Elsberg (L.)

PNEUMATOMETRY:

THE

NEW MEANS OF DIAGNOSIS

IN

DISEASES OF THE RESPIRATORY ORGANS.

BY

LOUIS ELSBERG, A. M., M. D.,
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PNEUMATOMETRY: THE NEW MEANS OF DIAGNOSIS IN DISEASES OF THE RESPIRATORY ORGANS.[1]

Definition.—Pneumatometry (from πνευμα, "air," appertaining to the breathing, and μετρον, "measure,") is the method of measuring inspiratory and expiratory force. For clinical purposes, the extreme respiratory power is measured which the patient is capable of exerting. This maximum, which is nearly constant for the same person in normal condition, varies characteristically in disease. The great value of pneumatometry for diagnosis consists in the fact that each of the two phases of breathing, inspiration and expiration, can be measured objectively and in figures, showing the deviation from health of either the one or the other separately, as well as the relation of the two to each other.

History.—A century and a half ago the Rev. Dr. Hales engaged in some curious researches upon the air. In the course of his experiments, he had occasion to breathe out of and into closed air receptacles, and, being desirous of ascertaining the force he could bring to bear, employed a mercury manometer. So far as I can find out, he is the first who entered upon such an investigation. The book in which he made it known was printed in 1726. Speaking of the use of bladders or leather bags filled with air, for temporarily sus-

[1] Read before the Academy, October 7th, 1875.

taining respiration in a room filled with suffocating vapors, in case of fire, for divers, etc., he says: "But in every apparatus of this kind great care must always be taken that the inspiration be as free as possible, by making large passages and valves to play most easily. For though a man by a peculiar action of his mouth and tongue may suck mercury 22 inches [about 558 millimetres], and some men 27 or 28 [685 to 712 millimetres] high, yet I have found by experience that, by the bare inspiring action of the diaphragm and dilating thorax, I could scarcely raise the mercury two inches [50 millimetres]. At which time the diaphragm must act with a force equal to the weight of a cylinder of mercury, whose base is commensurate to the area of the diaphragm and its height two inches, whereby the diaphragm must at that time sustain a weight equal to many pounds. Neither are its counteracting muscles, those of the abdomen, able to exert a greater force.

"For, notwithstanding a man, by strongly compressing a quantity of air included in his mouth, may raise a column of mercury in an inverted syphon, to five or seven inches in height [126 to 178 millimetres], yet he cannot, with his utmost strainings, raise it above two inches [say 51 millimetres] by the contracting force of the muscles of the abdomen; whence we see that our loudest vociferations are made with a force of air no greater than this."[1] I have quoted this passage in full here, because it is very interesting as presenting the result of the first pneumatometric investigation, although, as we shall see hereafter, the figures given do not accord with those that have since been ascertained.

Whether any one soon followed in the path of research thus opened up by Hales I do not know. More than a hundred years later, in 1844, Valentin published his text-book of "Hu-

[1] "Statical Essays: containing vegetable staticks or an account of some statical experiments on the sap in vegetables, being an essay towards a Natural History of Vegetation: of use to those who are curious in the culture and improvement of gardening, etc., also a specimen of an attempt to analyse the Air, by a great variety of chymio-statical experiments, which were read at several meetings before the Royal Society. By Steph. Hales, D. D., F. R. S., Rector of Farringdon, Hampshire, and Minister of Teddington, Middlesex. The third edition, with amendments." London, 1738, vol. i., pp. 270 and 271.

man Physiology," and in it recorded his observations for determining manometrically the respiratory power of an adult healthy man. To the apparatus employed he gave the name Pneumatometer; it was a modified hæmadynamometer, and, simple as it was, the instrument was essentially the same as that in use at the present day.[1] In 1845 Mendelsohn published some investigations in pneumatometry.[2] In 1846 Hutchinson followed with a large number of elaborately conducted observations and experiments.[3] In 1853 Donders added his valuable contributions.[4]

But notwithstanding the labors of these investigators—notwithstanding that the two last mentioned, Hutchinson and Donders, had even particularly pointed out the fact of the importance of these researches for recognizing disease—all these publications remained barren of practical results for medicine until Waldenburg, less than four years ago, introduced the method of pneumatometry as a means of diagnosis.[5] For eighteen months previous to that time Prof. Waldenburg had studied and tested the method, had demonstrated it in his courses to medical students, and had shown it to me during my stay in Berlin.

The Instrument.—Waldenburg made the original instru-

[1] "Lehrbuch der Physiologie des Menschen." Von Dr. G. Valentin, ordentl. Professor der Physiologie und vergleichenden Anatomie an der Universität Bern. Braunschweig, Friedrich Vieweg und Sohn, 1844, vol. i., p. 524, *et seq.*

[2] "Der Mechanismus der Respiration und Circulation oder das explicirte Wesen der Lungenhyperämien." Von A. Mendelsohn. Berlin, Behr'sche Buchhandlung, 1845.

[3] "On the Capacity of the Lungs, and on the Respiratory Function, with a View of establishing a Precise and Easy Method of detecting Disease by the Spirometer;" by John Hutchinson, Surgeon (with numerous Woodcuts). "Medico-Chirurgical Transactions," published by the Royal Medical and Chirurgical Society of London, vol. xxix. (second series, vol. xi.), London, 1846, pp. 137–252.

[4] "Beiträge zum Mechanismus der Respiration und Circulation im gesunden und kranken Zustande." Henle and Pfeufer's *Zeitschrift für rationelle Medicin*, N. F., Bd. iii., Heidelberg, 1853.

[5] "Die Manometrie der Lungen oder Pneumatometrie als diagnostische Methode." Von Prof. Dr. L. Waldenburg. *Berliner klinische Wochenschrift*, Jahrgang 8, No. 45, 1871, p. 541.

ment of Valentin more convenient, and has described and figured it in his latest publication on the subject.[1] Eichhorst[2] has added to Waldenburg's apparatus an air-tight stop-cock, which I have replaced by an automatic valve.

The pneumatometer, as I have had it constructed and represented in the following woodcuts, consists of a glass tube, bent upon itself so as to have two parallel limbs, attached to an upright metal scale. One end of the tube is expanded to facilitate the pouring in of mercury; being in contact with the atmosphere, it is covered, after sufficient mercury has been poured in, with gauze to prevent the entrance of dust; the other end is bent at a right angle, and with it is connected, in an air-tight manner, a rubber tube through which the breathing is accomplished. The scale has a zero-line in the middle and 125 millimetres above and below for each side of the glass tube. In addition to two fastenings which keep the glass in front of the metal, there is a slit below, in which slides a rest for it, controlled by a screw behind; this facilitates getting the glass tube, after being about half filled with mercury, in the proper position upon the scale, viz., the level of the mercury in each limb of the tube being made to correspond with the zero-line. The breathing-tube leads, either with or without the intervention of the hard-rubber valve-tube (*a* in Fig. 1), to either nose or mouth-pieces (Fig. 2, and *c*, *d*, in Fig. 1) or a nose-and-mouth-mask (*b*, in Fig. 1), all of which will be more particularly described presently. The foot of the pneumatometer is of wood, and about two inches high; the upright metal piece about thirteen inches high and two inches wide; the glass tube nearly one-half inch thick. Both limbs of the glass tube should have exactly the same bore, so that the mercury in one rises exactly as much as it

[1] "Die pneumatische Behandlung der Respirations- und Circulationskrankheiten im Anschluss an die Pneumatometrie, Spirometrie und Brustmessung. Bearbeitet von Dr. med. L. Waldenburg, Professor E. O. an der Kgl. Friedrich-Wilhelms-Universität in Berlin. Mit 30 Holzschnitten. Berlin, August Hirschwald, 1875.

[2] "Ueber die Pneumatometrie und ihre Anwendung für die Diagnostik der Lungenkrankheiten." Von Hermann Eichhorst aus Königsberg. *Deutsches Archiv für klinische Medicin*, Bd. xi., Heft iii., 1873, p. 268.

FIG. 1.

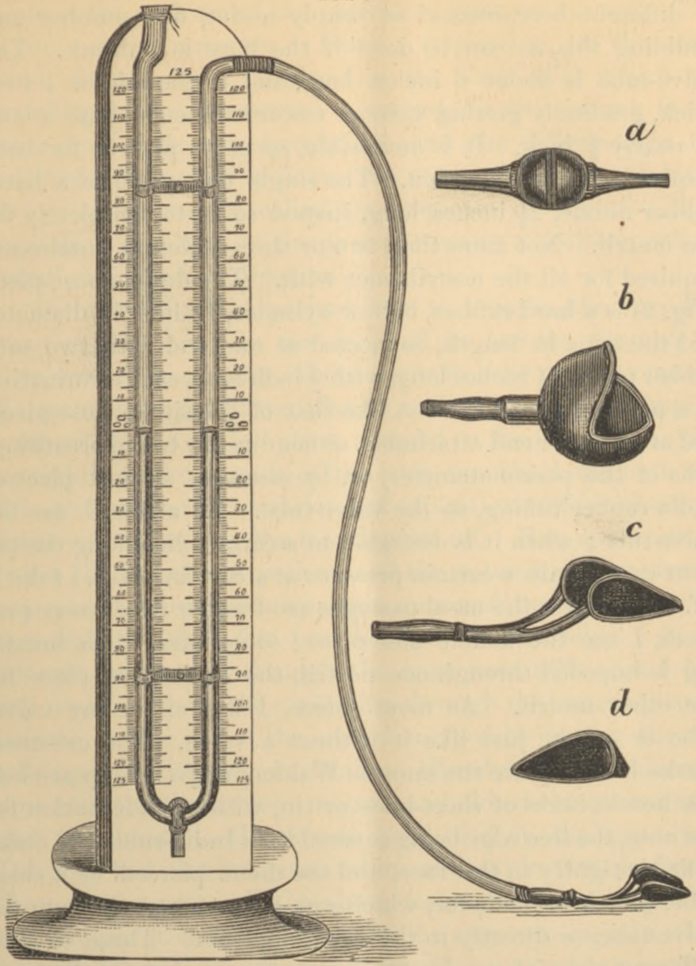
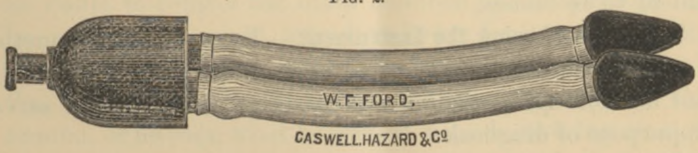


FIG. 2.



falls in the other, for, as the pressure upon the column of mercury is measured by the difference in level in the two, it would be necessary to note the number of millimetres both above and below zero, and add these together, if the two portions were of different bore, instead of simply noting one number and doubling this, as can be done if the bore is uniform. The valve-tube is about 6 inches long, and in the middle 1 inch thick, gradually getting thinner toward the ends, with a bore of nearly ½ inch. It is reversible, so as to answer for both inspiration and expiration. The single nose-piece is a hard-rubber nozzle, 2½ inches long, shaped so as to completely fill the nostril. Not more than two or three different nozzles are required for all the nostrils met with. The double nose-piece (Fig. 2) is a hard-rubber, hollow cylinder, 1½ inch in diameter and the same in length, connected at one end with two soft-rubber pipes, 3½ inches long, with ½ inch bore, each terminating in a nozzle of hard rubber, like that of the single nose-piece, and at the other end attachable, either directly to the breathing-tube of the pneumatometer, or, by means of a short piece of India-rubber tubing, to the valve-tube. As a rule, I use the valve-tube; when it is desirable to ascertain how long the patient can sustain a certain pressure at a certain point, I take it off. Whenever the nasal passages are free for respiratory purposes, I use the double nose-piece; sometimes, when breathing is impeded through one nostril, the single nose-piece for the other nostril. As mouth-piece, I use either my valve-tube or a tube just like it without a valve. The oro-nasal masks I employ are the same as Waldenburg's. They are hollow hemispheres of sheet-brass or tin, with an indentation for the nose, the free edge being covered with India-rubber to make it fit air-tightly to the face, and the dome pierced by a short tube, ¾ inch in diameter, which can be attached either to the valve-tube, or directly to the breathing-tube. Three or four different sizes of masks are required, varying in diameter from 2½ to 4½ inches.

The Mode of using the Instrument.—To carry out the method of pneumatometry is exceedingly simple; nevertheless, it must be thoroughly studied and practised before it can serve the purpose of diagnosis.

Upon breathing into the instrument, the pressure of the air upon the column of mercury with which it first comes into contact depresses the column, the mercury rises in the opposite limb of the glass tube, and the difference of level in the two limbs is the measure of the expiratory pressure exerted. This is the positive pressure. During inspiration, on the other hand, the mercury contained in the limb with which the breathing-tube is connected is sucked up, the column in the other limb falls correspondingly, and the difference in the levels of the mercury indicates the negative pressure of inspiration, which may be called the inspiratory traction. Thus, expiration yields us on the pneumatometer a positive, and inspiration a negative pressure.

In instructing the patient how to breathe, the very first question that must be met is, Shall he breathe through the nose, or mouth, or both? Hales seems to have used the mouth. Valentin employed three different methods, viz.: 1. He applied a funnel-shaped mouth-piece, adapted to the form of the lips, air-tightly to the outside of the open mouth, closed both nostrils, and had both inspiration and expiration performed several times without taking the mouth-piece off. But, as the air between the lips of the patient and the column of mercury became, under these circumstances, soon unfit to sustain respiration, only the first few breaths were of any value. 2. He allowed inspiration through the open nose with closed lips, and measured only the expiration through the mouth-piece as before. 3. He varied the second method by having the nostrils open during the expiration. Mendelsohn introduced a nose-tube tightly into one nostril, and closed the other nostril and the mouth. Hutchinson proceeded in the same way. Donders had also both inspiration and expiration performed through the nose. Waldenburg tested the same procedure, but dropped it entirely, except for the very rare cases in which he finds the patient intractable for other methods, or in which he wants to control the other methods by an additional one; he uses a mouth-piece, introduced very far into the mouth, if borne by the patient, to the very root of the tongue, beyond the *isthmus glosso-palatinus*, with the lips tightly closed around, or he uses, what he prefers, a mask covering air-tightly both nose and mouth, the patient breathing both in and out with his mouth widely open. Nearly all who have practised pneumatometry since, have followed Waldenburg in preferring the mask. After experimenting a good deal with the mask, and with my nose-tubes, I must confess that I think the latter more exact and unchanging in results, in all cases where freely applicable, i. e., where there is no obstruction to breathing by swelling, mucus, or otherwise, or where its use is not annoying to the patient. But Waldenburg's method of breathing through the mask yields good results, and I frequently employ it—and also the mouth-piece—in conjunction with the method of breathing through the nose-piece. In cases of catarrh or obstruction of the nose, I frequently, also, place Waldenburg's and my methods in juxtaposition, to determine the difference of the manifestation of respiratory power caused by the difficulty of breathing through the nose. Whenever the patient uses the nose-piece, he must keep the mouth shut.

Like Eichhorst (*op. cit.*), I have found that the sources of error which Waldenburg has very properly pointed out, can be avoided by attention and properly instructing the patient. These sources of error arise from the powers of suction and expulsion that can be exercised by the muscles of the mouth and throat; from inattention on the part of the patient to what he is doing, in breathing *out* during intended inspiration, and *in* during intended expiration; and from breathing irregularly and repeatedly in one effort.

The breathings should be deep, and with the exertion of all the power of which the individual is capable. Before breathing into the instrument, I let him fill his lungs well. After each expiration, I give him a moment's rest, during which he breathes naturally; he then takes a deep inspiration and makes another expiratory effort. The first few trials I hardly ever count. I show him just how to do it, and usually after the fourth or fifth experiment—in the case of an exceptionally unteachable patient, not until after the tenth or twelfth—he avoids all sources of error. I then try him (after a rest, if he is weak) five or six times more, and note down the maximum pressure attained in any one of these successful efforts. These last five or six experiments, as a rule, give the same or nearly the same result, which I have found unvarying, even at repeated rests at irregular intervals—a reasonably sure indication that it is pretty nearly correct. After finishing with the expiration, I proceed to measure the inspiratory power in a similar manner. Waldenburg found, however, that it is immaterial whether an ordinary or a deep expiration precedes the inspiration to be measured, and I have come to hold the same opinion.

In both phases of respiration, a difference can be made between a forcible effort and a slower, gradually increasing, but nevertheless as powerful, exertion. In the former, a greater pressure is attained for a moment, which sinks rapidly; but, in the latter, the column of mercury can be sustained at a certain height for one or more seconds. As I usually attach to the pneumatometer my valve-tube, which maintains the pressure achieved, I make use of the former mode, which upon the whole is certainly preferable; but occasionally I remove the valve-piece, and measure by the other mode as well. The latter, of course, gives smaller and more complicated results.

I must give a caution in regard to reading the scale. I have already mentioned that the bore of the two limbs of the tube containing the mercury should be uniform, in order that the pressure be correctly attainable by simply doubling the number of millimetres above or below the zero-line indicated in either limb. Every one can easily ascertain whether in this respect his pneumatometer is trustworthy, by determining whether the level of the mercury is at exactly the same figure in each limb. But the mercury, on account of its adhesion to the glass, has a convex surface in the tube, and care must be taken to note the tangential line. A mistake will certainly be made if the level of the observer's eyes be either too high or too low.

Immediately after a full meal, the respiratory power, especially the expiratory, is usually diminished, and the measurement is not reliable.

Pneumatometry in Health.—We have seen that Hales came to the conclusion that about 50 millimetres is the maximum attainable during inspiration "by the bare inspiring action of the diaphragm and dilating thorax;" and also during pure expiration, even with the "utmost strainings." He very properly excluded oral suction and expulsion as sources of error, but I suspect that his apparatus was not perfectly air-tight, and that therefore his figures are too low. Valentin obtained, in the cases of four different individuals, the following maxima: 1, deepest inspiration —130 millimetres, most forcible expiration +80 millimetres; 2, forced inspiration —232, forced expiration +256; 3, forced inspiration —220, forced expiration +256; 4, forced inspiration —58, forced expiration +224. In later publications, Valentin reports still higher figures, viz.: —232 to —266 millimetres for inspiration, +260 to 326 millimetres for expiration.[1] Waldenburg says, and I agree with him, that these figures are explicable only by assuming that instead of, or together with, inspiration, the aspiratory power of the mouth, and instead of, or together with, expiration, the power of expulsion of the mouth, entered into the measurement. Mendelsohn found, as the mean of experiments on seven persons —87 millimetres for forced inspiration, and +113 to 122 millimetres for forced expiration. In the different individuals the inspiratory power varied from 52 to 117 millimetres, the expiratory from 85 to 170 millimetres. The expiratory pressure always exceeded the inspiratory traction, say, by about one inch, or 26 millimetres. These figures, it will be seen further on, agree very well with my own. Hutchinson obtained figures also very accurate, although his average is smaller than mine. He constructed a table on his instrument, of which he says, "Certain words are marked on the plate, their position having been determined by 1,500 experiments." He gives his figures in inches, which I have calculated in millimetres, omitting fractions of a millimetre under $\frac{1}{2}$, and reckoning fractions over $\frac{1}{2}$ as a whole millimetre:

[1] From the fourth edition of his "Grundriss der Physiologie," Braunschweig, 1855, as quoted by Waldenburg, "Die pneumatische Behandlung," etc., p. 2.

Inspiratory power ranging about:	Characterization.	Expiratory power ranging about:
38 millimetres.	"Weak."	51 millimetres.
51 "	"Ordinary."	63 "
63 "	"Strong."	89 "
89 "	"Very strong."	114 "
114 "	"Remarkable."	147 "
140 "	"Very remarkable."	178 "
151 "	"Extraordinary."	216 "
178 "	"Very extraordinary."	254 "

He adds, "It will be observed that the figures on each side of the same word differ in their value, the expiratory side ranging about $\frac{1}{3}$ higher, because the power manifested (I do *not* mean power exerted) by these muscular efforts varies in this relation." This is certainly very frequently true, but occasionally the relation between the expiratory and inspiratory powers varies within very wide limits even in health, although the former is always greater than the latter. As an average, Hutchinson obtained about —76 millimetres for inspiration, and about 100 millimetres for expiration, for men. He does not seem to have determined the respiratory power of women. A certain relation exists, according to Hutchinson, between the height and the respiratory power, and he gives the following as the mean correspondence during health:

Height	Up to 5 ft.	5 ft. 1 in.	5 ft. 2 in.	5 ft. 3 in.	5 ft. 4 in.
Inspiratory power in inches	2.55	2	2.52	2.31	2.70
Expiratory power in inches	3.28	3.36	3.23	3.15	4.32

Height	5 ft. 5 in.	5 ft. 6 in.	5 ft. 7 in.	5 ft. 8 in.	5 ft. 9 in.
Inspiratory power in inches	2.84	2.70	3.07	2.96	2.91
Expiratory power in inches	4.33	3.87	4.18	4.13	4.28

Height	5 ft. 10 in.	5 ft. 11 in.	6 feet.	Over 6 ft.
Inspiratory power in inches	2.83	2.77	2.65	2.67
Expiratory power in inches	3.94	3.63	4.48	4.41

According to this, at the height of 5 feet 7 inches and 5 feet 8 inches, the inspiratory power is greatest, and thence the strength gradually decreases as the stature increases.

The men of 5 feet 7 and 8 inches elevate a column of about 3 inches of mercury = 76 millimetres: this Hutchinson calls a "healthy power." The men of 6 feet have the greatest expiratory power, viz., one of about 4½ inches = 114 millimetres. But Hutchinson says, "The expiratory power I do not consider such a test of strength, or, if I may be allowed the term, the *vis vitæ*, as the inspiratory." He refers here to the influence of vocation and habits upon the expiratory function. I have not been able to confirm this relation between the height of a person and his inspiratory and expiratory power. Donders published figures which are rather small; like Valentin, Mendelsohn, and Hutchinson, he found the expiratory power to exceed the inspiratory. He gives the negative pressure, for forced inspiration, as being from 36 to 74 millimetres, the positive pressure, for forced expiration, from 82 to 100 millimetres.

Waldenburg declares, as the result of his numerous observations, that the figures vary within wide limits: "Healthy adult men, who are not especially strong, reach on the average, by forced inspiration, a negative maximum pressure of 80 to 100 millimetres, by forced expiration, a positive maximum pressure of 100 to 130 millimetres. Very strong muscular men often considerably exceed these figures; they may attain by inspiration to from 120 to 160 millimetres, by expiration to from 150 to 220 millimetres. Weak persons, on the other hand, give lower rates; however, if they are healthy, we may regard for adult persons of the male sex 70 millimetres as the minimum negative, or inspiration, pressure, and 80 millimetres as the minimum positive, or expiration, pressure. Women can reach only considerably lower rates than men. With them, on an average, the negative pressure of forced inspiration amounts to from 60 to 80 millimetres, the positive pressure of forced expiration to from 70 to 110 millimetres. Higher figures are reached only by few. In the case of healthy women, about —50 millimetres may be regarded as the minimum for forced inspiration, +60 millimetres for forced expiration. Children of the age of about ten years and over usually show rates which correspond entirely, or nearly (with a difference of perhaps 10 to 20 millimetres), to the minimum of adults. Not a few children, indeed, reach the average of adults. I have, however, not a sufficiently large number of observations to be able to give exact figures for children of the various ages. The same is true of very advanced age. Here, I can state only this, that in the case of old men (sometimes, indeed, already at an age of beyond sixty years) the pneumatometrical figures fall to near the minimum, or even below this. All these numbers refer to the maxima obtained by forcible inspiration and expiration. The figures are much smaller for the more slow inspiration and expiration, gradually increasing in power, with which the person is able to maintain the pressure at the height for one or more seconds. With healthy adult men, the force of inspiratory traction observed in this manner varies from 50 millimetres to, at the most, 120 millimetres, the expiratory pressure from 60 to 150 millimetres; the mean values are, for inspiration, 60 to 90 millimetres, for expiration, 70 to 100 millimetres. With women, inspiratory traction reaches some 25 to 60 millimetres, expiratory pressure, 30 to 80 millimetres."[1] Waldenburg's figures closely, upon the whole, correspond to those which I have obtained by the examination of healthy persons; the extremes are within nearly the same limits, and I regard his results as very reliable. Eichhorst's figures (*op. cit.*) are smaller than Waldenburg's and mine, but he practised the mode of slow and gradual, though deep, rather than quick and forcible, respiration. His averages, obtained from twenty-four men, are 44 millimetres for inspiration, 60 millimetres for expiration; from eighteen women, 26 millimetres for inspiration, 36 millimetres for expiration. His lowest figures among men are, for inspiration, 17 millimetres (found in two cases, one a laborer fifty-one years old, with expiratory power of 35 millimetres, the other a merchant fifty-two years old, with expiratory power of 26 millimetres), for expiration, 26 millimetres (the case of the merchant just mentioned); among women, for inspiration, 11 millimetres (in a laborer's widow, fifty-three years old, whose expiratory power is given as 25 millimetres), for expiration, 25 millimetres (found in the case of this widow, and in that of a servant-girl

[1] "Die pneumatische Behandlung," etc. (*op. cit.*), p. 27.

of nineteen years, whose inspiratory power was 24 millimetres). His highest figures among men for inspiration are 86 millimetres (in the thirteen-years-old son of a shoemaker, whose expiration measured 91 millimetres), for expiration, 94 millimetres (in a student aged twenty-three years, whose inspiratory power was 82 millimetres); among women, for inspiration, 42 millimetres (in a girl of sixteen years, who worked in a factory, whose expiration measured 47 millimetres), for expiration, 55 millimetres (in a laboring woman, fifty-one years old, whose inspiration reached only 25 millimetres). Lassar,[1] who measured, not the maximum respiratory power of which the individual was capable, but took the average of a number of experiments, gives as the average of such averages, for breathing through the mouth, 50 millimetres for forced inspiration, and 60 millimetres for forced expiration; for breathing through one nostril, for forced inspiration, 41 millimetres, for forced expiration, 52 millimetres.

The result of my own investigations of pneumatometry in over 100 healthy persons is, briefly stated, as follows: For the male sex, the average of the maximum inspiratory power is —86 millimetres, the average for the maximum expiratory power +110 millimeters; for the female sex, the average of the maximum of forced inspiration —50 millimetres, that of the maximum of forced expiration +70. The highest figures I have met with in strong, healthy men are 170 millimetres for inspiration, and 230 millimetres for expiration. This is very exceptional, however. The maxima I have observed in healthy women—found also only very rarely—are 90 millimetres for inspiration, and 120 for expiration. The minimum of respiratory power compatible with perfect health in women, I am forced to place much lower than Waldenburg has done; as to men I am disposed to agree to his minimum figures, although all the healthy adult males that I have examined showed greater power than he gives as the minimum met with. I have full records of twenty-five individuals of each sex, sub-

[1] "Zur Manometrie der Lungen. Inaugural-Abhandlung, der medicinischen Facultät zu Würzburg vorgelegt." Würzburg, 1872. Waldenburg, "Die pneumatische Behandlung," etc., p. 28.

jectively in perfect health, who have been carefully clinically examined, more especially as to the condition of the respiratory organs, but really also as to the condition of other organs, stating age, occupation, habits, build, weight, height, trunk measurements and lung capacity (vital ratio), physical signs on examination of chest, previous history and present state in other respects, and respiratory power as shown by the pneumatometer. These records show that an adult woman may enjoy perfect health and yet not be able to reach on the pneumatometer a higher figure than —20 millimetres as the maximum for forced inspiration, and +30 millimetres as that for forced expiration. The lowest figures yielded by any one of the twenty-five healthy males were those of a strong, florid-complexioned gentleman of fifty-three years, viz., —74 millimetres inspiration, and 86 millimetres expiration.

With healthy children under ten years I have had very little experience. A boy of eight years has registered —50 for inspiration, and 70 for expiration; and a little girl of seven, very strong, however, for her age, —36 for inspiration, and between 40 and 50 for expiration. These are the highest figures reached. Children over ten years usually exhibit almost the same latitude and nearly the same figures as adults. In old age the figures often become surprisingly small. As a rarity I must mention the case of a hale and hearty gentleman, seventy-five years of age, who registered —112 millimetres for inspiration, and 130 millimetres for expiration.

I will add Prof. Waldenburg's respiratory power as shown by the pneumatometer, reported by himself, and my own:

I. Waldenburg's vital lung capacity: 3,000 cubic centimetres.

A. Breathing through a mouth-piece.

1. Inspiration.

a. Quick, forced inspiration. The mercury rapidly rises in one limb of the glass tube to 70 millimetres above zero, but sinks at once and keeps playing about a much lower point. The maximum inspiratory power is, therefore, —140 millimetres.

b. Slower, but the deepest possible, inspiration. The negative pressure increases slowly until it reaches 100 millimetres, then falls to 80 millimetres, and for two seconds varies from 40 to 80 millimetres and from 50 to 70 millimetres. The average number is, therefore, 60 millimetres, and about this point, indeed, the mercury remains longest.

2. Expiration—after deep but not strained inspiration.

a. Quick, forced expiration. The maximum pressure attained for a moment amounts to 150 millimetres.

b. Slowly-increasing, powerful expiration. The pressure of 100 millimetres is reached, then the column of mercury falls and pendulates up and down, indicating for four seconds from 60 to 80 millimetres, and about half that time a few millimetres above or below 70 millimetres.

The measures of inspiration, as well as of expiration, are the same whether the nose is closed or not.

B. Breathing through a nose-piece [through one nostril].

1. Inspiration.

a. Quick, forced inspiration. For a moment a negative maximum pressure of 140 millimetres is attained with imme diate falling of the mercury.

b. Slow, very deep inspiration. After reaching 100 millimetres, falling and pendulating of the mercury for three seconds at from 40 to 80 millimetres. Average 60 millimetres.

The figures are the same, whether the second nostril remains open or is closed with the finger. The nostril closes involuntarily of itself during the inspiration.

2. Expiration—after deep but not strained inspiration.

a. Quick, forced expiration. Maximum reached for a moment 170 millimetres.

b. Slow, profound expiration. The pressure rises to 100 millimetres, varies for two seconds between 100 and 70 millimetres, and then remains for two seconds longer at 70 millimetres.

Throughout this experiment the second nostril was closed with the fingers. In other experiments, during which it had been left open, the numbers obtained were very much smaller and indeed useless, on account of the unimpeded egress of air through it. The maximum of expiratory power with open nostril amounted to only 110 millimetres.

C. Breathing through the mask.

1. Inspiration.

a. Forced, quick inspiration. Maximum, for a moment, —130 millimetres. Rapid fall.

b. Slower, deep inspiration. The negative pressure increases slowly to about 100 millimetres, then trembling movements of the mercury indicate from 50 to 70 millimetres for one and a half second. Mean: —60 millimetres.

2. Expiration after deep but not strained inspiration.

a. Quick, forced expiration. For a moment 140 millimetres pressure is reached; mercury falls quickly.

b. Slower, strong expiration. Hovering of the mercury, for one and a half second, between 60 and 80 millimetres. Mean: 70 millimetres.

II. As to myself (data of over a year ago), age thirty-eight years; strong and muscular; weight, without clothes, 157 lbs.; height (five feet seven and three-quarters inches), 172 centimetres; height of trunk, measured from seventh cervical vertebra to end of coccyx, 66 centimetres; periphery, measured about 3 centimetres below nipple, 81 centimetres; vital lung capacity, 4,300 cubic centimetres (vital ratio, i. e., the relation of the "vital lung capacity" to the cubic contents of the trunk, 8.02); lungs healthy.

A. Breathing through a mouth-piece.

1. Inspiration.

a. Quick, forced inspiration. Maximum negative pressure 110 millimetres, with rapid sinking of the mercury.

b. Slow, deep inspiration. Mercury sustained for three and a half seconds between 40 and 60 millimetres negative pressure. Mean: —50 millimetres.

2. Expiration after deep but not strained inspiration.

a. Quick, forced expiration. Maximum, reached but for a moment, 130 millimetres.

b. Slow, unexcited, but powerful expiration. The mercury kept for over three seconds between 60 and 80 millimetres, longest about the mean of these figures, viz.: 70 millimetres.

No difference is observed in these results whether the nose is held shut or not.

B. Breathing through my double nose-piece. (For convenience of experimenting, breathing out was accomplished through the mouth when testing the inspiration, and breathing in when testing the expiration, which, it was found, did not disturb the mercury.)

1. Inspiration.

a. Quick, forced inspiration. Maximum —130 millimetres, reached with quick descent and oscillation of the mercury.

b. Slow and deep inspiration. A pressure of —120 millimetres is registered for a moment, and one of from —80 to —40 millimetres kept up for several seconds; most of the time about 60 millimetres.

2. Expiration after deep but not strained inspiration.

a. Quick, forced expiration. Maximum obtained, 150 millimetres.

b. Slow and powerful expiration. A pressure of 100 millimetres for an instant, one of 90 for a little longer, and a varying one from 50 to 80 millimetres for two and a half seconds is reached.

C. Breathing through the mask.

1. Inspiration.

a. Quick, forced inspiration. Maximum —130 millimetres.

b. Slow and deep inspiration. After the negative pressure of 120 millimetres has been just touched, it plays about —60 millimetres as a central point for nearly two seconds, varying from 10 to 15 millimetres above and below.

2. Expiration after deep but not strained inspiration as before.

a. Quick, forced expiration. Momentary maximum pressure, 150 millimetres.

b. Slow, strong expiration. The mercury, slowly descending, marks for more than two seconds a pressure varying from 60 to 80 millimetres.

Pneumatometry in Disease.—We have seen that in the normal condition the positive or expiration pressure is greater than the negative or inspiration pressure. We have also seen that, although the latitude of variation within the limits of health is a very great one, we still recognize for each sex a certain normal average and requisite minimum of inspiratory and expiratory power. Upon these considerations Waldenburg based his division and classification of the pathological breathing revealed by the pneumatometer. He made two groups, each of which he subdivided into three classes, viz.:

Group I.—Characterized by the inversion of the normal relation between expiratory and inspiratory pressure; the positive pressure is smaller than the negative—there is an insufficiency of expiration.

Class 1.—With the insufficiency of expiration, the inspiratory pressure is normal.

Class 2.—With the insufficiency of expiration, the inspiratory pressure does not reach the normal minimum; inspiration is therefore also insufficient; nevertheless, the expiratory pressure is still less than the inspiratory.

Class 3.—With the insufficiency of expiration, the inspiratory pressure is larger than normal.

Group II.—Characterized by insufficiency of inspiration, the normal relation between expiratory and inspiratory pressure being preserved; the negative pressure is smaller than the positive.

Class 4.—With the insufficiency of inspiration, the expiratory pressure is normal.

Class 5.—With the insufficiency of inspiration, the expiratory pressure, although larger than the inspiratory, does not reach the normal minimum; expiration is therefore also insufficient.

Class 6.—With the insufficiency of inspiration, the expiratory pressure is larger than normal. Waldenburg has added this class for the sake of completeness, admitting that he has never seen a case in point. It is difficult to conceive of a disease bringing about such a condition unless, perhaps, where, with normal inspiration, the expiratory power has become preternaturally strong through habits, vocation (that of "glass-blower, trumpeter, wrestler"), and the like, and disease should then interfere with inspiratory power and leave the expiratory at first still greatly in excess; thus Hutchinson reports the case of a wrestler in whom he found "the expiratory power exceed nearly four times that of the natural inspiratory power, which vast preponderance was purely the effect of his favorite amusement."

As Waldenburg has shown, the inspiratory traction as well as the expiratory pressure is a product of various factors, some of a positive, some of a negative character. These factors are: 1. *The muscular power.* 2. *The elasticity of the lungs.* 3. *The obstacles presented by the walls of the chest, its contents and their surroundings.*

"In *inspiration*, the set of muscles brought into action for forcibly breathing air into the lungs forms the only positive factor. The muscular force has, on the one hand, to work against the elasticity of the lung-tissue which opposes expansion; on the other hand, it has to overcome the obstacles to change in the form of the thorax. These obstacles are principally the force of gravity of the thoracic wall which has to be overcome in raising the ribs; the change of form and position to which the thorax and its contents—lungs, heart, vessels, and pleura—are exposed by expansion of the chest; the elasticity of the walls of the thorax; the difference of pressure between the outer atmosphere and the somewhat rarefied air within the lungs; and, finally, the abdominal tension resisting the lowering of the diaphragm.

"The case is different in *expiration*. Of course, the muscles coming into action for forcibly breathing air out form the main factor of the pressure produced. But the obstacles to inspiration are also active in favor of expiration. The pulmonary elasticity is an aid to expiration, increasing its power. Gravity also, and the other obstacles, directly aid expiration, as the parts disturbed tend of themselves to return to their former position. Only in very forced expiration—when the thorax is compressed beyond its former or balanced condition—new obstacles arise, expiratory obstacles in contradistinction to inspiratory obstacles, while the elasticity of the lungs still continues to act in favor. *Thus, in inspiration, the muscular power forms the positive, the elasticity of the lungs and the obstacles the negative, factors; while in expiration all these three factors are positive ones, with only a relatively small negative one from expiratory obstacles.*" [1]

[1] "Die pneumatische Behandlung," etc., pp. 53, 54.

Waldenburg has laid down the following general propositions:

1. By muscular atrophy or diminution of muscular strength, the pneumatometrical figures are reduced, the inspiratory and expiratory about equally if the disease of the muscles be general; but the former or the latter alone, or one more than the other, if the disease affect only single groups of muscles, especially subservient more to either inspiration or expiration. *Cæteris paribus*, an increase of muscular power increases in like manner the figures registered on the pneumatometer.

2. A diminution of the elasticity of the lungs reduces the pressure of expiration and tends to increase the negative pressure of inspiration.

3. An increase of inspiratory obstacles reduces the power of inspiration and increases that of expiration, in case expiratory obstacles are not present at the same time. But, on the other hand, there may appear expiratory obstacles, while the inspiratory obstacles are not at all or only slightly increased. In such cases the expiratory power alone, or mainly, will be reduced.

Hutchinson says, "As it is a common rule that inflammation and disease in general are attended with pain on pressure, these also may be perceived by the diminished power manifested on the instrument which measures the pressure exerted." He then gives a table showing the difference between the inspiratory power of the healthy and that of the diseased, and adds, "This difference is about one-half, as might be anticipated, because weakness is the most prominent symptom of disease." [1]

Among the individual diseases, in obscure or incipient cases of which pneumatometry has furnished most important aid in diagnosis, pulmonary emphysema and phthisis must first be named; but it has already been called into requisition not only in other diseases of the respiratory organs, but also in diseases of the circulatory and other organs.

I. **Diseases of the Respiratory Organs.** 1. *Pulmonary Emphysema.*—Donders already has pointed out that vesicular emphysema must be accompanied with diminution of pul-

[1] *Op. cit.*, pp. 225, 226.

monary elasticity. Waldenburg has discovered and demonstrated that pneumatometry is a means with which we can detect emphysema in its incipient stage, while yet all other methods of examination fail; this, too, even when no actual subjective disturbances exist at the time; and, moreover, pneumatometry enables us to distinguish with probability between the various forms or stages of emphysema. In all cases there is dilatation of the terminating vesicles of the lungs, and "either an abnormal accumulation of air within the air-cells, or an infiltration of air into the sub-pleural and interstitial connective tissue."[1] The various forms or rather stages come all under the head of Waldenburg's first group of pathological breathing, viz., that characterized by the inversion of the normal relation between expiratory and inspiratory pressure; the positive pressure is smaller than the negative, there is insufficiency of expiration. The incipient stage or slightest degree of the disease belongs to the first class, i. e., with little or much insufficiency of expiration, the inspiratory pressure is normal; the most severe form belongs to the second class, when, together with the insufficiency of expiration, the inspiratory pressure, also, does not reach the normal minimum, i. e., when inspiration is also insufficient, though nevertheless the expiratory pressure is still less than the inspiratory; while the cases belonging to the third class, where with the insufficiency of expiration the inspiratory pressure is larger than normal (which, however, is more difficult, if not impossible, to determine, unless the patient's inspiratory power has been examined during health and known for comparison), constitute the compensatory form, and may be ranged as to severity between those of the first and second classes.

I could append a large number of cases both from my own experience and those reported by others, but I will only mention, exceedingly briefly, a few illustrative cases:

L. P., aged forty years; merchant; complains of dyspnœa on any unusual exertion. This has probably occurred for

[1] "Lectures on Diseases of the Respiratory Organs, Heart, and Kidneys." By Alfred L. Loomis, M. D., Professor of Pathology and Practical Medicine in the Medical Department of the University of the City of New York, etc., etc. New York: William Wood & Co., 1875, p. 79.

years, but increased so gradually that he hardly noticed it until the last two or three months. No cough, no expectoration. Inspection, percussion, and auscultation, reveal nothing abnormal. Health otherwise excellent. Pneumatometer showed inspiration —120 millimetres, expiration 92 millimetres.

H. S., aged thirty-five years; broker. Has had a cough off and on for over five years; is out of breath very easily on walking fast, going up-stairs, etc. Lungs extend lower down than normally, and heart, partly covered, is pushed downward and toward middle line. Respiratory murmur enfeebled, expiration-sound prolonged, some "rustling." Inspiratory power —130 millimetres, expiratory 70 millimetres.

W. H., aged fifty-two years. Has greatly suffered from shortness of breath on exertion ever since he can remember, much worse during the last year. Dilatation of the chest very marked, "barrel-shaped;" percussion-sound abnormally clear, "vesiculo-tympanitic;" auscultation-sound almost suppressed, sibilant in many places. Inspiration —40 millimetres, expiration 30 millimetres.

Mrs. R., aged thirty-eight years. Previously remarkably healthy; has suffered from dyspnœa on exertion for three years. Has had to give up singing. Now suffers from great oppression each time she walks a few steps. Heart covered, liver pushed down; harsh vesicular breathing. Inspiration —20 millimetres, expiration 16 millimetres.

2. *Asthma.*—Emphysematous persons are so liable to attacks of asthma, and asthma, when it comes itself from other causes, is so apt, perhaps so certain, sooner or later to produce emphysema, that the results of pneumatometry in asthmatic patients may frequently be ascribed to the coexistence of emphysema. But, independently of the latter, there exists during the paroxysm an expiratory insufficiency which the pneumatometer registers for some time thereafter, as in a case of seemingly uncomplicated spasmodic asthma in a man, twenty-eight years old, whose inspiration measured during the interval —50 millimetres, expiration 34 millimetres.

3. *Bronchitis.*—We can say of bronchitis—at all events, of chronic or frequently-recurring bronchitis—that it is very

frequently associated with pulmonary emphysema, and that it must, then, exhibit the pneumatometrical measures peculiar to the latter; but in many cases where this is to be excluded, as, for instance, in some cases of acute bronchitis, both primary and secondary, we also find insufficiency of the expiration. Waldenburg explains this by assuming that by narrowing of the smallest bronchioles on the one hand and pulmonary hyperæmia on the other, the expiratory pressure is in such cases interfered with, while the inspiratory remains unaffected. At all events, he and Eichhorst report cases in point, and I will add the following: J. B., a middling-strong man, in somewhat impaired health, however, for some time, took a very severe cold, with the symptoms of acute bronchitis. Auscultation revealed rather feeble respiratory murmur and sibilant *râles*. He has a frequent, hacking cough, which gives him a sense of rawness in the upper portion of the chest. Inspiratory power —86 millimetres, expiratory 60 millimetres.

4. *Pulmonary Phthisis.* — Hutchinson, who has made many hundred pneumatometrical observations on persons suffering from disease, has left us the following record of what he found in some cases of consumption:

Case I.—Incipient phthisis. Age, thirty years; weight, ten stone three pounds; height, five feet eight inches; pulse while sitting, 100; number of respirations per minute while sitting, 28; circumference of chest, 36 inches; mobility of chest, 1½ inch; vital capacity, 186 cubic inches; power of inspiration 0.70, of expiration 0.80 inch = inspiratory power —18 millimetres, expiratory 20 millimetres.

Case II.—Phthisis. Age, sixty years; weight, ten stone; height, five feet eleven inches; pulse while sitting, 60; respirations per minute, sitting, 40; circumference of chest, 35¼ inches; mobility, 1½ inch; vital capacity, 108 cubic inches; power of inspiration 0.75, power of expiration 0.46 inch = inspiratory power 19 millimetres, expiratory 12 millimetres.

Case III.—Phthisis. Age, thirty-six; weight, ten stone; height, five feet nine inches; pulse sitting, 100; respirations per minute, sitting, 40; circumference of chest, thirty-five inches; mobility, one inch; vital capacity, 80 cubic inches;

power of inspiration 1.50, of expiration 2 inches = inspiratory power —38 millimetres, expiratory 50 millimetres.

CASE IV.—Phthisis. This is the case of Freeman the "American Giant," and in it the pneumatometer as well as the spirometer *indicated* "the commencement of the disease which ultimately caused his death, and that *before* the usual means availed." I shall quote the full details which Hutchinson relates, viz.: "This man came over to England in 1842, and in the November of that year trained for a prize-fight; I examined him immediately before his *professional engagement*, when he might be considered in the 'best condition.' His powers were as follows: vital capacity four hundred and thirty-four cubic inches; height 6 feet 11¼ inches; weight nineteen stone and five pounds; circumference of his chest forty-seven inches; inspiratory power 5.0 inches; expiratory power 6.5 inches. In November, 1844, exactly two years afterward, he came to town in ill-health. I then examined him in the same way as before, twenty times at various intervals, during which his vital capacity varied from 390 down to 340, and the mean of all the observations was 344 cubic inches, a decrease of ninety, or more than twenty per cent., his respiratory power had decreased one-fifth, and his weight two stone. At this time I took him to two physicians well skilled in auscultation, and they both affirmed that they could *not detect* any organic disease. After January, 1845, I lost sight of Freeman, and in the October following I was kindly favored with the following account of him from Mr. Paul, surgeon to the County Hospital, Winchester: 'Freeman was admitted into this hospital on the 8th of October, in an extreme state of debility and exhaustion; he was reduced almost to a skeleton, complained of cough, and was expectorating pus in large quantities. Percussion on the anterior part of the chest, *under the clavicles*, gave on the right side a very dull sound; on the left one much clearer, but still, I think, less resonant than natural; I made but one attempt at auscultation, but could come to no conclusion, from a rather singular reason: the ribs were so large, the intercostal spaces so wide and so sunk in from the extreme state of emaciation to which Freeman was reduced, that I could not find a level space large enough to receive the end of the stethoscope; could not, in short, bring its whole surface into contact with the chest. Freeman's great debility and the clearness of diagnosis from other sources prevented my repeating the attempt. Freeman, after death, measured 6 feet 7½ inches and weighed ten stone and one pound. On opening the chest, the lungs on both sides were found adhering by their apices to the superior boundaries of the thorax, and studded throughout their substance with tubercles. The tubercles, on the whole, were much less numerous in the right lung than in the left; both lungs were nearly healthy at their base; the tubercular matter gradually increased in quantity toward their upper part, and the apices of both lungs were almost completely occupied by large cavities, partly filled with pus, and capable of containing two or three ounces of fluid each. The heart was remarkably small. The rest of the viscera appeared healthy.' "[1] In this case, the inspiratory power, from having been 127 millimetres during health, had become reduced to about 100 millimetres at a time when percussion and auscultation did not yet reveal any change.

In his first publication on the subject, already, Waldenburg stated that in phthisis the inspiratory pressure becomes at once diminished, while the expiratory, usually, for some time nearly normal, is more slowly lessened and remains larger than the inspiratory. The breathing of phthisical patients belongs, therefore, to the second group, viz.: that characterized by insufficiency of inspiration, the relation between expiratory and inspiratory pressure being normal, the negative smaller than the positive. This is so entirely different from what the pneumatometer shows in bronchitis and emphysema that it is of great value for differential diagnosis in doubtful cases, especially of incipient phthisis. As the disease advances and involves more and more of the lung-tissue, the negative pressure becomes smaller and smaller, in extreme cases sinking to most insignificant values. At the same time the positive pressure diminishes, preserving its relation; but, though continuing to preponderate, it, too, becomes very greatly reduced; in severe cases to 10 millimetres, and even

[1] *Op. cit.*, p. 219.

below this figure. Waldenburg and Eichhorst have reported numerous cases. I have a large number in my books, from which I will transcribe the following, omitting all details:

S. D., aged thirty years. Phthisis, first stage, right apex posteriorly. Inspiration —60, expiration 100 millimetres.

Miss F., aged twenty-three years. Phthisis, first stage, both apices (hæmoptysis several years ago). Inspiration —18, expiration 36 millimetres.

E. B., aged forty-two years. Phthisis, evidences of softening. Inspiration —30 millimetres, expiration 50 millimetres.

Mrs. D., aged twenty-seven years. Phthisis. Softening; hæmorrhages. Inspiration —14 millimetres, expiration, 20 millimetres.

J. L. S., aged thirty-five years. Advanced phthisis. Inspiration —10, expiration 20, which changed to 16 in less than two weeks.

Mrs. W., aged thirty-eight years. Advanced phthisis. Inspiration —8 millimetres, expiration 12 millimetres.

5. *Pneumonia.*—In pneumonia the inspiratory pressure is reduced, and when the inflammation is extensive the expiratory also, but the latter remains always greater than the former. I have had no opportunity myself to test the respiratory power in pneumonia, and therefore cite the following three cases published by Eichhorst: [1]

Case I.—Laboring-woman, aged fifty-nine years. Croupous pleuro-pneumonia of the left inferior lobe. Inspiratory power —25 millimetres; expiratory 36 millimetres. On the day before the crisis, inspiratory power —31 millimetres; expiratory 32 millimetres. Eleven days after the crisis, inspiratory power —40 millimetres; expiratory 44 millimetres. Fifteen days after the crisis, inspiratory power —60 millimetres; expiratory, 63 millimetres.

Case II.—Laborer, aged forty-three years. Croupous pleuro-pneumonia of the left lower lobe. Inspiratory power —23 millimetres; expiratory power 37 millimetres. Six days after the crisis, inspiratory power —50 millimetres; expiratory power 54 millimetres.

[1] *Op. cit.*, p. 278.

Case III.—Laborer, aged twenty-seven years. Croupous pleuro-pneumonia of the left lower lobe. Inspiratory power —22 millimetres; expiratory power 24 millimetres. In the further course of the disease, inspiratory power —13 millimetres; expiratory power 14 millimetres. Day of the crisis, inspiratory power —36 millimetres; expiratory power 38 millimetres. Three days after the crisis, inspiratory power —43 millimetres; expiratory power 46 millimetres.

6. *Pleurisy.*—Here, similar pneumatometrical conditions obtain as in pneumonia and pulmonary phthisis. Aside from the pain which tends to prevent deep inspiration, and therefore may reduce to a minimum the inspiratory pressure and correspondingly also the expiratory, it is obvious that compressed or inflamed consolidated tissue, or effusion, or pleural adhesion, must considerably interfere with inspiration, even when there is no pain. In all cases of pleurisy the pneumatometer registers insufficiency of inspiration: in mild cases the expiration may appear nearly normal; in severe cases there is insufficiency of both expiration and inspiration, the positive pressure of the former almost always exceeding, however, the negative pressure of the latter. As an example, I may mention, from my own observation, the case of M. R., aged thirty-nine years. Has had pleurisy repeatedly in his life, "caught a bad cold a few days ago;" dullness over middle and lower portions of left lung, with feeble respiratory murmur and friction-sounds. Inspiration —26 millimetres, expiration 34 millimetres.

Eichhorst reports, in the case of a laborer forty years old, with pleurisy of the lower portion of the right side, exactly the same figures, while he found three weeks later the inspiratory power to be —44 millimetres, the expiratory 50 millimetres.

Eichhorst also reports an interesting case of empyema in a boy fifteen years old, in which, after being twice punctured, the pleural cavity was opened with free incision, and cleansed daily by injection. Three months after the incision, inspiration measured —24 millimetres, expiration 29 millimetres. In the course of recovery these figures increased, and in six weeks became about normal, thus—

April 12, 1872.—Inspiration —24 millimetres, expiration 29 millimetres.

17*th*.—Inspiration —35 millimetres, expiration 45 millimetres.

20*th*.—Inspiration —37 millimetres, expiration 43 millimetres.

25*th*.—Inspiration —42 millimetres, expiration 78 millime tres.

May 22*d*.—Inspiration —60 millimetres, expiration 84 millimetres.

7. *Narrowing of the Upper Air-Passages.*—The largest number of pneumatometrical observations which I have made concern cases of laryngeal, tracheal, and pharyngo-nasal disease. I shall not here specify the individual affections, but will merely remark that whenever swelling of the mucous membrane, neoplasm, obstructive accumulation of phlegm, presence of foreign body, paralysis of the vocal bands, or constriction or compression from the outside, interferes with the normal admission of air, the pneumatometer immediately in dicates the inspiratory insufficiency: the expiratory pressure may be normal, or even increased, or else diminished, according to the circumstances of the case. I shall relate no cases in this connection, for I would hardly know where to begin and still less where to stop.—In pharyngo-nasal catarrh, the difference of the pneumatometrical figures obtained by breathing through my nose-piece and the mask (breathing through the open mouth) is a significant measure of the insufficiency of per-nasal inspiratory power.

II. **Diseases of the Circulatory Organs.**—In fatty degeneration of the heart both inspiration and expiration are considerably reduced; in hypertrophy and dilatation, especially inspiration is. In mitral disease and stenosis of the left auriculoventricular orifice, there is mainly insufficiency of expiration, while in disease of the aortic valves there is insufficiency of both expiration and inspiration, but particularly of the latter, as in the following case: R. C., aged forty-two years. Aortic obstruction and regurgitation; commencing mitral regurgitation; hypertrophy of the left ventricle. Inspiration —60 millimetres, expiration 80 millimetres.

III. **Abdominal Affections.**—All painful processes in the abdomen interfere with the power of respiration, especially that of expiration. Pregnancy, abdominal tumors, exudations, and adhesions, cause expiratory insufficiency; even if the inspiration be also reduced, it nevertheless in these cases usually exceeds, instead of being less than, the expiration.

1. Of *pregnancy*, Eichhorst has reported fourteen cases [1] of which I will cite the following three. All these women were, of course, free from disease of the chest:

CASE I.—Servant-girl, twenty-eight years old, primipara, in the last month of pregnancy. Inspiration —65 millimetres, expiration 48 millimetres.

CASE II.—Laboring-woman, thirty-nine years old, eight children previously, six months pregnant. Inspiration —6L millimetres, expiration 21 millimetres.

CASE III.—Laboring-woman, twenty-six years old, one child previously, seven months pregnant. Inspiration —36 millimetres, expiration 11 millimetres.

2. Of *tumor*, I will cite two cases from Eichhorst, and a third from Waldenburg.[2]

CASE I.—Widow, sixty-eight years old; very painful cancer of the liver occupying the greater part of the right side of the abdomen. Inspiration —26 millimetres, expiration 18 millimetres.

CASE II.—Shoemaker, thirty years old. Cirrhosis of the liver in the first stage, with enlarged spleen. Intense icterus, at present no ascites. Inspiration —72 millimetres, expiration 40 millimetres.

CASE III.—Pl., machinist, fifty-seven years old. Carcinoma of the liver, principally left lobe. Inspiration —120 millimetres, expiration 52 millimetres.

3. Of *exudation*, the following two cases are reported by Eichhorst:

CASE I.—Laboring-woman, thirty-three years old. Painful peritonitic exudation in the left superior inguinal region, of traumatic origin. Inspiration —46 millimetres, expiration 17

[1] *Op. cit.*, p. 279.

[2] "Die pneumatische Behandlung," etc., *op. cit.*, p. 78.

millimetres. Thirteen days later, inspiration —23 millimetres, expiration 17 millimetres.

Case II.—Servant-girl, eighteen years old. Very painful extensive parametritic exudation.

April 28, 1872.—Inspiration —46 millimetres, expiration 17 millimetres.

May 5, 1872.—Inspiration —47 millimetres, expiration 20 millimetres.

23*d*.—Inspiration —29 millimetres, expiration 17 millimetres.

27*th*.—Inspiration —47 millimetres, expiration 34 millimetres.

4. Hutchinson claims that he has "frequently detected *hernia*" by his instrument for measuring the respiratory power. The case in point which he mentions is as follows:

Age, forty years; weight, ten stone four pounds; height, five feet six inches; pulse, while sitting, 86; number of respirations per minute, sitting, 16; circumference of chest, 34½ inches; mobility, 3 inches; vital capacity, 222 cubic inches; power of inspiration, 0.50 in. = about 13 millimetres; power of expiration, 1.00 in. 25 millimetres.[1]

IV. **Muscular Atrophy and Paralysis.**—" Atrophy of all the muscles of the body, of course, reduces the power of both inspiration and expiration. Atrophy limited to certain groups of muscles will influence that phase of respiration in which the atrophied muscles act. In progressive muscular atrophy, the inspiration will be principally affected, as usually the atrophy mainly concerns the muscles of the chest. If the atrophy extends to muscles concerned in expiration, this too will be influenced, till at length respiratory insufficiency becomes so great that life can no longer be sustained.

" An effect similar to that caused by atrophy of the muscles must be produced by paralysis within the range of the respiratory muscles. I had an opportunity to observe, and examine with the pneumatometer, a striking case of *bulbar paralysis (glosso-palato-labial paralysis) complicated with progressive atrophy of the muscles of the trunk and upper extremities.*

[1] *Op. cit.*, p. 245.

Miss L., twenty-two years old, has had for about a year a gradually-increasing nasal speech, afterward growing more and more peculiar and unintelligible. The patient cannot entirely close the lips so as to whistle, blow out a light, etc. Expectoration also difficult. When she swallows, the food returns through the nose. Respiration becomes increasingly difficult; the trunk and upper extremities very weak; the patient cannot hold up the head. The velum-palati is completely paralyzed (the vocal bands act normally); the tongue is atrophied, trembles continually, and does not obey the will; the cavity of the mouth and pharynx is covered with viscous saliva, the mucous membrane reddened. Pectoral muscles very much wasted, the left more than the right; fibrillar spasms. The trapezius and muscles of the trunk also emaciated, on the right side more than on the left. Both arms partially atrophied. The lower extremities appear normal." (Death ensued about six weeks later from insufficient respiration.) "Maximum power of inspiration —20 millimetres, of expiration 20 millimetres.

"When I made the patient perform suction through the mouth-piece of the pneumatometer, instead of inspiration, she could with difficulty raise the mercury to 60 millimetres. But it must be stated that she could not close her lips so tightly around the mouth-piece as to exclude the air."[1]

V. **Rupture of the Membrana Tympani.**—As a *Curiosum* I will mention that Hutchinson has recorded the following case of rupture of the tympanic membrane: Age, twenty-nine years; weight, ten stone one pound; height, five feet seven inches; pulse, sitting, 64; number of respirations per minute, sitting, 21; circumference of chest, thirty-four inches; mobility, three and a quarter inches; vital capacity, two hundred and sixty cubic inches; power of inspiration, 0.50 in. = 13 millimetres; power of expiration, 1.30 in. = 33 millimetres. When this man *closed* his ears, his respiratory power was manifested as nearly three times as strong.[2]

VI. **Phosphorus-Poisoning and some other Morbid Conditions.**

[1] Waldenburg, "Die pneumatische Behandlung," etc., *op. cit.*, p. 79.

[2] *Op. cit.*, p. 245.

—With a view of learning what influence different diseases might have upon the elasticity of the lungs, Perls[1] experimented upon one hundred dead bodies by bringing the trachea into air-tight connection with a manometer, and measuring the pressure the lungs exerted by their contraction on opening the thorax. From similar experiments previously made by Donders, as well as his own, Perls estimated the elasticity of healthy lungs after expiration, i. e., from the cadaveric position of the thorax to complete collapse, to be the same as what Donders had concluded, viz., about 80 millimetres. In the body of a person who had died from diphtheritic cystitis, he found the pulmonary elasticity, tested in this way, very much reduced, although there was no disease of the lungs or pleura. He found the same thing in other cases with healthy lungs and pleura; thus, in a person dead from poisoning by phosphorus, the elastic pressure amounted to only 11 mm.; of five cases of ileo-typhus, it was in one as low as 5 mm., in two 12 mm., in one 25 mm., and in the other 36 mm. It would be very interesting if the investigations which these experiments suggest, would be followed up in living patients by means of the pneumatometer.

Conclusion.—"With pneumatometry, the case is the same as it is with the other methods of examination, especially percussion and auscultation; it does not directly point out the presence of a particular disease, but it reveals certain abnormal conditions which may be caused by various, accurately recognizable diseases, between which differential diagnosis has to decide."[2] By means of the pneumatometer, dyspnœa, difficulty of breathing, which could hitherto be denoted by indefinite expressions only, can be characterized with exactitude both qualitatively and quantitatively—the first by showing whether it is inspiratory or expiratory, or both combined, the latter by determining in figures its precise extent or degree. And not only can the difficulty of breathing be determined when it exists subjectively as well as objectively, but in the first beginnings of a respiratory insufficiency, before the

[1] "Ueber die Druckverhältnisse im Thorax bei verschiedenen Krankheiten," "Deutsches Archiv für klinische Medicin," Bd. vi., 1869, p. 1.

[2] Waldenburg, "Die pneumatische Behandlung," etc., p. 63.

patient himself is conscious of it, except perhaps upon very unusual exertion, before we can discover its existence by any other method of examination hitherto known, the pneumatometer may indicate a deviation from healthy respiration. Again, in obscure cases of differential diagnosis, the weight of the evidence supplied by the pneumatometer may turn the scale in the right direction, when this might not be discernible without its revelation. The importance and value of pneumatometry can, therefore, not be doubted, and, without allowing it to take the place of other means of diagnosis, to it should unhesitatingly be awarded a prominent place alongside of the recognized and not-to-be-omitted methods of physical examination.