ON THE
RESPIRATORY MOVEMENTS IN MAN,
WITH AN
ACCOUNT OF A NEW INSTRUMENT FOR MEASURING
THE MOVEMENTS OF THE CHEST.

BY
ARTHUR RANSOME, M.D., M.A. CANTAB.,
CONSULTING SURGEON TO LLOYD'S HOSPITAL, ALTRINCHAM.

COMMUNICATED BY
WILLIAM OGLE, M.D., OF DERBY.

Received November 11th—Read November 12th, 1872.

THE various movements of breathing have often attracted the attention of observers of the different actions of the human body. Non-medical writers have spoken of their significance as signs of the various emotions. Physiologists and physicians have found in them evidence either of healthy function or of disease.

Diversities in the movements of respiration are often too obvious to require an "experienced eye" or a "practised hand" to detect them. We need only to watch the quick panting breathing of children at play, or their breasts heaving with convulsive sobs, to notice the deep inspirations of professional singers, or the fully expanded, almost motionless, chest of an expectant athlete; and, on the other hand,

a student of disease would readily compare the quick short breath of a consumptive patient with the laboured action of the rigid chest of an asthmatic.

All these variations in the working of the mechanism of the chest are sufficiently plain without the aid of instruments of measurement, but something more is required when they become the subject of careful study. Dr. Whewell has well said "the reference of objects to exact ideas of space, number, position, motion, and the like, is the first step in science." Before we can hope, therefore, to attain to a scientific knowledge of these movements, and of the mode in which they are produced, exact numerical records of their extent under different circumstances are required.

Many attempts have been made to obtain these data, and very various instruments have been devised for the purpose.

Woillez and Piorry simply measured the circumference of the chest with an unyielding band, marking with ink the points corresponding to the middle of the sternum and the spines of the vertebræ.

Chomel and Walsh, Hirtz and Wintrich, used graduated tapes. Montault combined this with a plessimeter and stethoscope, and Dr. Stokes employed callipers with which to measure the different diameters of the chest.

Woillez¹ also invented an ingenious instrument, which he named the "Cyrtomètre," consisting of a jointed band of whalebone, which so retained the shape of the chest that its curves could be transferred to paper, giving correct diagrammatic representations of the contour of the two sides. Woillez was sanguine enough to think that by means of this instrument he could show variations in the perimeter, or in the antero-posterior diameter, at different epochs of such maladies as pulmonary congestion, coming on in the course of acute febrile disorders, in all acute thoracic affections, in eruptive fevers up to the appearance of the rash, and in advancing pleuritic effusions.

* 'Rech. pratiques sur l'Inspection et la Mensuration de la Poitrine.' Paris 1840.

Various stethometers have also been devised by Drs. Wintrich, Quain, and Leared. Dr. Sibson has employed his well-known chest measurer, and Dr. Burdon Sanderson his ingenious stetho-cardiograph. Much valuable information has undoubtedly been the result of all these investigations, and many important facts relating to the mechanism of respiration have been settled by them, especially by the elaborate researches of Dr. Sibson in England, M. Bert in France, and MM. Traube and Rosenthal in Germany.

But there is one important defect in all these measurements. Owing to the obliquity and partially circular shape of the ribs, and to their rotation on two axes, it may readily be seen that the motions of any point on the walls of the chest, on either side of the sternum, may, in forced breathing, take place in three planes at right angles to one another. Owing also to the variations even in healthy breathing, it is further important to measure the movements in different directions during one act of breathing. Now, all the modes of measurement so far enumerated simply give either the gross enlargement of the circumference of the chest, or the resultant of the movements of its different parts, without estimating their extent in the several directions.

The measurement simultaneously of the three dimensions of the movements of points on the chest-wall is obviously a difficult task. It is, however, essential that its difficulty should be overcome—first, in order to obtain an accurate knowledge of these movements; and, second, to learn rightly the action of the different parts of the thorax.

I venture to hope that the problem has been solved by the instrument sketched in the accompanying diagrams. It records on three dials the simultaneous motions of any point on the chest in three planes during one or more acts of respiration.

I propose in the present paper to state the results which I have obtained with this instrument upon both healthy and diseased subjects.

DIAGRAM 1.—Sectional end elevation.

DIAGRAM 2.—Sectional plan.

DIAGRAM 3.—Sectional side elevation.

DIAGRAM 4.—Plan.

U. Upwards. F. Forwards. O. Outwards.

1. *Description of the stethometer.*

This stethometer consists of a light steel rod (L),* having at one end a small button (B) attached to it by a ball-and-socket joint (J); the other end of the rod is attached to some simple machinery, which records the motions of the rod, giving duly the movements of the button-end of it forwards, upwards, and outwards.

The forward movement is marked by the sliding forwards of a carriage (figs. 2 and 3, A C D E), carrying a pinion (F), which is turned by a rack (R) placed in the course of the slide (S L), and in its turn this pinion moves an index (figs. 1 and 4, f') upon a dial, and the amount of movement is registered by two small loose fingers (fig. 4, s and s'), which are pushed to each side by the oscillations of the index. The dial is divided into 100 parts, of which each division represents .01 of an inch.

The upward and downward motion of the button-end of the rod is transmitted through the lever (L) to a shaft (fig. 2,

* See Diagrams 1 to 4.

NN') placed at right angles to it, which turns upon pivots (fig. 2, PP') at each end, and upon this again is fastened a segment of a wheel (w, figs. 2 and 3), racked at the side, so as to turn a small pinion (figs. 1 and 2, v) which is attached to the carriage; this pinion turns another index (fig. 4, u) which registers the upward motion upon the dial in the same way as index f. Every degree of this dial represents $\cdot 02$ of an inch.

The *outward* motion of the chest is recorded upon a third dial by means of a pinion (o, figs. 2 and 3), also connected with the general carriage.

This pinion is set in motion by the rackwork (figs. 2 and 3, κ) attached to the end of the rod (l) beyond the pivot (fig. 2, q). In order to allow of the upward and downward movements of the end of the rod, this rackwork is made in a peculiar fashion, consisting of vertical divisions of a portion of a sphere, so arranged that only the outward and inward movements of the rod are recorded by the pinion, not those in the upward or downward direction. Every degree on this dial represents $\cdot 02$ of an inch. It will be evident that by this arrangement of parts each motion is indicated without interference with the others.

The only appreciable error in the indications is to be found in the influence of the radial movements upon the forward motion. This is, however, very easily calculated, and depends upon the length of the lever. Mathematically stated, the distance through which the button moves forwards is registered as less than it really is, by the versed sine of the angle formed by the rod in its angular motion.

The longer the rod or arm, therefore, the less the error from this source. In the model before you it amounts to $\cdot 021$ of an inch for every 100 degrees of upward or outward motion.

When the instrument is used it is placed in a box and fixed by means of a split ring and screw to a pillar at the required height, and this pillar is furnished with a clamp, by which it is fastened perpendicularly to any convenient table.

Mode of application.

The patient, with the chest exposed and devoid of any ligature, &c., is seated upon a straight-backed chair, which fixes the head and shoulders, and, if possible, his head is also allowed to rest against a support. In this manner the probability of any side movement and any bending of the spine not due to respiration is reduced to a minimum. The button-end of the rod is then brought against any point of the chest, in such a manner that the direction of the rod is perpendicular to the plane of the shoulders, and also perpendicular to the front of the box containing the apparatus.

The distance of the patient from the apparatus also is so arranged that in ordinary breathing the carriage containing the machinery rests about half way upon the slides; in other words, that the index f is about its mid position upon the dial. The registering fingers are then applied to each side of the indices, and when it is required to know the extent of forced breathing, the patient is directed to take a deep inspiration and then to make as complete an expiration as possible. The rod is then fixed, and the extent of the movements in the three directions read off upon the dials.

When it is desired to take the extreme extent of several respirations this is done by allowing the patient to go on breathing forcibly several times before the instrument is stopped, and if it is needful to ascertain the extent of movement in ordinary breathing, the patient is permitted to take several quiet respirations before the registering fingers are placed in position.

Sources of error.

From what has been said before, it will have been obvious that there are several sources of fallacy to be regarded in applying the instrument, and corresponding precautions to be taken. In the first place, the mode of

breathing, especially when it is forced, may be unnatural and irregular from nervousness, officiousness, or anxiety; the ribs may be even kept entirely fixed, and the breathing abdominal.

It is necessary, therefore, to urge the patient to breathe easily and naturally, and when a deep inspiration is needed, to ask him to breathe quietly and deeply; and sometimes a little time has to be given, and the attention has to be drawn away from the instrument.

It is not necessary to state that those observations in which the breathing has not been natural were rejected as worthless.

It is also desirable that the muscles of the arms should not be allowed to take part in the process of breathing, as they generally introduce some irregularity in the movements. In all cases, therefore, the patient is directed to rest the tips only of the fingers upon the edge of the table; this arrangement also steadies the body of the patient.

Obesity is a complete bar to the use of the apparatus. If there is much fat upon the ribs it is almost impossible to keep the button of the lever pressed equally upon them; in any case care has to be taken not to move the skin over the bone.

This circumstance is of less consequence, however, since most of the patients who require these observations to be made are already reduced in flesh by disease, and are spare and even thin.

For physiological observations the subjects were purposely selected from such persons.

Points of observation.

It was necessary to fix upon certain points on the chest upon which to apply the button, and most of the observations have been made on the anterior region of the chest. I have also considered it important that the end of the rod should rest on bone; the points selected have, therefore, for the

most part been the top, middle, and lower end of the sternum, the middle of each clavicle, and the middle of each third rib. In males, also, observations were made on the fifth rib, close to the nipples.

Graphical representations of the respiratory movements.

The degree of variation in the different motions may be shown graphically by means of lines drawn to scale as in the annexed diagrams, (diagram 5, &c.), but since one of the

DIAGRAM 5.—Showing the movements of the fifth ribs in a healthy young man, æt. 28.

planes of movement is perpendicular to the other two, the course of one of the three movements must be imagined. The lateral or outward push is, therefore, represented by the device of tracing it at an angle of 45° to the other two.

General movements of breathing.

In ordinary breathing the extent of movement of the ribs is very small, especially in the upper part of the chest, and it is very irregular in extent, even in the same person.

In both men and women a large part of the respiratory

act in ordinary breathing is performed by the diaphragm, a fact remarked by Haller, who says :*—"In naturali inspiratione solum movetur diaphragma, costis ad sensum immotis, nisi quod inæ una vel altera septi motium sequantur."†

Little information, therefore, as to the action of the chest can be obtained by means of any stethometer except in deep or forced respiration.‡

Forced breathing.

When the button of the lever of the above-described stethometer is applied during forced respiration to the front part of the chest, on either side of the sternum, it is observed that a considerable amount of movement is indicated upon the dials, the chief motions being those forward and upward. The forward movement is the more equable of the two, and starts much more rapidly at first than the upward motion. In men the upward movement takes place chiefly at the latter portion of the respiratory act, when the extraordinary muscles of respiration are brought into play.

In most full-chested men the earliest portion of the expansive act seems to be accomplished by an increase of the ordinary action of the diaphragm, then the chest seems gradually to swell outwards, in an ascending order, from below upwards; the ribs are gradually raised by their special

* 'De Musculis Diaphragmatis,' p. 27. Berne, 1733.

† Quod in dormientibus, sanis, tranquillis, planum est. Comp. Winslow, 1165; Galenus, 'De loc. adf.,' l. 4, c. 6; also Hier. Fabricius ab Aquapendente, de Respirationis instrumentis.

‡ Sibson's 'Medical Anatomy,' p. 63. "In the majority of males the thoracic movement during tranquil inspiration is about one twentieth, the abdominal movement one third of an inch. This indicates that the diaphragm descends about half an inch. In the robust the thoracic movement is even less. In two remarkably well-built men, Sewell the American runner, and the third best English runner, it was only one thirtieth of an inch. In many weak persons, on the other hand, it is as much as one tenth of an inch."

muscles, and the lower ribs are probably at the same time straightened at the anterior angle between them and their costal cartilages; at last, for the final effort of inspiration, the head and shoulders are fixed, the spinal column is curved backwards, and all the muscles capable of producing upward movement of the bony cage are exerted to their utmost powers.

In expiration after this effort the operation is reversed. The first to give way seems to be the diaphragm, the abdomen in spare subjects collapses, and then the ribs descend more gradually, beginning first with the upper ribs, and when a forced expiratory effort is required the abdominal muscles are strongly contracted; the ribs, or even the scapulæ, are pressed downwards, and the spine is pushed forward, so as to contract the cavity as much as possible. This seems to be the most frequent order of events so far as I have observed them, but it is important to remark that the action is undoubtedly greatly under the control of the will, and thus variations in the order of movement may be brought about by various causes—habit, disturbing emotion, suggestions from others, or antecedent ideas of what ought to take place. This fact may, perhaps, account for the different descriptions which have been given of the process by different observers.

Order of movement of the ribs.

Haller* considered that the first rib is the fixed point towards which all the others move in succession, the third following the second and so on. Sabatier stated that the ribs differed in the direction of their movement according to their position, the superior ribs moving upwards, the lower ribs downwards, the middle ribs outwards.

Magendie, on the other hand, thought that all the ribs moved at once, and Dr. Sibson seems to share this opinion, whilst Hutchinson and Humphry both take the same view

* De respiratione experimenta anat. Gotting., 1747.

as Haller ; thus, Hutchinson says, "The clavicles, shoulders, scapulæ and superior ribs are raised, the sternum advances, the infra-clavicular region swells remarkably upwards and outwards (particularly in females) like a rolling wave, the supra-clavicular region is raised, the whole apex of the thorax is rendered more obtuse, particularly the antero-posterior diameter. The lower ribs at their cartilaginous extremities spread outwards, increasing both the lateral and antero-posterior diameter of the base of the thorax, the cartilaginous (Gothic) arch formed by the junction of the sixth, seventh, eighth, ninth and tenth ribs below the sternum, becomes more obtuse by their lateral motion, the abdominal space under this arch down to the umbilicus sinks inwards.

"There is an indescribable undulating roll produced by the consecutive action of the respective ribs, which always commences with a superior rib ; in costal breathing a lower rib *never* moves first."

Humphry repeats the statement, "In the normal expansion of the thorax," he says,* "the upper ribs are raised first, the others following in quick succession." Dr. Walshe again says that "even in the male the expansile action, if abrupt, commences superiorly." ('On Diseases of the Lungs,' 4th ed. p. 17.)

I do not profess to place my limited experience in opposition to opinions expressed by such able observers, but in working with the stethometer my impression was that the most usual form of breathing, at any rate in males, was the direct opposite of that mentioned by Mr. Hutchinson and Dr. Humphry. I have taken some pains therefore to try to learn which account of the order of movement was most usually correct, and have adopted two methods of testing the matter.

1st. I have fastened tapes of paper around the chest at different heights, whilst the ribs were stationary in the position of somewhat forced expiration, abdominal breathing only being permitted during the process of fastening ; slow but deep inspiration was then allowed, and in every instance

* 'Human Skeleton,' p. 349.

which I have so far examined, the order in which the tapes were torn was from below upwards.

2nd. I have had several opportunities of using Dr. Burdon Sanderson's stetho-cardiograph and have applied the button simultaneously to the second and fifth or sixth ribs in both males and females. Diagram 6 gives the tracing obtained in a case to which Dr. Sanderson himself kindly applied it, a young man, in good health and of average size.

DIAGRAM 6.—Simultaneous tracings of the movements of the fifth and second ribs in an adult male, made by the stetho-cardiograph.

The vertical strokes show the points at which the two pens were working simultaneously.

The diameters taken were (*a*) from the fourth vertebra to the second rib, one inch to the right of the sternum; and (*b*) from the eighth vertebra to the fifth rib, half an inch to the right of the sternum. The strokes at the bases of the undulations show the corresponding points of the curves. A comparison of the tracings shows that in every act of breathing, whatever the extent of the inspiration, the lower rib is the first to rise and the last to descend.

It will be noticed that towards the end of the diagram the waves are smaller than at the beginning, showing that respiration was being performed with less effort. The result, however, as far as the action of the ribs is concerned, is the same in every case.

The movements of the second rib are, moreover, less extensive than those of the fifth, as might have been anticipated

from the greater length of the latter bone ; but they are also less acute, and more equable in their rise and fall, showing that the work done by the upper ribs is performed more gradually, and that they remain at the point of extreme expansion rather longer than the lower ribs.

This is, I think, what might have been anticipated in the inferior costal type of breathing, since it would need a longer time for the expansion of the upper portions of the lung, if the action had previously commenced in the lower part of the elastic organ—in other words, the inspired air would be partly taken up in expanding the lower part of the lung, and would need a longer time to overcome the elasticity of the upper lobes.

In females, displaying as they do the true “superior costal” type of breathing we might have expected to find that the upper ribs would have a very decided precedence in the order of movement, but this does not seem to have been very decidedly the case in the examples which I have been able to examine by this method.

Several tracings of female respiratory curves were made with the kind assistance of Mr. Hawksley of Blenheim Street, and of these, diagrams 7 and 8 may be taken as examples. The curves show the simultaneous movements of the second and sixth ribs in two healthy young women, during forced breathing, in another instance both ordinary and extraor-

DIAGRAM 7.—Simultaneous tracings of the movement of the second and fifth ribs in an adult female during forced respiration.

DIAGRAM 8.—Tracings of the movements of the second and sixth ribs in an adult female, forced respiration.

dinary acts of breathing were registered. In each case the stays were removed during the experiments.

The positions of the buttons of the stethograph were approximately the same as in the previously given tracing of male respiration.

The peculiar predominance of the action of the upper ribs in female breathing is at once perceived in these diagrams, but it may be observed that in all the curves there is much less difference in the times at which the ribs come into action than in the male chest. As it has been well pointed out by Bérard,* in this type of breathing, the whole of the chest often seems to be raised at once, so that "one sees the clavicles, the sternum, and the first ribs raised, and this action communicated, though in less degree, to the upper part of the inferior portions of the chest." A close examination of the undulations, however, does show a slight difference in the times of rise and fall. A difference, which unlike that observed in male breathing, is sometimes in favour of the upper ribs, sometimes of the lower. In tranquil breathing there was apparent in every act of respiration

* 'Cours de Physiologie,' Paris, p. 258.

a small precedence in the moving of the second rib. In forced respiration the two cases differ on this head, in one (diagram 8) the sixth rib is the first to move and is the longest time in action ; and the second rib, although it still has the largest extent of motion, yet lags somewhat behind the other. In the other (diagram 7) the case is reversed, and the second rib retains to a very small extent its precedence. It may also be noticed that for the most part the female respiratory curves are more abrupt in their rise and fall, and hence more pointed than those in the male subject.

Diagram 7 somewhat resembles in its character the tracing of male breathing especially in the more prolonged sustaining of the inspiratory effort by the upper ribs ; but even in this tracing there is more abruptness in the general action of both sets of ribs.

It would not be just to assume that these few examples are sufficient to decide this question, but they may serve to show the value of this method of inquiry. It may be observed also that the subject is not without practical importance. There is still some controversy as to whether pulmonary phthisis appears most readily or lasts longer in the more or the less used portions of the lungs, and when definite results have been obtained as to the relative movements of the ribs they may probably be advantageously compared with other statistics relating to this disease.

Ratio of forward and upward movements.

Another point in the description which I have given of the general movements of breathing should also be fully explained since its accuracy might be called in question.

It is stated in the description of the general movement of breathing, that in deep inspiration the stethometer shows a difference in the rates of movement, forward and upward, in the early and late periods of that act. Now since the movements of any point on the chest are, to a great extent, determined by the radial motions of a chord line between that point and the vertebral articulations of the underlying rib, it might appear that there was an error in the observa-

tions, and that the forward motion must necessarily be accompanied by an upward or an outward movement in some definite degree, and, except when the rib is nearly horizontal, there can be little or no upward motion without a simultaneous and commensurate forward or outward movement.

This question is one of much importance and touches upon a very interesting problem relating to the causes of the respiratory movements, which must be fully considered hereafter; but, in the mean time, it may be sufficient to remark that the action of the stethometer gives a strictly accurate representation of the movement, and that the discrepancy noticed is partly due to complex actions of the mechanism of respiration, partly to a simple geometrical law by which the versed sines and cosines of angles are governed.

The movements of the chest in forced breathing.

The regions which have been examined in the greatest number of subjects were, 1st, the sternum at its highest point, its middle, and just above the ensiform cartilage; 2nd, the clavicles near their centres; 3rd, the anterior ends of the third ribs, near their articulations to the cartilages; 4th, the fifth ribs near the nipples.

The actual extent of these movements varies in different individuals and in different regions of the chest; probably no two persons breathe with the same kind or extent of motion. It becomes necessary, therefore, to examine the details of each individual case, and then to attempt to extract from them some general conclusions which represent what is usually found to exist. A fair representative selection of examples must thus first be given in order to illustrate the results obtained with the three-plane stethemoter.

The following table records the motions of different parts of the chest in healthy adult males, who were purposely selected as men of average capacity in breathing. No examples of extraordinary power are given, as they would be less suitable to the objects of the inquiry.

6. Forwards	75	25	25	25	35	30	...	...	Male, æt. 40, tall, rather stout.
Upwards	60	50	60	60	50	60	...	...	
Outwards	...	...	...	...	10	10	...	...	
7. Forwards	50	50	40	45	50	65	85	90	Male, æt. 23, slight, healthy, left-
Upwards	110	120	100	110	110	120	160	160	handed.
Outwards	...	...	...	...	15	15	25	30	
8. Forwards	93	95	80	85	135	115	115	110	Male, æt. 32, tall, healthy, muscular.
Upwards	120	115	130	130	160	150	110	120	
Outwards	...	...	...	...	30	25	30	30	
9. Forwards	55	100	55	50	85	78	100	100	Male, æt. 42, 6 ft., healthy, active.
Upwards	110	100	100	90	130	115	130	110	
Outwards	...	...	...	...	15	12	20	15	
10. Forwards	35	40	25	25	50	50	50	50	Male, æt. 21, slight, healthy, middle
Upwards	35	40	30	30	35	35	50	40	height.
Outwards	...	...	...	...	10	10	12	14	
11. Forwards	30	43	25	23	...	...	68	50	Male, æt. 32, 6 ft. high, healthy, strong.
Upwards	65	65	60	60	...	...	84	90	
Outwards	...	...	...	...	...	...	20	25	
12. Forwards	15	30	25	20	70	60	55	65	Male, æt. 22, 5 ft. 6 in., healthy,
Upwards	30	85	100	35	120	100	100	100	athletic.
Outwards	...	...	...	...	15	14	20	20	
13. Forwards	85	...	50	50	105	105	...	...	Male, æt. 45, 5 ft. 8 in., healthy,
Upwards	100	...	60	54	95	100	...	...	slight.
Outwards	...	...	...	...	10	15	...	...	

Regional movements.

The sternum.—It might be supposed that, in consequence of the mode of its attachment to the ribs and clavicles, the sternum would only be able to move in the upward and forward directions, and that it could not deviate from the middle line of the body, but owing to the different size of the two halves of the thorax, and to the varying strength of the muscles on each side, it is usual even in healthy persons to find a slight difference in the degree of motion of the right and left ribs, either in the forward and upward or outward directions; this fact must needs cause some slight lateral movement of the sternum, especially at its lower end, which would be drawn towards that side which has the least power of expansion.

It would, however, require great care in fixing the body in order to note the very small deviations which would arise from this source in most individuals, and the readiness with which this outward reading of the instrument is affected by movements of the body renders it untrustworthy for very small readings. It is on this account that the record of this motion is sometimes omitted from the tables even in the measurement of the third or fifth ribs.

In disease or malformation of the thorax, either congenital or accidental, the lateral movement of the sternum may, however, become very perceptible; the following table gives the movements of the sternum in three cases.

TABLE 2.—*Movements of the sternum.*

Movements of the sternum.	Forward.	Upward.	Outward.
(1). Male, æt. 21. Tubercle; contracted pleuritic adhesions on left side . . .	85	45	12 (L.)
(2). Female, æt. 48. Spinal curvature to right side	35	60	8 (L.)
(3). Female, æt. 33. Crushed ribs on the right side; upper sternum . . .	25	20	12 (R.)
(4). Same case. Lower sternum . . .	55	100	15 (R.)

As a general rule, the sternum moves forward and sometimes upward more freely than the clavicles, and the motions of the lower portions of the bone are greater than those of its upper end. There is thus an alteration of its plane towards a less vertical position, but this tilting forward of the lower sternum is not as great as might have been concluded from the greater length of the lower ribs, their greater mobility, and the obliquity of the costal cartilages. If the problem were purely a mathematical one, there ought to be some definite relation between these conditions and the extent of motion of the sternum, but it cannot be traced in the record of measurements given in the tables. The explanation of this fact is probably to be found in the yielding nature of the levers employed, and in the action of the great inspiratory muscle, the diaphragm. The action of this muscle on the six lower ribs will probably prevent the forward and upward motion of the sternum and, perhaps, also of the ensiform cartilage in children. To some extent it would appear from the tables that the more elastic the thorax, the more is this influence of the diaphragm felt.

Many of the remarkable vivisections made by Traube would seem to bear out this explanation of the lesser degree of motion of the lower end of the sternum.

For example, at p. 150 ('Gesammelte Beiträge') he says, "The only influence which, according to our experience, the diaphragm exerts upon the lower part of the thorax, consists in the drawing inward of the foremost (bony) ends of the seventh and eighth or from the seventh to the ninth rib." This opinion is fully borne out by his experiments, notably the tenth, eleventh, and the seventeenth.*

The clavicles show, as might have been predicted, more upward than forward movement, and they are especially affected by the final effort of breathing, when the extraordinary muscles attached to them are brought into action.

There is little or no outward motion of any point on these bones, or on the first and second ribs in the anterior region

* See also Mr. Le Gros Clark's "Remarks on the Mechanism of Respiration," 'Proc. of Roy. Soc.,' vol. xx, p. 122.

of the chest, but on the third rib this motion is already distinct, and it increases in amount as we descend to the lower ribs, where the costal cartilages become more and more oblique.

The ribs at their anterior ends generally move more decidedly upward than the sternum, owing, perhaps, to their power of outward rotation, which permits them to rise more freely. Their forward push is also very considerable, especially in the lower ribs, the fifth and seventh, and in some cases even the second and third ribs enjoy more forward movement than the sternum.

In most healthy male subjects the fifth and seventh ribs enjoy much more general mobility than the third, but this is by no means universally true, and possibly in obese persons this might not be even the usual case, since in them the so-called superior costal type of breathing may prevail. I have not, however, been able to apply my instrument in these cases.

There is certainly no regular increment of movement in the ribs as we descend from the upper to the lower. Owing to the gradual increase in the length of the ribs from the first to the eighth or ninth, we might have expected that this circumstance would have given them a wider sweep at their anterior ends, but I can fully corroborate Dr. Sibson's statement that in some cases the second or third ribs have more power of forward movement than the fifth or even the eighth. There is also in the tables abundant evidence of the independent action of the different ribs. Mr. Hutchinson has well pointed out this power of independent movement in the case of certain chest diseases, and in most of the cases of the table it will be found that the third and fifth ribs are by no means in exact accord in the proportion which the several dimensions of the movements bear to one another.

The outward movement of points upon the five or six upper ribs appears to increase as they recede from the sternum until a limit is reached about midway between that bone and the vertebral column, beyond this point, measuring from behind, this motion naturally again gradually diminishes.

TABLE III.—*Dimensions of the movements of respiration in 100ths of an inch. Adult females.*

Extent and direction of movement.	Top of sternum.	Middle of sternum.	Eniform cartilage.	Centre of clavicle (right).	Centre of clavicle (left).	3rd rib (right).	3rd rib (left).	Remarks.
1. Forwards	51	...	...	51	51	61	59	J. H., female, æt. 27, healthy (stays on).
Upwards	45	...	...	51	60	60	63	
2. Forwards	117	...	...	85	102	...	...	E. R., female, æt. 27, healthy (wearing stays).
Upwards	114	...	...	99	99	...	...	
3. Forwards	76	102	96	60	85	119	105	L. E., female, æt. 29, healthy (no stays).
Upwards	75	90	90	90	90	105	105	
Outwards	...	...	...	...	...	30	30	
4. Forwards	51	85	93	51	60	60	76	M. F., female, æt. 22, healthy (no stays).
Upwards	54	51	45	60	75	96	96	
Outwards	...	...	...	...	...	30	33	
5. Forwards	31	51	...	42	46	68	76	M. D., female, æt. 33, healthy (no stays).
Upwards	105	94	...	60	75	99	105	
Outwards	...	...	...	...	...	...	...	
6. Forwards	37	40	...	42	38	51	51	B. M., female, æt. 36, healthy (no stays).
Upwards	70	75	...	75	75	90	105	
Outwards	...	...	...	...	...	21	18	
7. Forwards	30	35	...	50	55	75	90	M. R., female, æt. 34, healthy (no stays).
Upwards	50	60	...	70	75	110	120	

Variations in healthy breathing.

1. *Influence of sex.*—The preceding table gives a few of the results which have been obtained by means of the three-plane stethometer in young and healthy women.

It has been noticed by most observers that in women both the ordinary and extraordinary breathing is chiefly costal; and since this fact has not been successfully traced to the fashion of dress, it seems to be probably arranged to facilitate gestation.*

It does not appear to have been remarked, however, that the superior costal type of breathing does not give proportionately any increased power of raising the ribs in forced inspiration.

In the cases which I have examined it was rare to find any female who could raise the clavicles and third ribs more than one inch, and if the proportions between the motions are altered at all it is rather to the advantage of the forward thrust, which in several instances attained to or exceeded one inch.

Diagram 9 gives a representation of the movements of the third rib in a healthy male and female.

DIAGRAM 9.—Dimensions of movements in males and females.

* This opinion was held by Boerhaave and Haller, but, as Dr. Walshe points out, if this were true ascitic females ought to escape dyspnoea, and the difference between male and female breathing is much less during sleep, and male and female animals breathe almost exactly alike.—'Diseases of the Lungs,' Ed. 4, p. 16.

The peculiarities of motion of the different bones are also for the most part similar in females and males.

The forward movement of the middle of the sternum slightly exceeds in most cases that of the manubrium, and again we find the total movement of the ensiform cartilage somewhat lessened. The clavicles move at about the same rate as the sternum, in most cases rather less, in some rather more than that bone, and they move considerably less than the third rib, which as in men moves more than either sternum or clavicles.

The fifth ribs were not examined. It is somewhat remarkable that, in most of the women examined, the motions on the left side exceeded those of the right.

2. *Age*.—The following table contains the measurements of the respiratory movements in children and old persons of both sexes :—

NOTE.—The measurements recorded in the following tables were obtained before I became acquainted with Dr. Sibson's observations on this subject. It is, however, interesting to notice that his records of the forward motion of the several parts correspond very closely with those which I have obtained, and his deductions from the figures are often strikingly similar to those which I have ventured to draw. (See Table VII (*a*), on page 91.)

TABLE IV.—*Dimensions of the movements of respiration in 100lbs of an inch, in young children and old people.*

Direction of movement.	Top of sternum.	Middle of sternum.	Eniform cartilage.	Clavicle (right).	Clavicle (left).	3rd rib (right).	3rd rib (left).	5th rib (right).	5th rib (left).	Remarks.
1. Forward	98	98	...	64	64	110	102	110	102	Male, æt. 11, healthy, tall.
Upward	111	96	...	117	120	75	100	100	100	
Outward	...	...	...	...	...	20	20	30	25	
2. Forward	...	...	...	30	29	...	...	...	...	Female, æt. 6, healthy, small.
Upward	...	...	...	36	36	...	...	...	...	
3. Forward	45	...	...	55	55	95	85	...	...	Male, æt. 9, healthy, strong.
Upward	50	...	...	110	120	120	120	...	...	
Outward	...	...	...	...	...	30	30	...	...	
4. Forward	17	25	30	45	40	35	30	30	35	Male, æt. 80, gardener, healthy.
Upward	45	50	54	50	50	45	55	50	55	
Outward	...	...	...	...	...	10	10	10	10	
5. Forward	30	20	10	20	...	25	35	25	25	Male, æt. 59, merchant, healthy.
Upward	100	75	60	100	...	100	100	70	75	
Outward	...	...	...	...	...	15	15	20	20	
6. Forward	10	25	25	15	15	30	35	30	30	Male, æt. 66, healthy, spare.
Upward	50	30	30	45	35	50	70	55	60	
Outward	...	...	...	...	...	...	...	...	...	
7. Forward	45	35	...	30	30	50	45	...	...	Male, æt. 70, healthy.
Upward	70	70	...	50	35	90	100	...	...	
Outward	...	...	...	...	...	20	20	...	...	

It is interesting to observe the large relative movement of the chest-walls in children as compared with that of adults, and to notice the diminution in the power of chest motion as age advances.

This fact arises partly, no doubt, from the greater mobility of the bones, and elasticity of both bones and cartilages in youth; partly, perhaps, from the shape of the thorax in children, the deep lateral grooves on each side of the spine being absent; there is thus less difference between the chord lengths of the ribs of children and those of adults than might be anticipated, and the chest in children being shorter from above downwards, all the movements forward and upward are necessarily exaggerated in order to produce a corresponding alteration in the capacity of the chest. It is possible also that muscular energy in children may be comparatively greater in proportion to the amount of resistance in the respiratory muscles.

I have not observed that the proportions between the three dimensions of the movements are very different in children and adults, especially female adults, except that the forward push is somewhat increased. In old age, however, there is both a general diminution in all the dimensions of the movement, and in some cases the forward motion is lessened to the lowest degree compatible with any angular rise of the ribs.

The following diagram affords a means of comparing the movements of the third ribs in a child of eleven and a man of fifty-nine; the difference in the degree of forward movement is very striking:—

DIAGRAM 10.—Showing dimensions of movements in youth and age.

3. *Position.*—It is scarcely necessary to point out that position has much to do with the freedom of breathing, and interesting observations on this subject have been made by Drs. Sibson and Hutchinson. I have myself, as yet, only made observations upon the influence of the position of the arms upon the breathing of persons in a sitting posture, especially as to the relative motions, upward and forward, of the sternum.

The following tables show the variations in these movements in three individuals :—

TABLE V.—*Movements of the centre of the sternum in different positions of the arms.*

	Case I.		Case II.		Case III.	
	F.	U.	F.	U.	F.	U.
a. Hands supported on a level with the shoulders or on the table	102	105	107	114	90	100
b. Hands resting on the sternum	93	99	92	84	90	90
c. Hands locked behind the head	90	70	43	70	75	60

TABLE VI.—*Showing the movements of the lower end of the sternum in different positions of the arms.*

	Case I.		Case II.		Case III.	
	F.	U.	F.	U.	F.	U.
a. Hands supported on a level with the shoulders or on the table	76	115	115	150	100	120
b. Hands resting on the chest ..	73	84	105	129	95	115
c. Hands locked behind the head	65	66	98	129	...	...

The movements most affected were those forward, but both the upward and forward motions were impeded by any position of the arms, except that on a table or on a level with the shoulders. This observation shows, therefore, that the well-known position of the asthmatic patient during a paroxysm of dyspnoea is the one which really gives the greatest amount of power of moving the chest-walls.

4. *Muscular power*.—In a very large proportion of the male cases examined it was found that the movements on the right side of the chest exceeded those on the left—a fact which may be placed in relation to the observations of different observers, notably Drs. Sibson, Wintrich, and Walshe, that in right-handed men the circumference of the right side may naturally exceed that of the left by from one half to three centimetres. But it appears probable that both the increased power of movement and the increased size on the right side are due to the greater force of the muscles on this side. The power of movement certainly is remarkably affected by the muscular force of the subjects, and it is reasonable to believe that the increased size of the right side of the chest may be, partly at least, due to the same cause. The cases in which the greatest amount of movement of the ribs and sternum was observed were almost always men of considerable muscular development, although, even in these men, those who were most lithe and active, and who therefore had the greatest freedom in their joints, could exceed in some of their chest measurements the more sturdy and more muscularly strong.

Variations in the Respiratory Movements in Disease.

The following table gives the dimensions of the respiratory movements in phthisis and other lung diseases.

TABLE VII.—*Dimensions of the movements of respiration in 100ths of an inch in phthisis—males.*

Extent and direction of movement.	Top of sternum.	Middle of sternum.	Lower end of sternum.	Clavicle (right).	Clavicle (left).	3rd rib (right).	3rd rib (left).	5th rib (right).	5th rib (left).	Remarks.
1. Forward.....	51	...	...	48	39	67	42	...	...	Male, æt. 50, right, large incontracted vomica, dry; left, recent tubercle.
Upward.....	45	...	...	45	51	66	51	...	...	
Outward.....	...	...	...	...	...	30	27	...	...	
2. Forward.....	...	...	...	54	44	...	...	...	...	Male, æt. 18, incipient phthisis, on left side.
Upward.....	...	...	...	75	63	...	...	...	...	
3. Forward.....	92	...	...	...	...	80	85	...	...	Male, æt. 26, right, first stage of phthisis.
Upward.....	90	...	...	...	...	90	105	...	...	
Outward.....	...	...	...	...	...	24	36	...	...	
4. Forward.....	42	...	...	34	54	93	85	...	...	Male, æt. 60, slight, incipient tubercle on right side.
Upward.....	69	...	...	69	57	69	105	...	...	
Outward.....	...	...	...	...	...	...	...	...	...	
5. Forward.....	...	...	...	...	...	68	59	...	...	Male, æt. 24, side tubercle softening on left side.
Upward.....	...	...	...	...	...	70	69	...	...	
6. Forward.....	24	34	34	...	...	59	41	105	51	Male, æt. 25, incipient deposit on left side, not
Upward.....	39	36	35	...	...	60	45	45	36	
Outward.....	...	...	...	...	...	30	15	30	20	
7. Forward.....	46	...	...	24	24	39	42	...	...	Male, æt. 32, small weak chest, deficiency of breathing left side.
Upward.....	60	...	...	33	39	60	43	...	...	
Outward.....	...	...	...	...	...	20	15	...	...	
8. Forward.....	56	85	...	85	54	110	68	110	68	Male, æt. 21, tubercle both sides, formerly pleurisy on left, and contraction.
Upward.....	39	45	...	41	39	75	39	75	39	
Outward.....	...	12	...	...	...	...	...	...	...	
9. Forward.....	50	55	55	55	55	48	55	60	45	Male, æt. 21, tubercle under right clavicle.
Outward.....	80	80	80	90	90	60	90	60	50	

TABLE VII (a). [See note, page 85.]

The following table gives a few of Dr. Sibson's measurements in healthy subjects in forced breathing :

1.—ADULT MALES.

10. Forward.....	24	34	34	...	...	59	41	105	51	Male, æt. 26, chronic phthisis on left side, extending five or six inches.
Upward.....	39	36	...	...	...	60	45	45	36	
Outward.....	...	...	...	...	...	20	15	20	15	
11. Forward.....	25	30	...	50	15	100	70	70	45	Male, æt. 29, chronic phthisis on left side.
Upward.....	45	40	...	50	25	60	60	60	40	
Outward.....	...	...	...	...	10	10	12	25	10	
12. Forward.....	25	35	30	25	20	55	35	50	40	Male, æt. 57, chronic phthisis on left side, first stage.
Upward.....	65	60	60	70	60	70	70	60	60	
Outward.....	...	...	...	...	...	15	10	20	15	

Case.	Age.	Sternum.		2nd rib.		4th and 5th ribs.		6th rib.		8th rib.		10th rib.		Remarks.
		Upper.	Lower.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	
4	23	120	75	130	125	120	120	120	120	...	...	...	...	
8	28	100	120	115	115	120	120	130	130	...	...	80	80	
9	37	130	110	110	100	95	90	80	80	95	90	95	80	
12	26	180	190	225	...	...	...	...	...	...	...	...	...	
13	26	100	100	150	...	...	...	...	...	...	...	...	...	
16	22	90	60	100	100	100	100	50	40	...	...	...	...	
2.—BOYS.														
18	16	50	110	90	70	60	90	...	...	100	75	60	45	
22	15	60	70	100	80	...	...	...	95	90	75	80	70	
25	11	110	50	130	130	...	85	40	35	60	60	35	25	
26	10	70	50	100	100	100	100	...	...	50	50	...	...	
3.—OLD MEN.														
39	61	90	90	75	70	80	80	60	60	60	60	22	22	
40	68	100	80	50	50	75	75	50	50	30	25	...	...	
41	65	80	90	50	40	50	45	73	35	30	30	...	...	
42	71	50	50	55	55	35	20	20	20	10	50	2	2	

TABLE VIII.—*Dimensions of movements in phthisis—females.*

Extent and direction of movement.	Upper sternum.	Middle sternum.	Lower sternum.	Clavicle (right).	Clavicle (left).	3rd rib (right).	3rd rib (left).	Remarks.
1. Forward	30	40	...	35	45	65	50	Female, slight tubercular congestion under right clavicle.
Upward	50	50	...	40	53	70	50	
Outward	...	...	...	...	...	10	7	
2. Forward	49	...	...	47	39	68	56	Female, F. D., æt. 19, right side healthy; left, softening tubercle.
Upward	57	...	...	75	36	63	45	
Outward	...	...	...	...	...	36	21	
3. Forward	34	...	...	17	27	42	42	Female, W. B., æt. 48, incipient tubercular deposit under right clavicle.
Upward	60	...	...	60	24	60	51	
4. Forward	56	...	...	46	39	59	59	Female, æt. 47, tubercle on both sides, softening on left.
Upward	39	...	...	45	45	48	36	
5. Forward	39	42	56	19	37	42	68	Female, æt. 37, right side, extensive tubercular deposit, softening; left, incipient tubercle.
Upward	60	60	60	45	54	60	81	
6. Forward	42	42	34	...	...	54	41	Female, æt. 16, left side, incipient deposit.
Upward	45	45	45	...	...	45	39	
7. Forward	25	30	...	30	25	35	35	Female, æt. 38, left side, incipient deposit.
Upward	50	50	...	60	60	75	75	

8. Forward.....	15	35	...	30	12	35	30	Female, æt. 32, left side, softening tubercle advanced.
Upward.....	50	60	...	40	40	70	40	
Outward.....	...	...	...	...	...	12	4	
9. Forward.....	...	45	...	25	20	65	50	Female, æt. 23, incipient tubercle on left side.
Upward.....	...	60	...	50	55	80	70	
Outward.....	...	...	...	...	...	...	...	
10. Forward.....	25	55	...	58	28	60	75	Female, æt. 23, chronic tubercular deposit under left clavicle.
Upward.....	70	80	...	90	70	100	100	
Outward.....	...	...	...	...	...	20	20	
11. Forward.....	15	35	...	30	12	35	30	Female, æt. 32, advanced phthisis on both sides.
Upward.....	25	30	...	20	20	35	20	
Outward.....	...	...	...	...	...	6	2	
12. Forward.....	30	30	...	30	25	40	35	Female, æt. 20, chronic phthisis both sides, large dry vomica on left.
Upward.....	20	15	...	25	20	30	52	
Outward.....	...	...	...	...	...	...	...	
13. Forward.....	15	10	...	10	15	16	22	Female, æt. 25, advanced phthisis on both sides.
Upward.....	50	40	...	24	50	55	55	

TABLE IX.—*Dimensions of movements in other chest affections.*

Extent and direction of movement.	Top of sternum.	Middle of sternum.	Lower end of sternum.	Clavicle (right).	Clavicle (left).	3rd rib (right).	3rd rib (left).	5th rib (right).	5th rib (left).	Remarks.
1. Forward.....	17	19	...	17	17	20	34	3	20	Male, æt. 30, advanced emphysema and chronic bronchitis.
Upward.....	36	45	...	45	36	45	45	21	30	
2. Forward.....	28	...	21	...	...	42	34	...	...	Male, æt. 50, chronic bronchitis, incipient tubercle on left side.
Upward.....	51	...	51	...	...	60	45	...	...	
Outward.....	...	...	...	...	...	20	15	...	...	
3. Forward.....	56	...	...	46	39	59	59	...	...	Female, æt. 47, chronic bronchitis, slight tubercle on both sides.
Upward.....	39	...	...	45	45	48	36	...	...	
4. Forward.....	5	25	...	...	...	25	25	20	20	Male, æt. 50, chronic bronchitis, with asthma.
Upward.....	20	40	...	...	...	40	38	30	35	
5. Forward.....	...	...	...	39	34	42	41	...	...	Male, æt. 50, emphysema and chronic bronchitis.
Upward.....	...	...	...	57	36	57	54	...	...	
6. Forward.....	...	35	35	...	...	30	25	25	40	Male, æt. 65, chronic bronchitis (incom- plicated).
Upward.....	...	57	40	...	...	50	50	35	50	
7. Forward.....	39	...	...	68	29	54	39	51	25	Male, æt. 19, pleurisy left side.
Upward.....	75	...	...	80	66	99	84	135	60	
8. Forward.....	42	...	...	68	34	42	59	34	34	Same case after two months, pleurisy on the right side having intervened.
Upward.....	150	...	...	135	165	150	180	180	210	

9. Forward..... Upward..... Outward.....	35	55	...	50	95	50	67	20	75	Male, æt. 13, pneumonia and pleurisy on right side.
	45	50	...	40	100	40	70	40	100	
	...	...	...	...	...	...	8	...	...	
10. Forward..... Upward..... Outward.....	25	35	...	15	20	32	50	...	...	Female, æt. 48, spinal curvature to right side.
	40	60	...	30	50	41	64	...	...	
	...	8 (1)	...	...	...	6	8	...	...	
11. Forward..... Upward..... Outward.....	25	55	...	15	18	55	55	...	...	Female, æt. 25, ribs on right side crushed severely.
	20	100	...	25	20	100	100	...	...	
	12	15	...	...	...	6	12	...	...	
12. Forward..... Upward..... Outward.....	25	87	...	30	25	75	110	2nd rib.		Male, æt. 48, with syphilitic nodes on 2nd and 3rd right ribs.
	55	82	...	45	40	90	100	R.	L.	
	...	...	...	...	...	...	...	72	80	
13. Forward..... Upward..... Outward.....	25	35	...	18	18	45	40	...	...	Male, æt. 21, pleurisy on both sides, commencing tubercle on left.
	25	40	...	25	20	80	40	...	...	
	...	...	...	...	...	15	3	...	...	

The cases of disease are thirty-eight in number, not sufficient for a detailed account of the modifications of movement caused by the various lung diseases; but since the number of separate measurements recorded in the tables amounts on the whole to nearly 500, they may, perhaps, afford data for remarks upon the results—at least, so far as they bear upon the physiology of respiratory movement.

A survey of all the cases on the register shows, as might have been expected, that the movements of respiration in disease are, on the whole, much less extensive than those in health. It is difficult at first glance to see how disease can ever produce exaggeration of motion except by bringing about an enlargement of the sound side to compensate for the loss of breathing on the other. The extent of motion of the bony walls also in the ordinary breathing of some diseased subjects may, by habit, be increased, the voluntary muscles being more brought into action; but, even in this case, the limits of extreme expiration and inspiration will probably be less than in health.

Increased movement may, however, in rare cases, be brought about by disease, especially in the extent of the upward motion.*

Cases 7 and 8 (Diagram 11), affords a good instance of this fact. From this patient two series of measurements were taken, the first soon after the pleuritic effusion on the left side had taken place; the second about two months afterwards, another attack of pleurisy with effusion on the right side having intervened.

It is very interesting to note the great increase in the upward readings in this last series of observations, due, no doubt, to an increased use of the respiratory muscles, which seem to have become stronger by use; at the same time it may be remarked that in the lower regions of the chest the forward motion is reduced to the smallest dimension compatible with the degree of upward motion recorded.†

* Dr. Walshe says, the chest movements may “exceed the healthy standard where a muscular effort is made to overcome some obstruction seated low in the chest.”

† If the initial angle of the rib be taken to have been about 65° , and the

DIAGRAM 11.

Cases 4, 8, 9, amongst the male phthisical patients are also probably examples of some exaggeration of motion to compensate for the loss in other ways. In No. 4 it is the forward push of the third rib which seems to be attempting to do the work of the clavicle over the injured portion of lung, and in No. 8 it is again the forward dimension which

chord-length of the rib about 6.5 in., both average dimensions in a man of nearly six feet in height, then it will be found that the forward push must have been at least 0.5 in. to permit of an upward rise of 1.70 in.

is increased out of all ordinary proportion to the upward rise.

In No. 9 perhaps both the forward and upward movements of the right fifth rib are increased to take the place of the deficient working of the right third rib.

Amongst females the examples of this compensatory increase of motion are less frequent; perhaps because the action of the fifth ribs could not in them be examined. Nos. 1, 3, and 10, however, show an increase; in case No. 3 of the upward, in the latter in the forward, motion of the third rib on the affected side. In No. 1 both forward and upward motions are increased in the third rib on the diseased side.

Diminished movement.

It is amongst emphysematous and asthmatic patients that the most distinct examples of extreme diminution of motion are to be found, and in these cases all the three dimensions of the movement seem to be equally lessened. Diagram 12 represents the movements of the third rib in a case of advanced emphysema.

DIAGRAM 12.—Case of emphysema, æt. 30.

The rigidity of the thorax in these disorders seems to offer an almost equal impediment to all the movements of the ends of the ribs.

In chronic bronchitis there is also usually to be found considerable diminution of motion.

An observation from which it would appear that even in this disease there must be in most cases a loss of elasticity, and in many, probably, some emphysema as well. It might otherwise have been anticipated that the respiratory muscles in these patients might at times have increased in power, and thus might have given greater extent of forced breathing.

There can be no doubt, however, that in all these cases there is exaggerated costal motion in ordinary enforced respiration.

In phthisis cases are recorded in which both lungs were affected, and others in which only one lung was as yet attacked. For the purpose of comparison with the healthy movements, the latter class was most valuable; but some use may be made of the other records to show the effect of softening or of the formation of vomicæ, as compared with that of the incipient deposition of tubercle.

In both males and females it was found that one of the earliest indications of the disease was a diminution of movement over the part immediately affected, and here again it is usually the forward indication which is most retarded.

In most cases the proportion of this dimension to the upward rise is more or less diminished.

In some the upward dimension is unaltered, and in others it is apparently increased.

In three cases amongst the males (Nos. 1, 8, and 10) and four cases among the females (Nos. 1, 2, 4, 8), the ratio of the forward to the upward movement was somewhat in excess on the side on which the disease was most advanced; but it is a significant fact that in five of these cases softening had taken place to a considerable extent, and in 3 (M. 1, 8, F. 4), not only had vomicæ formed, but they had dried up, and were for the time quiescent.

It may be remarked also, that these cases were of very long standing, and that they seemed to have a tendency towards a more or less complete recovery, notwithstanding the fact that these patients had exhibited at one period of this malady excessively severe symptoms.

Cases (males) 4 (females) 3, 7, show plainly the mode in which the comparative loss of motion is confined to the clavicle or to the ribs immediately over the diseased portion of lung, and to some extent also in these patients, a compensatory increase of some of the dimensions had taken place.

In conclusion, permit me to say a few words as to the stethometer used in these inquiries. The importance of the instrument for physiological purposes has, I think, been abundantly shown, even by the results which I have ventured to bring before you in this paper, and it may probably be serviceable in several other inquiries of a similar nature. We may hope that by its means the conclusions respecting the action of other respiratory muscles may be put upon a surer basis than they rest upon at present, that its use may lead to a more exact knowledge of the movements of the lower as well as of the upper ribs, and that the whole mechanism of respiration may in time be more thoroughly understood.

In medical practice also this new arm of precision may prove of great value.

The number of cases of disease hitherto examined by its aid is still too small to allow us to base upon them practical conclusions. It can scarcely be doubted, however, that important results must flow from such measurements as it affords.

Already there are indications that the prognosis of phthisis is more favorable when the ribs over the affected portions of lung begin to exercise their power of forward motion, that is, when the proportions between the several movements become more like those of health; and in emphysema and chronic bronchitis the probabilities of prolongation of life lessen directly with the diminution in the movements of the thorax, and we may probably judge of the extent to which these diseases have progressed by comparing the action of the lower with that of the upper parts of the chest wall. And we may, perhaps, learn at least one practical

lesson as to treatment from the facts which have been noted respecting the mechanism of respiration in disease.

In the first stage of phthisis it has been shown that the ribs over the irritated lung substance are deprived of one part of their motion, that, namely arising from the bending of the rib, and although this loss of movement may be partly due to the consolidation or loss of elasticity in the lung tissues; yet from the fact that it is one of the earliest symptoms of disease, and, from the analogy of nature's operation in the case of other movable parts when they become inflamed, it seems probable that the want of motion is greatly due to cessation of the action of the intercostal muscles, and that it is intended to give rest to the underlying parts.

There is ample proof that independent *action* on the part of these muscles is possible, and hence there may be an independent temporary *cessation* from action. May we not then follow the guidance of nature in thus imposing rest upon the affected parts. The good effects of entire rest in bed during the acute stages of lung disease is well known.

Mr. Hilton, in his admirable work on 'Rest and Pain,' has boldly suggested the application to medical cases of the principle of Mechanical rest, which is so important in the treatment of surgical disorders. We have, also, in the facts brought forward in this paper, examples of the method adopted by nature.

It would, therefore, surely be a rational proceeding to endeavour, as much as possible, to restrict the movements of the ribs over the portions of lung affected by acute inflammation or irritation. In the cases of pleurisies and pneumonias by the application of carefully devised jackets or bandages, and in phthisis of the upper lobes by divesting the lower ribs of all ligature, and, perhaps, by the use of pads made to fit over the upper ribs and to restrain their movements.

To the consulting physician the numerical records of this instrument obtained at different stages of the various lung diseases would supply accurate data upon which to found his

opinion on the probable course of the cases brought before him, and he could refer with confidence to his notes respecting them without the vagueness which necessarily attends any mere verbal description of the results of unaided palpation.

In hospital teaching I could conceive that it would prove of distinct value, not only by enabling a clinical teacher to demonstrate the fact of alterations in the mobility of different parts of the thorax, and to point to the directions in which the motions are impaired; but it would be an additional means of inculcating those habits of exact observation and of definite measurement of morbid changes which are or ought to be the characteristic of modern medical research.