ON THE
ACOUSTIC PRINCIPLES AND CONSTRUCTION
OF
STETHOSCOPES AND EAR TRUMPETS.

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THE stethoscope, or chest explorer, is the well-known acoustic instrument invented by Laennec, to convey sounds from the chest of the patient to the ear of the observer. After his discovery of the utility of such an instrument by using a thick roll of paper, he substituted a cylinder of wood, perforated lengthways, and excavated at its pectoral end. At first he made this hollow conical, but afterwards preferred a parabolic form, as more easily made, and not inferior in efficacy.

The first great improvement in the stethoscope was that of Piorry, which reduced its bulk from a solid cylinder to a slender stem, with an expansion at each end for the ear and chest; and such an instrument, variously modified, has been in common use ever since.

After a vast number of experiments and comparisons of

instruments of different forms, about thirty years ago I devised the trumpet shape for the pectoral end;¹ and I have found reasons ever since to prefer it, on account both of its greater efficacy, and of its facility of application. A series of investigations convinced me that the stethoscope conducts the sounds from the chest both through its solid fibres, and through its column of contained air—some sounds passing best by one medium, and some by the other. Assuming for the present this to be the principle of its operation, it may be useful to consider how these objects may be best combined in the same instrument; and first, with regard to the *material*.

As a conductor of sound, wood has been proved to be superior to all solids, except iron. Fir, aspen, cedar, and such kinds of wood as are rigid in longitudinal fibre, and at the same time light in weight, are the best, for the same reason that renders them the proper material for the sounding-boards of musical instruments; they readily receive and transmit sonorous vibrations from other bodies, without any modifying note or ring of their own, such as we find in metals and glass. But the great objection to wood, is its fragility; especially when reduced to the shape best suited for the purposes of the stethoscope. Metals are also good conductors; but besides their tinkling note just noticed, their weight, and their coldness when first applied to the chest and ear, are objectionable. Ivory, horn, gutta-percha, or papier-maché, would answer well; but the most suitable material of all seems to be the preparation of india-rubber, called *ebonite*, being easily formed into any shape; and being also light, durable, and a good conductor of sound.

We next have to consider the *form* of the instrument. It is obviously important that a stethoscope, which is to convey sounds from the chest to the ear, should be of such a form as to ensure complete contact with both chest and ear; and this not only because the conduction of sound is thereby facilitated through the solids, but also because the enclosed

¹ 'Med. Gazette,' 1842, p. 400.

column of air is thus made *air-tight*, and excluding all external noises and motions, is the more sensitive to the vibrations proceeding from within the chest. Every auscultator knows how imperfect contact from tilting, or from inequalities of the chest in thin persons, almost destroys the conducting power of the stethoscope, and gives entrance to confusing external noises.¹ The trumpet-shaped pectoral end secures this perfect contact by bringing both the solid and the contained air of the instrument into the closest apposition to the walls of the chest. This form is also more comfortable to the patient, by its flatter contact, than that of the conical stethoscopes, the edges of which often give pain. For the same reason its application is easier and more steady for the observer, who may even augment the intensity of the sound, when desired, by increased pressure, without inconvenience.

The power of an enclosed column of air to transmit sound to considerable distances, notwithstanding curves and angles in its course, as shown in flexible ear-tubes and speaking-pipes, proves that the conveyance of sound through tubes is not merely in straight lines undergoing reflection, as in open air, as was formerly supposed, but takes place in waves, through the whole body of the confined air, vibrating through curves and angles with very little loss of force; so that through many feet of tube a whisper may be heard which would be inaudible at half the distance in the open air. But the loudness of the sounds so transmitted, is not accompanied by an equal degree of distinctness. On the

¹ Many years ago, I fitted to the pectoral end of a stethoscope a diaphragm of thin india-rubber, which, by enclosing the air, enabled it to transmit sounds from the chest without complete contact; and I found this instrument peculiarly effective in examining very thin persons, or others, through garments. The same result may be obtained, with some intensification of the sounds, by filling the end of the stethoscope with a small hollow sphere of the thinnest india-rubber. This closes the column of air by an elastic drum, highly sensitive to the vibrations of sound. I understand that M. König, of Paris, has constructed a stethoscope with an india-rubber diaphragm on the same principle.

contrary, flexible tubes, and others also when long or with a large hollow, have always more or less reverberation, a note or echo of their own, which confuses and obscures the original sounds. I shall presently have to notice this as the great fault of ordinary ear trumpets; but it exists also to some extent in stethoscopes with long tubes or large hollows.

In the small trumpet-shaped stethoscope we have the best kind and form of solid, combined with the smallest volume of enclosed air, fitting it to receive and transmit the sounds from the chest, directly, simply, and without alteration. I have been using it, constructed in wood, during the last thirty years; my only cause of dissatisfaction having been that it has so frequently got broken. For the sake of greater durability and elegance, I now recommend *ebonite*, which I have found to answer equally well.

It is constructed in two forms. One is a single piece, which may be carried in the hat. The other is made more portable for the pocket by the ear-piece taking off (somewhat conical like the stopper of a bottle without screw), and slipping into the hollow trumpet end; this secures it from injury in case of its falling or being sat upon. In this form, applied with its ear end to the chest, it may be used to indicate the direction and limits of the pulsations of the heart or of aneurisms.

In ordinary use the trumpet end concentrates, and thereby somewhat augments the diffused sounds of the chest, such as the breath sound. By reversing the tube, and applying the aural end to the chest, we have the means of avoiding this concentration, and of isolating the sound of a small spot, as Laennec used to do by adding a perforated stopper to his cylinder. This especially is sometimes useful in distinguishing the sounds of cavities and of valvular murmurs. But the same object may be better attained by using the stethoscope with the earpiece in the pectoral end, as carried in the pocket; for the small end has also a little trumpet expansion, adapted to explore small spots or hollows on the chest.

FIG. 1.—Stethoscope as commonly used.

FIG. 2.—The stethoscope packed for the pocket. In this form it is also used for exploring small spots with its small end; or if applied by its broad end, it may be used to indicate the pulsations of the heart or of aneurisms.

EAR TRUMPETS.

The acoustic principle of the ear trumpet is quite distinct from that of the stethoscope. Instead of being both a solid conductor and a closed tube of air, like the stethoscope, it is an aerial reflector and an open tube, to catch the waves of sound in the open air, and to concentrate them with increased force into the ear. Sounds are ordinarily conveyed to the ear through the air, and as this is both a slower and a weaker conductor of sound than solids, we have but few means of intensifying its sounds, and the chief of these is by reflection and concentration.

The best *materials* for reflecting aerial sounds, are those solids which most differ from air in hardness and density, such as metals, glass, porcelain, &c. ; but the weight of some of these, the fragility of others, and the intrinsic tinkling note of all, form objections to their use as ear trumpets.

Still, the best instruments in common use are made of silver, plated metal, or japanned iron. The lightness of aluminium might claim for it a preference. Polished ebonite also forms a good reflecting surface ; and although inferior in power to metal, it has advantages over it in point of lightness, and freedom from intrinsic sounds.

The *form* of the ear trumpet requires careful consideration. The simplest and most efficient reflector is a hollow cone, with a wide base open to receive as large a body of sound as possible, which is reflected directly to the apex, and conveyed through a short curved tube to the ear. All repeated or secondary reflections of sound, such as those in parabolic or spheroidal cavities, are to be avoided ; because being retarded, they confuse the sound by an echo following, instead of adding to its distinctness. Such instruments may increase the noise, but they impair the clearness of the articulate sounds, which hearing trumpets ought to convey to the ear pure, and unmixed with echoes or extraneous noises.

Now, in point of fact, these confusing sound are heard, more or less, in all ear trumpets, as commonly constructed.

They all have the *conch-like roar*, resembling that of the sea heard in large shells, which confounds the clearness of words or other definite sounds. This noise is a reverberating echo of any sounds from without, and takes its tone from the note proper to the size of the cavity or tube. Every tube has its proper note, resulting from the vibrations of its columns of air from end to end, and every cavity has its note produced by repeated reflections across its diameter; and these notes respond to every noise or impulse communicated to the tube or cavity. Now, these noises not only confuse the original sound, but are often painful to the ear, which may be sensitive in feeling, although its hearing is impaired. It is therefore an important object to get rid of them, and I have now to bring before you various means, which I have devised to remove these confusing sounds from my conical ear tube. I may premise that one circumstance favoring this result, may be found in the shape of the cone, which is large, subtending an angle of from twenty to twenty-five degrees. When narrower, the cone takes in less sound, and has more internal reverberation. But even in wide cones, there remains much of this noise that needs correction, and the following expedients have been tried with this object.

1. Perforating the sides of the cone with a few scattered holes to give vent and diversion to the transverse vibrations.

2. By introducing a diaphragm of stiff paper longitudinally, in the axis of the cone.

3. By using a less perfect reflector, such as stout paper, for the expansion of the cone at its broad end.¹

4. By opening one side of the cone by oblique truncation, and prolonging the opening by a slit to within a few inches of the ear.

Each of these experiments succeeds more or less in removing the confusing sound; but they all also impair the power of the instrument as a reflector. For practical

¹ I exhibited ear trumpets thus corrected at the Meeting of the British Association for the Advancement of Science, at Bristol, in 1886.

purposes the last plan answers best—leaving open a considerable length of one side of the cone. In so doing, we get an instrument which has an obvious resemblance to the ear of many quadrupeds; and there can be little doubt that this form of external ear is wisely designed to aid their hearing in the simplest and most efficient way, by directing and concentrating sounds, without the confusing reverberation produced in complete tubes and cavities. It is not improbable, too, that the hairs which fringe the margins of the ears in some animals, may subserve a like purpose, in muffling stray and superfluous sounds. If found necessary, we might profit by this hint, by trimming our ear tubes with a silk fringe or some similar drapery.

I have made some attempts to estimate the magnifying power of these instruments; but it is difficult to make accurate observations in a city where disturbing noises are rarely absent. Taking as a test sound the ticking of a small French clock, by the aid of these tubes I have heard it at from ten to a hundred times¹ the distance at which it could be heard by the unaided ear. A large pasteboard cone, twenty-two inches long, and ten inches broad at its base, made the sound audible at about a hundred times the distance at which the unassisted ear could hear it; whilst the magnifying power of smaller ebonite ear trumpets for use, measuring respectively twelve inches by four, and nine by three, showed magnifying powers of twenty and ten times—which are sufficient to enable most deaf persons to hear more or less distinctly.

In the case of all aids to hearing hitherto noticed, the use of the external ear, or pinna, is superseded by the small tube of the ear trumpet being inserted into the auditory passage. But we ought not altogether to disregard the aid to our hearing which nature has provided in our outer ears, although she has been less bountiful to man than to many of the lower animals. Judging from my own experience and that of others whose hearing is impaired, I think that much

¹ These numbers are much higher than those first given, and are the result of more careful experiments.

help might be obtained from the use of a sound collector behind the ear, and directing it forward in the direction of the sound, as we instinctively do with the hand with good effect. A light cowl of india rubber or gutta percha, of semi-parabolic form, with a rounded notch to fit behind the ear, and with its free margin projecting three or four inches in a parabolic curve beyond the pinna, would probably prove a considerable aid to the hearing; but the ear, although directed forward, must be freely open in front.

I feel that an apology is due to the Society for the hasty manner in which these observations have been put together. They were not hastily made, but are the result of many years' experience and thought; and although an imperfect endeavour to clear up a confessedly obscure subject, I hope its discussion may induce others to cultivate the application of acoustics to medicine with further success.

(At the conclusion of the paper Dr. Williams exhibited and explained various forms of stethoscopes and ear trumpets, an account of which will be found in the 'Proceedings,' vol vii, p. 189.)

N.B.—The ebonite stethoscopes and ear trumpets above described are made by the India Rubber, Gutta Percha, and Telegraph Works Company, Silvertown, and 100, Cannon Street, E.C.

FIG. 3.

FIG. 4.

Figs. 3 and 4.—Outline of Ear Trumpets, half the real size of the larger and two thirds that of the smaller one.