THE RESPIRATORY CHANGES OF PRESSURE AT THE VARIOUS LEVELS OF THE POSTERIOR MEDIASTINUM.[1]

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PLATE III.

INTRODUCTION.

Some pathological phenomena manifest a predilection for certain parts of the lungs. Emphysema, for instance, occurs preferably in the peripheral parts of that organ. Tuberculosis, on the other hand, shows a predilection for the apices. Furthermore, in experimental pneumonoconiosis, India ink or ultramarin seem to lodge first in the cranial part of the upper lobes. Are these preferences founded on, or at least favored by, some differences in the respiratory capacity of the various parts of the lungs? For the preference of tuberculosis, such an assumption was made indeed by various clinical writers. In the prebacterial period, it was simply assumed that the apices of the lungs participate in a lesser degree in the respiratory movements and that their ventilation is, therefore, not as satisfactory and the resistance to disease not as good as that of the rest of the lungs. However, with the advent of the tubercle bacillus, especially from the point of view of the theory of the aërogenous origin of tuberculosis, such an assumption manifestly made matters even more difficult; the diminished inspiration in the apex would be rather a hindering than a favoring factor in the invasion of the bacilli. To meet this difficulty Hanau[2] tried to adapt the hypothesis to the new requirement by assuming that the inspiration is better in the apex than in the rest of the lung, but that the expiration is not as good. Such an arrangement would indeed have the tendency to retain easily some of the invading bacilli. But Meltzer[3] called

[1] Received for publication September 17, 1909.

[2] Hanau, *Zeit. f. klin. Med.*, 1887, xii, 1.

[3] Meltzer, *Jour. of Physiol.*, 1892, xiii, 218.

attention to the intrinsic impossibility of such a hypothesis. No part of the lung can persist when air enters into its vesicles with better facilities than it can leave them; the vesicles would break in no time. Furthermore, the question arose as to the correctness of the assumption that the apices participate in the act of respiration in a manner different from the rest of the lungs. What basis was there for such an assumption? The question whether all parts of the lungs take an equal share in the act of respiration is a physiological problem. The discussion of this problem in the physiological literature was only very scanty, but the opinion of the few writers who have dealt with that subject was rather the reverse of that of the clinicians and the pathologists. Rosenthal[4] states that despite the fact that the greatest motion of the lungs occurs at their lower (caudal) part, each vesicle of the entire lung increases (or collapses) in the same degree. He compares the lung to a strip of elastic rubber, the one end of which is fixed, while the other end is stretched. The degree of stretching is the same at all parts of the band, although the visible motion seems to take place only at the stretched end. These, however, were only *a priori* opinions which were not supported by any experimental tests. Meltzer tried to approach this subject by the experimental method. The result of this investigation was published seventeen years ago.[5] The most satisfactory answer to the question whether all parts of the lungs respire in the same manner would be obtained if the intra-pulmonary pressure prevailing in all parts of the lungs could be studied and compared. This answer is impossible, at least for the present. The next best method would be a comparison of the intrathoracic pressure prevailing in all parts of the thoracic cavity during the respiratory changes. An attempt to study it in the pleural cavity by the methods then at hand failed. The posterior mediastinum was then attacked. A comparison of the pressures prevailing at the various heights of the esophagus gave unsatisfactory results. Meltzer finally settled upon a new path for exploration of the respiratory pressure in the posterior mediastinum; it is the path which is sometimes unfortunately selected by the retropharyngeal abscess.

[4] Hermann's Handbuch der Physiol., 1882, iv, pt. 2, 180.

[5] Meltzer, *loc. cit.*

A calibrated narrow tube, one end of which was connected with a manometer or a kymograph, was carefully and slowly pushed behind the esophagus down the entire depth of the posterior mediastinum. This was done in rabbits. These experiments gave definite and even surprising results. In the upper part of the thorax the inspiratory decrease of pressure was very little marked. Testing if further down, the decrease of pressure during inspiration increased either gradually or abruptly. In some thirty per cent. of the experiments, in pushing the tube down a short section was encountered in which the inspiratory changes became insignificant again. In the last (caudal) third of the mediastinum, the inspiratory decrease of pressure was in all experiments well marked and of uniform extent throughout the entire section. In many of the experiments the lungs were watched through a window made in the intercostal muscles. It was thus established that the sudden rise of the negative pressure in the mediastinum was not coincident with any change in the position of the lung in the pleural cavity.

It was thus demonstrated that the upper (cranial) part of the mediastinum reacts differently to the effect of an inspiration than the lower (caudal) part. While this seemed to be a well secured fact, Meltzer nevertheless hesitated to commit himself to the interpretation that the diminished inspiratory negative pressure in the upper part of the mediastinum means positively a diminished intrapulmonary pressure in the upper part of the lungs during inspiration. He calls attention to the presence in the upper third of the mediastinum of such bulky organs as the venæ cavæ, the aortic arch, the tracheal bifurcation, etc., which may account for the lagging behind of this part of the mediastinum in the adequate response to the inspiration. Meltzer concludes by saying: "Although it seems to me that my experiments on the mediastinum make it indeed probable that the apices and the back part of the upper third of the lungs do not participate in the breathing so largely as the other parts of the lungs, in consideration of the importance of this conclusion, we should not consider it as proven until it has been tested by experiments on the pleural cavity directly, or within the lungs themselves."

Recently the subject of the respiratory changes of pressure in the various parts of the lungs has been dealt with extensively by N. Ph. Tendeloo in journal articles, addresses and in a book especially devoted to that question.[6] Tendeloo is of the opinion that any change in the intrapulmonary pressure of one part of the lung does not necessarily cause an intrapulmonary pressure in any other part of it, and he is emphatic in the assertion that the cranial and paravertebral parts of the lungs take a lesser share in the respiration than the other sections of the lungs. He supports his views by extensive arguments based on a fine analysis of known physical, anatomical and pathological facts. As to the experimental evidence of a physiological nature, Tendeloo has at his disposal only the above mentioned results of Meltzer, which, in disagreement with this author, Tendeloo thinks are absolutely convincing that the respiratory changes in the intrathoracic pressure are not the same in the entire thoracic cavity, but are diminished in the superior-posterior direction.

While the present writers were also inclined to believe in the correctness of the hypothesis that the normal respiratory changes of pressure are not the same in all parts of the cavity, they were of the opinion that, despite the experiments of Meltzer and the interesting arguments of Tendeloo, this hypothesis can not be considered as proven and that further investigations contributing to the elucidation of that problem is still very desirable. By bringing forward step by step some well established new facts, be they ever so small, it may so happen that the problem will be solved some day on a safe basis. In the following we intend to offer such an experimental contribution of modest dimensions.

THE EXPERIMENTAL CONTRIBUTION.

Method.—It has already been mentioned that the esophagus offers a natural path for the study of the intrathoracic pressure. This method, however, was discarded by different investigators for various reasons. In the first place, the thickness of the wall of the

[6] Tendeloo, Studien über die Ursachen der Lungenkrankheiten, Wiesbaden, 1902. Address at the meeting of the Gesellschaft Deutscher Naturforscher und Aerzte, Dresden, 1907. International Congress of Tuberculosis, Washington, 1908. *Med. Klin.*, 1909, v, 1300.

esophagus does not permit one to draw a conclusion regarding the actual respiratory pressure in the thoracic cavity. Secondly, the presence of the tube within the esophagus acts as a foreign body and causes irregular local contractions of that tube, thus obscuring the respiratory changes. Occasional peristaltic contractions due to deglutition add to the confusion. Furthermore, the occasional opening of the cardia and regurgitation of air or liquid into the esophagus is another disturbing factor. Finally, the presence of mucus in the esophagus coming from above might cause an obliteration of the "windows" in the tube within the esophagus, or might cause a stickiness of the rubber capsule, if such is used, and hamper its responsiveness to the changes of the respiratory pressure.

Notwithstanding these objections, we decided to try the esophageal method again. The first objection does not hold good for the present experiments, since we did not study the actual pressures obtaining within the thoracic cavity; we intended only to compare the pressures prevailing in the upper and the lower parts of the posterior mediastinum. For this purpose the thickness of the wall of the esophagus can be no obstacle as long as the thickness is practically the same throughout the thoracic part. As to the other objections, we met them by the following arrangements: In the first place both vagi were cut in the neck which eliminated the tonicity and possible contractions of the esophagus. Then the esophagus was tied in the upper part in the neck and beneath the diaphragm, thus preventing the entrance of mucus from above and of gas from below. The esophagus presented then a closed sausage-shaped soft bag fitted into the posterior mediastinum and readily responding to the changes of pressure within it. Through a small opening made beneath the cervical ligature a catheter was introduced into the esophagus and again a ligature was tied around the esophagus beneath the opening in order to prevent the entrance of air. This ligature, however, was not made too tight to prevent the catheter from moving up and down. The side openings of the inner end of the catheter were either free or had a small bag of thin rubber, a thin finger cot, tied around them. The outer end of the catheter was connected by means of rubber tubing with a Marey's tambour which transmitted the respiratory changes of pressure within the esophagus to a kymograph in the usual manner. A T-tube connected with a stopcock was inserted in the tubing for the regulation of the pressure within the system, when necessary.

Dogs were used in this series of experiments. On account of the section of the vagi the animals were tracheotomized. They were narcotized with morphine and ether; in some cases magnesium sulphate, by intramuscular injection, was given instead of ether. It is important for the success of the experiment that the respirations should be neither too shallow nor too deep (dyspneic). On account of the section of the vagi, respiration is apt to be too deep. A carefully conducted anesthesia helps greatly in regulating the respiration.

Results.—The results which were obtained were strikingly uniform. The increase of the negative pressure during inspiration was studied extensively. At the beginning of the study of a new level of the esophagus the inspiration started from the atmospheric pressure. This was accomplished by opening the stopcock connected with the tubing and closing it during the expiratory pause. In this way we obtained a series of tracings presenting normal inspirations for each level of the esophagus. At the autopsy, the location of these levels and their relations to the neighboring organs were established.

In general, the esophagus may be divided into three sections. In the uppermost part of the first section the inspiratory undulations are quite small, but they increase, more or less gradually, with the depth of that section. In the next section the undulations become again very small, but increase more or less gradually when the end of that section is approached. Then follows the third section in which the undulations abruptly become large and practically remain so to the end of the section. Any inspiratory undulation of this section is distinctly larger than any undulation in the first section.

The first section extends from the thoracic aperture to the level corresponding to the bifurcation of the trachea. The second section extends from the bifurcation to a level corresponding to about the apex of the heart. The third section extends to the diaphragm. When the small balloon approaches the passage of the esophagus through the hiatus of the diaphragm, the undulations become very small, even if the cardia is not tied. In other words, the reduction in pressure within the thoracic esophagus due to normal inspiration is small at the level of the apex, but increases gradually until it reaches the level of the bifurcation, where it becomes considerably reduced again or may even disappear completely. While the balloon passes the level of the heart, the inspiratory reduction of pressure may more or less gradually increase again. However, as soon as the balloon emerges from opposite the apex of the heart the inspiratory negative pressure reaches its maximum abruptly and remains so until the diaphragm is encountered. In brief, the inspiratory changes within the thoracic esophagus differ greatly with the different levels; the changes are most pronounced at the caudal part and are only moderate opposite the apex of the lungs, while opposite the tracheal bifurcation and the heart the changes are very small.

These differences in the inspiratory changes remain practically the same even with a one-sided pneumothorax; with a double open pneumothorax there are practically no respiratory changes within any part of the esophagus.

With open double pneumothorax and artificial respiration the inspiratory changes are the same in the upper and the lower part of the esophagus, but are considerably lessened in the middle part. The increase of pressure is, of course, positive with each inspiration, when the artificial respiration is carried out by blowing air into the trachea. In one case, artificial respiration was carried out immediately after death by rhythmically pulling the diaphragm (liver) downward. In this case the inspiratory changes of pressure within the esophagus were the same as in normal respiration.

In dyspnea, when the inspirations are very deep, there is practically no difference in the respiratory changes at the various levels of the esophagus.

The expiratory changes within the esophagus were not studied with the same attention as the inspiratory changes. From what we have observed we may conclude that all that was said for the inspiratory pressure holds good also for the expiratory changes in pressure at the various levels of the esophagus.

DISCUSSION.

The esophagus is a natural path. In the way it was prepared by us it presents a closed canal with passive responsive membranes fitted lengthwise into the posterior mediastinum. There is no room for doubt that the changes of pressure which were found to occur at the various levels represent actual conditions within the esophagus and are not accidental artefacts. It was found that the changes of pressure accompanying the normal respiratory phases were invariably smaller in the upper than in the lower part of the thoracic esophagus and that at a certain middle part the changes were smaller than at either end. That demonstrates, in the first place, that in normal respiration each section of the esophagus presents a separate compartment, and respiratory changes in pressure in this compartment are not transmitted, at least not in full force, to any distant part of the cavity of the esophagus. We may, therefore, take the changes of the respiratory pressure which take place in each segment of the esophagus as an expression of the respiratory changes which take place in the corresponding segment of the adjacent cavity outside of it, that is in the first place in the various segments of the posterior mediastinum. Our experiments, therefore, prove first, that the respiratory changes in the posterior mediastinum are much larger in the lower than in the upper part. This corresponds exactly with the findings of Meltzer, who studied the mediastinum by an artificial path which invited the objection that the finding might have been an artefact. The full agreement between the two findings gives the result the assurance of a well-established fact.

It was found further that in all cases of normal respiration at the beginning of the middle third of the esophagus the respiratory changes were the lowest. In Meltzer's investigation this occurred in only about thirty per cent. of the experiments. The discrepancy may be due to the fact that the artificial path made in the last mentioned experiment varied perhaps in its course; or it may be because in rabbits, upon which these experiments were made, the conditions differ from those obtained in dogs. At any rate, it is a well-established fact that in dogs, at the level of the bifurcation and a little further down, the respiratory changes are less manifest than at any other place within the thoracic esophagus.

We are then sure that within the posterior mediastinum the respiratory pressure varies in various sections of the mediastinum. What is the cause of these variations? Can this mean that there is a corresponding variation in the degree of respiration in the parts of the lung adjoining these sections? With reference to the reduced changes in the respiratory pressures in the section of the mediastinum occupied by the tracheal bifurcation and the heart, we may readily answer that it is not due to a reduced respiration in the corresponding parts of the lungs. It is rather probable that the inelastic bulky tissues of the bifurcation and the heart which separate the esophagus (and posterior mediastinum) from the corresponding part of the lungs prevent the full transmission of the respiratory changes. This plausible interpretation is borne out by the fact that even the inspiratory positive pressure produced by the intratracheal artificial respiration is not well transmitted at the level of the esophagus adjacent to the bifurcation and the heart; it can not be assumed that these parts of the lungs can not be reached by the artificial respiration as well as any other part.

It is different, however, with regard to the diminished respiratory changes in the esophagus and mediastinum in the proximity of the upper part of the lung. Here the lung is not separated from the mediastinum by any specially resistant tissues and here we find that in artificial respiration the respiratory changes are in the upper part, indeed, of the same magnitude as in the lower part. We, therefore, assume that the difference in the respiratory changes between the upper and the lower part in the mediastinum has its origin in the fact that the respiratory changes within the lungs themselves are in the upper part not as extensive as in the lower part. This difference cannot be due to any difference in the elasticity in the different parts of the lungs, since artificial respiration distends all parts of the lungs apparently in the same degree. It is rather probable that the change of the respiratory pressure which is brought about by the change of position of the diaphragm and the ribs, and which begins at the caudal part of the lungs, loses a part of its force on its way to the upper part.

That in very deep, dyspneic respirations the changes in pressure become equal at all levels of the esophagus finds its explanation in the plausible assumption that by very deep inspirations the lumen of the esophagus becomes sufficiently opened up so as to convert the entire thoracic esophagus into a well connected canal.

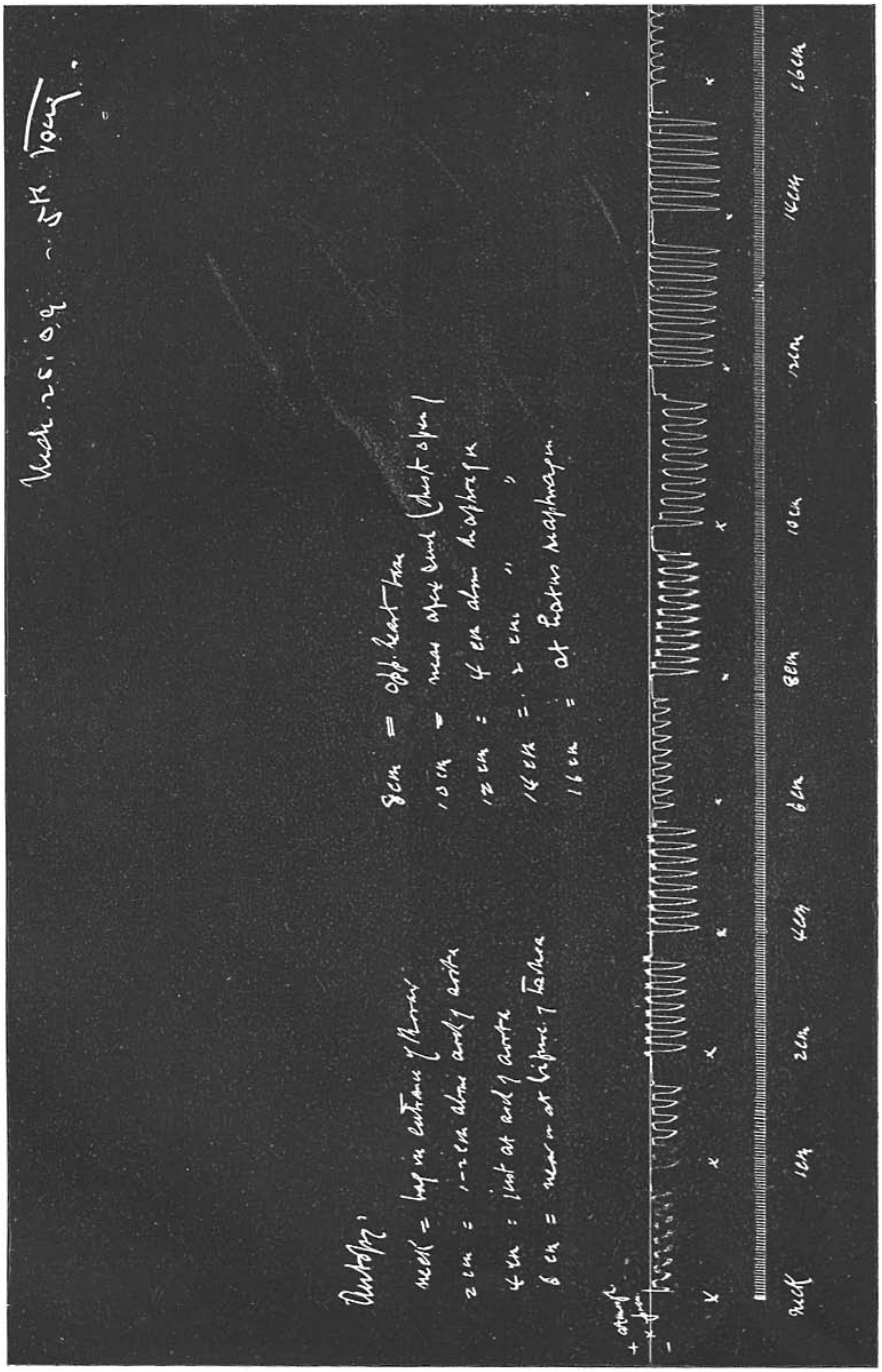
SUMMARY.

The changes of the respiratory pressure within the esophagus, as well as within the posterior mediastinum, differ greatly in their various levels. They are best in the section between the heart and the diaphragm; they are moderate from the upper aperture of the thorax to above the tracheal bifurcation, and they are very much reduced in the region of the bifurcation and the heart. In the latter case the normal respiratory changes are reduced in their transmission to the mediastinum by the intervention of the inelastic tissues of the bifurcation and the heart. The difference in the changes of the respiratory pressure between the lower and the upper part of the mediastinum is due to a difference in the respiratory changes of pressure between the lower and upper parts of the lungs. The changes in the respiratory pressure which begin in the lower part of the lungs lose some of their force on their way to the apices of the lungs. In artificial respiration by intratracheal insufflation there is no difference in the respiratory pressures between the upper and the lower parts of the lungs.

This investigation supports the view, frequently entertained by clinicians, that the respiratory changes in the apices of the lungs are not as good as those of the rest of the lungs, and it disproves the claim of some physiologists that a decrease or increase of pressure at any part of the lungs must be equally distributed through all parts of the lungs, a claim based upon merely *a priori* physical considerations.

EXPLANATION OF PLATE III.

This tracing shows the respiratory changes of pressure obtained by means of a balloon-tipped sound from different levels of a dog's esophagus. With each change of position of the sound, atmospheric pressure, shown by the straight horizontal line at the top of the curve, was reëstablished during expiration; above this line is positive pressure, below is negative. Downstroke represents inspiration. Time is marked in seconds.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