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From the Author

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SOUNDS OF RESPIRATION AND OF THE VOICE.

BY PEYTON BLAKISTON, M.D.

PHYSICIAN TO THE MAGDALEN ASYLUM, AND THE GENERAL DISPENSARY, BIRMINGHAM.

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ON THE

SOUNDS OF RESPIRATION AND OF THE VOICE.

Respiration.—On applying the ear to the neck and chest of a person in health, certain sounds are heard during respiration, which vary with the region in which they are listened to.

In the trachea, a coarse hollow sound is heard during inspiration and expiration, (Tracheal respiration.)

At the upper part of the inter-scapular region, the sound during expiration is less intense than that during inspiration, and both are softer and weaker than in the trachea, (Bronchial respiration.)

At the remaining parts of the chest, the sound during expiration is scarcely perceptible, being in most cases reduced to a short puff; while the sound of inspiration is much softer and weaker than at the inter-scapular region (Vesicular respiration.)

This description of vesicular respiration differs from that of Laennec, who remarks, "en entend pendant l'inspiration et *l'expiration* un murmure très legère, mais extrêmement distinct, qui indique la pénétration de l'air dans le tissu pulmonaire, et son *expulsion*"; thus failing to observe the disproportion between the duration of the sounds of inspiration and expiration. Those persons who are in the daily habit of practising auscultation of the chest, will, however, I think, confirm the accuracy of the description here given.

I shall now endeavour to ascertain the manner in which these sounds are produced, and the causes of the variations in quality, intensity, and comparative duration, observed at different parts of the apparatus in which they are engendered.

This apparatus consists of a tube commencing at the mouth, divided and subdivided until it terminates in the air cells. During inspiration air is pressed into it by the weight of the atmosphere, and is expelled during expiration by muscular reaction, and by the resilience of the air cells and of the cartilages of the ribs. In thus passing and repassing through these tubes, the air meets with obstacles at every point where their direction is changed. Now when a current of air meets with opposing obstacles, as the wind blowing upon trees, or into a tube inclined at an angle to its direction, it is thrown into sonorous vibration, and therefore noise must be produced in the trachea and its division during respiration. This sound is not sufficiently intense to be heard until the listener places his ear in contact with the trachea; in the same manner as the noise produced by a gentle blowing on a sheet of paper is not heard until the ear be placed on the paper.

The coarse hollow sound, then, heard in the trachea, is produced by the whole air of respiration passing and repassing through this tube, and its upward and downward continuations.

At the upper part of the inter-scapular region many circumstances concur to render the sound weaker and softer than that heard in the trachea. This tube has now been divided into at least two branches, one for each lung, and hence only half of the air which enters the trachea can pass through each division; and therefore the sound generated in either of them by the friction of the air becomes proportionably weaker: and as regards the sounds similarly generated above and below this point, and respectively carried up to it by the current of inspiration and expiration, those produced in the mouth, fauces, and trachea, are weakened by divergence, and those produced in the bronchial tubes are those of one lung only, whereas the sounds generated in both lungs were carried through the trachea. Besides this, the bronchial tubes are not in actual contact with the walls of the chest, even in this spot, but are separated from them by more or less of the spongy tissue of the lungs, which, being a non-homogeneous substance, and consequently a

very indifferent conductor of sound, deadens and weakens the respiratory sounds in their passage from the tubes to the ear of the auscultator. I stated that the sound during expiration was less intense in this region than that during inspiration. This arises from the additional force given to the latter sound by the vesicular respiration of the intervening portion of lung just mentioned, the sound of which is chiefly confined to the time of inspiration.

When at length the ear is placed on the remaining portions of the chest, it is no longer approximated to the *sides* of the bronchial tubes, but to their vesicular *extremities*. These are so numerous (being not only spread over the periphery of the chest, but also forming the greater part of its internal substance) that only a very minute portion of the air of respiration can reach them at any one spot, and hence very little noise can be produced in them by friction; while the sound generated in the larger tubes, although confined from total divergence in the air, is amazingly weakened and softened by the extent of surface over which it is thus spread. The sounds previously heard at the sides of the bronchial tubes are here effectually prevented from reaching the ear by the great intervening mass of spongy lung. All these causes combining to weaken the respiratory sound, the maximum intensity of which in the trachea can only be heard when the ear is brought into contact with its side, it would not be surprising were no sound detected during respiration at the surface of the chest. Another force, however, is in action. As the wind bears upon it sounds which from their great distance would be otherwise inaudible, so does the current of air during inspiration carry up to the ear those sounds which are engendered in its passage, while that during expiration acts in a contrary direction: hence the sound of inspiration is distinctly heard at the surface of the chest, while that of expiration is barely perceptible.

I shall now endeavour to ascertain *where* the sound of *vesicular respiration* is produced. Sound must be generated in every part of the trachea and its divisions during respiration, but it does not follow that every portion of it should be sufficiently intense to reach the ear of the auscultator at the surface of the chest. I cannot deny that a fraction of that which is heard in vesicular respiration may be produced by the friction of air against the interior of the vesicles, or by that of one vesicle against another, or by that of the pulmonary on the costal pleura, because a slight sound is heard at the commencement of expiration when the force of ~~resistance~~ is at its maximum; but I contend that the *principal* part of it is not thus produced; otherwise, taking place immediately under the ear, and therefore unaffected by the direction of the current of air, it would be heard as distinctly during expiration as inspiration; nor on the other hand can it be principally formed in the mouth and fauces, otherwise it would be much strengthened by stertorous breathing, which is not found to be the case. The sonorous waves formed in these parts, in passing through tubes, the calibre of which rapidly diminishes, and the direction of which is constantly changing, would seem to be in a great measure broken and destroyed before they reach the vesicles. We seem, then, to have arrived, *par la voie d'exclusion*, at the bronchial tubes, as the parts in which the sound heard in vesicular respiration is principally generated; and this conclusion derives some confirmation from the fact that sibilous and sonorous râles, which are undoubtedly formed in these tubes, modify, and in some cases, totally mask the sounds of vesicular respiration.

When in certain diseases a portion of the lung becomes converted into a solid mass, vesicular respiration is replaced over the spot where that portion is in contact with the walls of the thorax, by bronchial respiration, as it has here been defined, coarse, with prolonged expiration. In endeavouring to account for this alteration, Laennec remarks*, "Les raisons de la respiration bronchique me paraissent assez faciles à donner. En effet, lorsque la compression ou l'engorgement du tissu pulmonaire empêche la pénétration de l'air dans les vesicles, la respiration bronchique est la seule qui ait lieu;" and Andral writes†, "Elle nous paraît dépendre de ce que l'air ne peut pas pénétrer au-delà des gros tuyaux bronchiques." Thus both writers agree in considering the bronchial tubes, which lead to the solidified lung, as the seat of the bronchial respira-

* Vol. i. p. 56; 3d Edition. Paris.
† Vol. i. p. 432; 3d Edition. Bruxelles.

tion which is heard in such cases. It must be remembered, however, that the current of air in the bronchial tubes owes its existence to the expansion of their vesicular extremities, and that when their expansibility has been destroyed by the deposition of solid matter in them, that moment the current must cease in these tubes, and with it the sound of respiration within them. Were the larger tubes sufficiently elastic to keep up a current, then, in a solidification of a whole lung, we should hear loud bronchial respiration, which is not found to be the case.

Dr. Jackson, of New York, was the first to notice prolonged expiration as a characteristic sign of bronchial respiration. He writes*, "In some commencing cases of phthisis, where the respiration is not yet truly bronchial under the clavicle, when we still hear the vesicular expansion and nought else on *inspiration*, I have discovered the bronchial sound on *expiration*. In other words, as the tubercular deposit advances, the bronchial *expiration* may be heard before the bronchial *inspiration*; it may be heard at an earlier period of the disease, and may thus become a very important sign, as making known the disease yet sooner after its origin. This circumstance is very explicable. As soon as tubercular matter is deposited, there exists a solid material around the bronchia, which will transmit the sound made by the passage of the air through these tubes; but thus early a great portion of the lung, even in the part affected (the summit), is permeable to the air, and therefore the murmur of vesicular expansion on *inspiration* entirely masks the sound of the air passing through the bronchia, which would otherwise have been transmitted through the surrounding denser medium. On expiration, however, circumstances have changed: the air, on passing through the bronchia, produces the same sound as on its entrance, and as now there is no vesicular expansion to mask it, it is easily transmitted through the diseased or condensed part to the ear of the observer." Fully acknowledging the practical value of the prolonged sound of expiration as a diagnostic sign, I cannot admit the correctness of Dr. Jackson's observation that it is heard at a period when the sound of inspiration is purely vesicular. Although it is easier to discover the presence of a sound at a time when none was previously heard, than to detect an alteration in the quality of one previously existing, yet whenever I have perceived the sound of expiration prolonged at the surface of the chest, I have at the same time found the sound of inspiration stronger and coarser than usual; in short, I have found both sounds bronchial. Neither do I think can Dr. Jackson's explanation be considered satisfactory. We cannot understand how the strong coarse sound of bronchial respiration can be masked by the softer and weaker sound of vesicular inspiration, which has in fact been shewn principally to consist of that bronchial respiration modified and weakened by divergence, and borne up to the ear by the current of air. Again, were any portion of lung to be solidified and made sufficiently homogeneous to transmit the sound of expiration, it would also transmit the coarse undiverged sound of inspiration which takes place in the same tubes.

I would submit that when bronchial respiration is heard over a solidified portion of lung, it is caused by the passing and repassing of the air through bronchial tubes leading to *healthy expansible* vesicles, and it is made sensible to the auscultator by his ear being brought into mediate contact with their sides by the solid lung.

Voice.—I shall next endeavour to discover the causes which tend to modify the sounds of the voice.

According to the researches and experiments of Professor Willis, the voice is formed in the larynx by the vibration of the vocal cords or plates when their planes are in a vertical position, being put into motion by the passage of the air from the lungs. The vocal apparatus, therefore, is a wind-instrument, consisting of a tube with membranous tongues.

It has long been noticed that *timbre*, a quality of tone of wind-instruments, depends much upon the material of which they are made. Wishing to know more upon this subject, I successively placed similarly constructed pipes of wood and of metal on the wind-chest of an organ; and I found that the tone became coarse, and buzzing, in proportion to the elasticity of the material. Having next varied the weight on the bellows, I found the coarseness of tone

* Life of Dr. Jackson, p. 129.

to increase with the force of the blast. Lastly, by making use of pipes of different degrees of thickness, but of the same material, I found that the coarseness varied inversely with the substance of the pipe. In each of these experiments the coarseness of timbre was proportionate to the degree in which the material of the pipe entered into vibration. Hence, I concluded that *the timbre of wind instruments depends upon the proportion in which the solid vibrations of their material are united with those of the air within them, in the formation of the resultant undulations.* Now we can hardly conceive two kinds of undulations thus uniting in different proportions, without an effect being produced on the *form* of the resultants to which they give rise; and therefore it is rendered highly probable that each timbre has its corresponding form of wave. Leaving the further consideration of this subject for another time and place, I would merely remark that a jarring must take place between the undulations of the air, and those of the material of the tube surrounding it. For when the instrument is sounded, each section of the column of air, having a tendency to spread in all directions, will produce an outward bulge in the elastic material; in the next moment reaction will take place, and an inward bulge will be produced in the same spot; but by this time (the blast continuing) the next section of air will have been forced on to this spot, and, expanding, will tend to produce an outward bulge in the material, and must meet and receive a jar from the inward bulge just mentioned.

The correctness of the law which I have thus deduced from experiment, is further confirmed by reference to a few facts of daily observation. The upper notes of a flute, formed by small feeble aerial vibrations, are soft and sweet; the bass notes, formed by large powerful waves, which strongly affect the material of the instrument, are coarse and buzzing. The timbre of all reed-instruments partakes more or less of this character, inasmuch as the vibrating reed communicates its motion to the solid instrument to which it is fixed, and causes it to vibrate with some force. Owing to the elasticity of their material, brass instruments give out the greatest possible coarseness of timbre. In the French horn, which is very long, this is not so much marked as in the trumpet, in which the whole column of air can be suddenly thrown into strong vibration by a quick forcible blast, and can thus be made to act powerfully on its material. A certain degree of thickness is required for a flute, in order that its tone may be sweet and clear. So when any one is desirous of imitating the tone of a brass instrument with his voice, he shapes his lips in such a manner as to make them vibrate strongly; and the moment the nose is closed, a coarse nasal twang is produced by the vibration of the nose itself, which may be felt with the finger, and which is produced by the reverberation of the aerial undulations within its cavity.

To return to the voice.

When the stethoscope is placed on the trachea of a person engaged in speaking, the voice seems to mount up the instrument, as if the speaker's mouth were placed close to the ear of the auscultator, and it has a peculiar buzzing tone, which excites a tingling sensation in his ear, (Pectoriloquy).

On placing the stethoscope at the upper part of the inter-scapular region, the voice seems to issue from the spot on which it is placed, and its timbre is still coarse and buzzing, (Bronchophony).

When this instrument is placed on most other parts of the chest, no resonance or unusual quality of the voice is perceived.

It appears to me, that this alteration of the timbre of the voice in pectoriloquy and bronchophony, as compared with that which it has when heard issuing from the mouth, when the ear does not approach the neck or chest, has not been sufficiently noticed. Laennec, it is true, speaking of bronchophony, remarks*, "Son timbre a quelque chose d'analogue à celui d'un porte-voix;" but the modification which the voice undergoes in passing through a speaking trumpet has very little resemblance to the buzzing timbre of bronchophony, in many cases.

In the formation of the voice, as in the notes of wind-instruments, two kinds of undulation are exercised—those of the air which passes through the larynx during expiration, and those which are communicated to the trachea by the vocal plates; and, according to what has been proved in regard to wind-instruments, the timbre of the voice

* Vol. i. p. 66; 3d Edition.

must depend upon the relative proportion between these two undulations.

When the stethoscope is applied to the trachea, the sounds generated within the latter have to pass through its substance before they can reach the ear of the auscultator, and are therefore conveyed to his ear much more freely through the solid material of the stethoscope, than through the column of air contained in it, inasmuch as all sounds are propagated much more freely through media of similar molecular construction to those in which they are generated, or to which they have, as in this case, been transferred, than through those which are differently constructed. In the sound, therefore, thus conveyed to the ear, the solid bear a greater proportion to the aerial vibrations than in that which reaches it in the ordinary way through the air, when the converse takes place. This accounts for the voice sounding coarser and more buzzing when heard through the stethoscope, than when heard issuing from the mouth of the speaker. Its sound, too, in the former case, is transmitted to the auscultator with an intensity undiminished by the divergence between the mouth of the speaker and the ear of the listener, which takes place in the latter case.

These undulations which enter into the formation of the voice have a teddency to spread, not only in the direction of the mouth, but also towards the periphery of the chest. Their progress in this direction, however, is opposed by the current of air during expiration, and by the increasing mass of spongy non-homogeneous lung. When, therefore, the voice is listened to at the upper part of the inner-scapular region, it is found to resound less than in the trachea, because the aerial vibrations have been opposed by the current of expiration between this point and the larynx, and because the spongy lung has already begun both to surround the air-tubes, to interpose itself between them and the walls of the chest, thus deadening the solid vibrations of the tubes, and more or less interfering with the transmission of sound from them to the ear.

Lastly, at the surface of the chest, between which and the larynx the *whole* current of expiration has opened the aerial vibrations, and where a very large mass of spongy lung surrounds the air-tubes, and is interposed between them and the ear, nearly all resonance of the voice ceases.

In certain states of disease, pectoriloquy and bronchophony are heard at parts of the chest where no resonance of the voice is perceived in health; and not only does the resonance vary in different cases, but also the timbre of the voice; in some cases sounding remarkably clear, in others very coarse and buzzing, with every shade between these two extremes. The law of timbre laid down in this paper, will, I think, account for these differences. Thus, when a tuberculous cavity exists near the surface of one of the lungs, and contains but little fluid, the resonance of the voice is strong, and its timbre clear. In this case, owing to the diminished elasticity of the lung which surrounds the cavity, the current of air is lessened, and in some cases stopped, in consequence of which the aerial undulations are propagated freely into the cavity, and are there strengthened by reflection and echo; hence they predominate over the solid vibrations, and soften the timbre of the voice, while they increase its resonance. When a cavity exists, surrounded by much solidified lung, the resonance is still great, and the timbre becomes much coarser, owing to the increased force of the solid vibrations. When the lung is solidified, without containing any cavity, the resonance is usually less than in the former case, but the coarseness of tone is much increased by the same law. Much depends on the proportion between the power of the voice and the extent of solidification. When the voice is very strong it will throw a whole solidified lung into vibration, and give rise to coarse bronchophony, but this is rare. In the case of a female with medullary sarcoma of the upper half of the right lung, there was no resonance of voice, because the main tube of the lung was filled with solid and semifluid matter, so that the vibrations of the voice could not penetrate the bronchial tubes at all. The buzzing quality of the voice was most strongly marked in the case of a man in the wards of Addenbrook's Hospital, Cambridge, whose right lung was studded with lumps of chronic induration, varying in size from that of a nut to a walnut. The tingling sensation excited in the ear when it was applied to the back of the right side of his chest, during the act of speaking, was quite painful. I

will not pursue this subject further, nor will I, on this occasion, enter upon the consideration of those modifications of the voice which are observed in pleuritic effusion; I am, however, engaged in making experiments on the propagation of sound through different media, the results of which will, I trust, throw some light upon this subject.

The following conclusions may, I think, be deduced:—

1. That the respiratory sound is caused by the friction of the air against the interior of the air-passages, and that it becomes softer and weaker from the mouth towards the periphery of the lungs, owing to the divergence of sound caused by the great space over which it is spread, and to the diminution in the calibre of the air-tubes.

2. That the sound of *vesicular respiration*, confined almost entirely to the time of inspiration, is *principally* generated in the bronchial tubes, and would be scarcely perceptible to the ear at the surface of the chest, were it not borne up to it by the current of air during inspiration.

3. That the coarse respiratory sound, heard both during the inspiration and expiration over a solidified portion of lung, is generated in tubes leading to healthy expansible vesicles, and is made sensible to the ear by its being brought into immediate contact with their sides by the solid lung.

4. That the timbre of wind-instruments and of the vocal apparatus depends on the proportion in which the solid vibrations of the material of which they are made are united with those of the air within them, becoming coarser as the former predominate.

5. That in accordance with this law, the voice sounds coarser and buzzing through a stethoscope placed over the larynx, because its vibrations are propagated more freely to the ear through the solid material of the instrument (a similar medium) than through the air contained within it.

6. That the resonance of the voice diminishes from the larynx to the periphery of the chest, where it ceases, from its vibrations being gradually stifled by the opposing current of air during expiration, and by the increasing mass of spongy non-homogeneous lung.

7. That in certain diseases resonance of the voice is perceived at the surface of the chest, owing to the current of air being weakened or destroyed, and the conducting power of the lung increased; and that its timbre is altered in proportion as the propagation of one or other of its component vibrations is favoured or retarded by such morbid changes—the aerial undulations predominating in cavities, and giving rise to clear pectoriloquy, and the solid undulations predominating in solidification, and producing buzzing bronchophony.