A Contribution to the Study of the Mechanism of Respiration, with Especial Reference to the Action of the Vertebral Column and Diaphragm.

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In studying the alterations which occur in the shape, size, and position of the internal organs as the result of their functional activity, previous observers have worked at a disadvantage. During the past nine years X-rays methods, though indicating an advance in our knowledge of abdominal and thoracic visceral movements, have not been of absolute utility, since the rays, being divergent, produce magnification of the shadow of the object. Hence, exact measurements have been unattainable.

In the present investigation the chief results have been obtained by means of Groedel's orthodiagraph, which Dr. Hugh Walsham and myself have been the first, to our knowledge, to work with in this country, and of which we have already published a detailed description.* By means of this instrument it is possible, with almost mathematical accuracy, to measure motionless objects which lie in a plane parallel with the vertical transverse plane of the body, and to measure moving objects with greater approach to exactitude than can be obtained in any other manner.

Summary of the Results of the Investigation.

I. *Results obtained by Orthodiagraphic Measurement of Changes in the Trunk which occur during Respiration.*

One hundred healthy subjects, of ages varying between 15 and 35, were examined, the average measurements being recorded as follows :—

(1) The neck is shortened 10 mm., and widened, on the right side 9 mm., on the left side 7 mm.

(2) The shoulders are raised on the right side to a greater extent than on the left, the average on the right being 16 mm., that on the left 14 mm.

(3) The presternum moves 30 mm. in an upward, and 14 mm. in a forward, diameter.

(4) The clavicles execute a combined upward, forward, and outward

* 'Brit. Med. Journ.,' September 14, 1907, p. 651.

movement, the vertical range of their inner ends on the right side being 28 mm., on the left side 27 mm.; of their outer ends, on the right side 21 mm., on the left side 16 mm. The divergence from the median line is, on the right side 7 mm., on the left side 6 mm.

(5) The meso-metasternal articulation either may remain in the same horizontal plane, or may rise as much as 46 mm. The average ascent is 28 mm.

(6) Widening of the infra-costal angle occurs, the interval between the costal margins, measured on each side at a level of 30 mm. below the meso-metasternal articulation, being increased by 26 mm.

(7) The trunk is widened at the level of the meso-metasternal plane 9 mm. on the right side, and 8 mm. on the left, and midway between the meso-metasternal plane and lowest point of the costal margin 9 mm. on the right side, and 11 mm. on the left.

(8) The umbilicus is retracted and drawn upwards in deep respiration for a distance of 13 mm., on account of the active recession of the abdominal wall produced by the contraction of the abdominal muscles, which, in this phase of respiration, act as antagonists of the spinal muscles. The upward displacement of the umbilicus is usually to the right, but may be median or to the left, the lateral deviation being 7 mm.

(9) The heart and pericardium together undergo important changes in size and position as a result of the respiratory movements, being lengthened and narrowed in inspiration, shortened and widened during expiration.

(10) The pericardium, at the level of its attachment to the central tendon in the adult, measures 80 mm. in antero-posterior diameter.

II. *The Movement of the Vertebral Column in Respiration.*

I can find no reference to this movement in eight of the latest and best known text-books of physiology. That this movement is actual and of mechanical advantage in breathing can be verified by visual and orthodiagraphic examination. In the latter the subject is rotated through an angle of 30° to 45° into the "lateral oblique" position. The shadow of the vertebral column is seen clearly separated from that of the pericardium and great vessels by a transradiant triangle, the base of which is formed by the upper surface of the diaphragm. On inspiration the posterior wall of this triangle, formed by the vertebral column, recedes, to a greater extent below than above, and so opens out the interval from before backwards. With subsequent expiration the spine advances.

Explanation of the Spinal Respiratory Movement.—A general rectification of the curve of the thoracic spine takes place. In eight orthodiagraphic

examinations of healthy adults, in deep inspiration, the average antero-posterior range of movement was as follows:—

At upper aperture of thorax opposite 1st thoracic vertebra, 6 mm.

Midway between upper aperture of thorax and level of diaphragm opposite 5th thoracic vertebra, 7·5 mm.

At level of posterior part of diaphragm opposite 10th thoracic vertebra, 9 mm.

These measurements show that on the average the spinal column is most displaced towards the lower part of the thoracic curvature, and that rectification lessens from below upwards. Individual differences, however, are not infrequent. This straightening, which occurs especially in that segment of the spine which articulates with the 6th, 7th, 8th, and 9th ribs, happens as a consequence of the backward push of the sternal ribs when the sternum is raised upwards and forwards by contraction of the cervical and thoracic muscles, thus bringing a larger costal arc into the place previously occupied by a smaller one, and so increasing the antero-posterior diameter of the thorax. Upon the ribs assuming a position of less obliquity, the spinal column, being far more limited in its possible range of movement than the sternum, on account of its multiple attachments can only execute a fraction of the sternal movement. Towards the end of inspiration, as the movement of the sternum reaches its dynamic limit, the remainder of the force of the respiratory cycle is spent upon the spine, which accordingly, during the latter half of inspiration, shows progressive mobility.

In the lateral oblique position the apparent movement of the vertebral column is 6 to 9 mm.; the real movement may be readily calculated by means of a mathematical formula.

Importance of the Spinal Movement.—The antero-posterior enlargement of the thoracic cavity produced by simultaneous extension of the thoracic vertebræ in deep breathing has an important influence upon the aeration of the apices of the lungs, the forward and upward movement of the thorax, together with backward movement of the spine, being of far greater value than the lateral movement in promoting free access of air.

III. *Anatomical Dissimilarity of the Two Halves of the Diaphragm.*

Anatomically the two halves of the diaphragm differ in size and shape, the right half being the larger and the more powerful, the reason being that this half has to overcome the resistance of the mass of the liver, whereas the stomach is much more easily compressed by the left half. Functionally, although the two halves of the diaphragm are of unequal size and strength, yet, owing to the difference in resistance on the two sides, their range of

movement is but little dissimilar, the difference, if any, being usually in favour of the right half.

IV. *The Means by which the Diaphragm is supported.*

In another paper I have dealt with the superior, or thoracic, and the inferior, or abdominal, supports of the diaphragm.

V. *Level of the Diaphragm.*

(1) *After Death.*—The cadaveric position of the diaphragm indicates only the position of expiration. From the results of an examination of 80 dissecting-room and post-mortem-room cases, I find that the average highest point of the dome of the diaphragm is situate, on the right side at the level of the upper border of the 5th rib in the mid-clavicular line; on the left side, in the mid-clavicular line at the lower border of the 5th rib. This corresponds with the results of orthodiagraphic measurement in bodies of healthy persons who have met with sudden death.

(2) *During Life.*—Owing to the great variability in position of the landmarks usually adopted in measuring the range of the diaphragm, I have taken the meso-metasternal articulation, *i.e.*, junction between gladiolus and ensiform, as the basis from which to measure, and a line drawn horizontally through this point—the meso-metasternal plane—as the plane to which the level of the rise and fall of the diaphragm may be referred, and all orthodiagraphic measurements of the position of the domes and central tendon have been taken in millimetres above and below this plane.

VI. *Absolute Range of Movement of the Diaphragm.*

The absolute range of movement of the diaphragm between deep inspiration and expiration in the adult male is, on the right side 34 mm., on the left side 32 mm. The range in adult females amounts to 27 mm. on the right side, and 25 mm. on the left side, making the total average range 30 mm. on the right side, and 28 mm. on the left.

The fact that these figures are only about half as great as those previously given* is due to the greater accuracy of orthodiagraphic measurement. In quiet respiration the total average movement is 12·5 mm. on the right side, and 12 mm. on the left. Hence this movement is approximately equal on the two sides, whilst in deep breathing, the excursion is, for most people, slightly greater on the right side than on the left. In diagnosis, the movement in deep respiration is the important one to observe.

* The 'Lancet,' June 27, 1903, p. 1802.

VII. *The Costo-phrenic Pleural Reflexion.*

According to the surfaces with which it is in contact the parietal layer of the pleura conveniently may be divided into costal, diaphragmatic, and mediastinal portions. The foldings of the pleura constitute three marginal grooves or recesses:—

1. Pericardio-phrenic groove.
2. Pericardio-sternal pleural reflexion.
3. Costo-phrenic pleural reflexion.

1. *The pericardio-phrenic groove* is a shallow recess formed at the junction of the pericardium with the diaphragm, and lodges the plicæ adiposæ.

2. *The pericardio-sternal reflexion* forms the anterior marginal pleural recess.

3. *The costo-phrenic reflexion* must be considered in greater detail, since it facilitates to such a marked extent the action of the diaphragm. It is formed by the meeting of the costal and diaphragmatic portions of the pleura, and, beginning at the lower border of the 6th rib close to the termination of the gladiolus, it passes downwards and outwards, reaching the lateral aspect of the spinal column at the lower border of the twelfth thoracic vertebra. Practically the limit to which the lung descends in ordinary inspiration marks its upper boundary. Here, owing to friction between the pleural surfaces, a line of demarcation, best seen in the recent state, indistinct in the young child, but increasingly definite with advancing age, gradually forms. If evidences of pleurisy are present, not infrequently a ridge of organised lymph, concave on its upper surface, delimits the lower lung margin, forming a groove into which the lung fits. The lower border of the reflexion is wavy or festooned, the festoons being in relation with the intercostal spaces. In a series of 20 male and female subjects, of ages varying from 18 to 56 years, who had died from causes not involving the lungs, the average depth of the costo-phrenic reflexion, measured in the mid-axillary line from lower margin of lung to lowest limit of pleural cavity, on the right side was found to be 8·62 cm., and on the left side 8·34 cm. The greatest interval in the series was 11 cm. on the right side (corresponding to 9 cm. on the left), and the smallest, 5 cm. on the left side (corresponding to 6 cm. on the right). In a female infant aged three months the depth of the reflexion on the right was 1·5 cm., and on the left 1·4 cm.

Function of the Costo-phrenic Pleural Reflexion.—The two serous surfaces constituting the reflexion remain in apposition for a distance varying with inspiration and expiration, and are not separated until the wedge-shaped

lower lung margin glides downwards in inspiration and insinuates itself between them. As the lung recedes the surfaces again come together. The diaphragmatic pleura, owing to its elasticity, accommodates itself to contraction of the diaphragmatic circumferential muscle-fibres, and its smooth surface allows it to glide easily over the apposed costal layer, which is fixed in such wise that it cannot be displaced. Owing to negative intra-pleural suction and positive intra-abdominal pressure, together with molecular cohesion of the lubricated pleural surfaces, the pleural union thus formed is of sufficient strength to bind the diaphragm during its action closely to the chest-wall, and, moreover, is of mechanical advantage to the diaphragm, since in function it resembles the band or loop through which a muscle acts in order to change the direction of its line of force.