very likely that with normal breathing in rest, the depth of respiration amounting to about 400 c.c., the inequality of the ventilation is most pronounced (see tables in Chapters VIII and X).

The ventilation of the lungs even during a maximum inspiration following a maximum expiration, is not equal.

Chapter IX. Some experiments give the impression that the best ventilated parts of lungs are best perfused with blood. The alveolar air is during the normal breathing in rest not homogeneous in composition. It is not known how great the differences in the concentrations are.

Chapter X. On the strength of the experiments in 4 subjects the conclusion may be drawn that there exists a clear influence of the type of respiration on the inequality of the ventilation of the lungs. By changing the type of respiration, special parts of lungs can be ventilated best at will. The view of Keith and Weber, who suppose the upper lobe to be ventilated by the sternocostal and the lower lobe
by the costo-diaphragmatic mechanism is incorrect. The interpleural pressure must show local differences.

The view of Tendeloo, Keith, Sonne and Roelsen regarding the ventilation mechanism of the lungs is in general confirmed in this thesis.

By changing the sitting into the recumbent posture the reserve air decreases greatly and the type of respiration changes. Probably the ventilation in recumbent posture becomes less equal.

Chapter XI. The criteria of mixing indicated in the literature have been checked on their correctness. The criteria 1, 5, 6 and 8 and the criterion M are correct theoretically. The criteria 2, 3, 4, 7, 9, 10 and 11 are incorrect. The formulation of the criteria is found at the beginning of Chapter XI.

Chapter XII. The significance of the experiments described in this thesis for the determination of the cardiac output is discussed. A survey of the different views regarding the problem of recirculation is given. If one makes a maximum expiration and thereafter rebreathes deeply in a bag, the mixture in the lung-bag system is after 3 to 4 respirations sufficiently homogeneous.

The duration of the mixing is ceteris paribus dependent upon the depth of respiration, the lung volume and the respiratory frequency, and may be reduced to a few seconds.

The recirculation takes place during the rebreathing from a bag about 20 seconds after the beginning of the hyperventilation.

During the hyperventilation the $O_2$ line of the bag contents falls in a rectilinear way after about 10 seconds till the moment of recirculation. It follows that during that time the $O_2$ content of the venous blood and the cardiac output remain constant.

With a normal determination of the cardiac output, according to Grollmann's method, it is not necessary to eliminate the dead space. For checking errors in the mixing or through recirculation it is desirable to take at least three bag samples at equal intervals and to use criterion M.A. and criterion of mixing 4.

During the rebreathing in a bag the cardiac output is about doubled. The specifications of Grollmann regarding the value of the cardiac output in rest are confirmed (cardiac index $2.2 \pm 0.3$ litres).

Chapter XIII. The significance of the experiments described in this thesis for the knowledge of the nature of the ventilation of the lungs and for determination of the cardiac output, is, together with several data from the literature critically discussed.