ORIGINAL ARTICLE

The stethoscope: some preliminary investigations

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Textbooks, clinicians, and medical teachers differ as to whether the stethoscope bell or diaphragm should be used for auscultating respiratory sounds at the chest wall. Logic and our results suggest that stethoscope diaphragms are more appropriate.

HISTORICAL ASPECTS

Hippocrates advised ''immediate auscultation'' (the application of the ear to the patient's chest) to hear ''transmitted sounds from within''. However, in 1816 a French doctor, René Théophile Hyacinth Laennec invented the stethoscope,[1] which thereafter became the identity symbol of the physician.

Laennec apparently had observed two children sending signals to each other by scraping one end of a long piece of solid wood with a pin, and listening with an ear pressed to the other end.[2] Later, in 1816, Laennec was called to a young woman with ''general symptoms of a diseased heart''. Both application of his hand to the chest and percussion offered little of diagnostic assistance. Laennec was reluctant to start ''immediate auscultation'' because of the age, sex, and embonpoint (plumpness) of the patient. In his moment of embarrassment, Laennec recalled the children's wood borne signalling. He rolled a paper cone and applied one end over the heart and the other to his ear and discovered that heart sounds were louder than ''immediate auscultation''. Initially Laennec built paper instruments before settling on a hollow cylinder of wood, later named ''stethoscope'' from the Greek *stethos* = breast and *skopein* = to explore.[1]

Laennec began applying his device and compared auscultory findings with postmortem findings[3] and wrote his treatise on auscultation, *L'auscultation Mediate* in 1819. Laennec's ideas spread slowly and were aided by the translation of the treatise into English by John Forbes in 1821.[4] At the time of Laennec's death in 1826, acceptance of stethoscopes was widespread and gradual development in design began (table 1).

There are numerous stethoscope designs but curiously whether the stethoscope bell or stethoscope diaphragm is best for pulmonary auscultation is still undecided. Casual observation (PDW) had suggested that about half of doctors prefer the stethoscope bell for pulmonary auscultation whereas the other half use the diaphragm. A previous review concluded that diaphragms were most appropriate.[5]

PHYSICS OF BREATH SOUNDS

There are two main descriptors of single tone sound vibrations, frequency and amplitude, which we perceive as the pitch and loudness respectively. In a complex sound, such as the breath sounds, it is the presence of simultaneous higher frequencies, in particular harmonics, which give the sounds their distinctive character. When we listen to a complex sound, we usually hear the lowest note (in musical terms the fundamental note). The predominance of the lower note is increased as the amplitude of the sound rises, resulting in masking of higher frequency components by lower frequencies—''turning up the volume accentuates the base'' as anyone with teenage children will have noted.

Breath sounds are generated by turbulent air flow in the trachea and proximal bronchi. Airflow in the small airways and alveoli is of lower velocity and laminar in type and is therefore silent.[6] What is heard at the chest wall depends on the conductive and filtering effect of lung tissue and the characteristics of the chest wall. The lung parenchyma and chest wall act as a low pass filter (reducing higher frequencies) and sounds transmitted from the proximal airways are greatly attenuated and consist mainly of low frequencies.[7,8] Most normal ''vesicular'' breath sounds are found between 37.5–1000 Hz, with the main energy below 100 Hz where they are mixed with muscle and heart sounds.[9,10] The intensity of sound is progressively reduced between 100–200 Hz with only little energy between 400–1000 Hz. Higher frequency sounds do not spread as diffusely or retain as much amplitude across the chest wall as do lower frequencies. The high frequency but low amplitude sounds are thus important for localising the breath sounds to underlying pathology. When lung tissue is consolidated there is an increase in higher frequency energy because filtering of higher frequencies is reduced. There is also a reduction of low frequency sounds which leads to less masking of the higher frequency sounds.[9] The resultant sound is of higher pitch and resembles its source in the bronchi and trachea.[10]

Frequencies range from 240–1000 Hz.[11] Added sounds contain strong peaks of energy and can be continuous and musical, for example, wheezes, or discontinuous, explosive and non-musical, for example, crackles. The main energy of wheezes is $>$400 Hz, rhonchi $<$200 Hz, and crackles 750–1200 Hz.[11–13]

Selective hearing

The capacity of individuals to hear selectively ''focus on what they wished to hear while ignoring other sounds'' was also studied to see if this were the explanation why physicians who advocated use of the bell (despite its poorer performance) believed their use of the bell was preferable for them and others.

METHODS

Teaching practice

Standard textbooks proffering advice on clinical examination were read to ascertain whether the bell or diaphragm was recommended for pulmonary auscultation.

Table 1 The development of the stethoscope

Date	Inventor	Development
1816	Laennec	Rolled paper cone, later a wooden tube
1828	Priorry	Funnel shaped bell, a lightened stem, and thinner earpiece for a better seal
1843	Williams	The first binaural stethoscope, using lead pipes for earpieces
1851	Marsh	Stethoscope chestpiece was fitted with a flexible membrane
1855	Cammann	Binaural stethoscope with flexible tubing
1894	Bianchi	First stethoscope with a rigid diaphragm, known as a ''phonendoscope''
1925	Bowles and Sprague	Combination of bell and a rigid diaphragm chestpiece as used today
1945–46	Rappaport, Sprague, and Groom	Experimented with various designs to determine ideal properties for the modern binaural stethoscope—for example, a combination chestpiece, short tubing with low internal volume and well fitting earpieces[8–10]
1956 onwards	Various (for example, Leatham, Littman, etc)	Various modern stethoscopes have been developed with improvements to weight and appearance but using the same principles described by Rappaport, Sprague, and Groom

The views of respiratory tutors at each clinical teaching medical school in the UK (excluding the Oxbridge colleges) and various respiratory physicians of various grades in Edinburgh and Glasgow were sought.

Stethoscope properties

The acoustical properties of a Littmann Classic 11 SE stethoscope were investigated utilising apparatus illustrated in fig 1.

It was necessary to provide a standardised and reproducible input signal for the stethoscope bell or diaphragm. Several strategies could have been used to apply defined vibrations to a human chest and for a researcher to observe the output at other, inevitably ill defined, points elsewhere on the chest wall, which would have produced many unknown and uncontrollable variables. The simulator provided a signal source that simulated the reality of clinical stethoscope use and experimental conditions were defined and repeatable, enabling valid comparisons.

Oscillator generated impulses were amplified before being applied to the vibrator which delivered vibrations of determined frequency and amplitude to a blood pressure cuff filled with water. The system was very sensitive to external noise and vibration, and care was needed to avoid the effects of mechanical resonance in the various supporting structures. The simulator and associated equipment produced a number of interfering artefacts. The power amplifier produced an audible hum at 100 Hz which was reduced by siting the amplifier in an adjacent room and enclosing it in an acoustic enclosure.

The simulator was prone to resonate at certain frequencies and measurements at these frequencies were avoided. Electronic filters eliminated interfering signals other than those of the intended frequency.

The bell or diaphragm was placed on to the rubber surface and the application pressure was kept constant by utilising a holder which allowed the stethoscope head (whether bell or diaphragm) to rest using its (constant) weight. The area of contact with the simulator was different, and would obviously affect results but this reflects perfectly the reality of stethoscope usage in clinical practice.

Two miniature microphones, inserted into the stethoscope earpieces, measured the output as presented to the ears. During all experiments the earpieces resided in the normal situation in the ears of one experimenter (GP), who had normal audiograms, to ensure stable and natural acoustical termination. The variation of sensitivity of the human ear over the frequency range of interest precludes the use of a constant amplitude of vibration at all frequencies. Unlike the artificial ears used in some other evaluations of stethoscope characteristics the living observer requires that the amplitude is adjusted to a comfortable level at each frequency. Identical amplitudes must then be used for subsequent measurements at the same frequency in order that a valid comparison is made between bell and diaphragm. A ratio of the outputs for bell and diaphragm was then obtained at each frequency. For each frequency tested the output signals from each earpiece microphone were amplified equally.

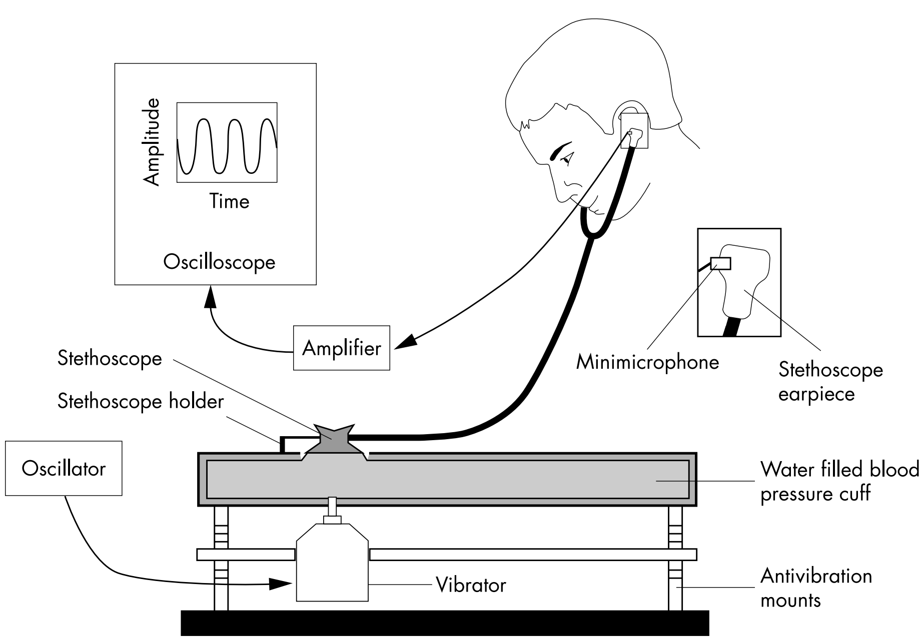

Figure 1 Diagram of the apparatus used.

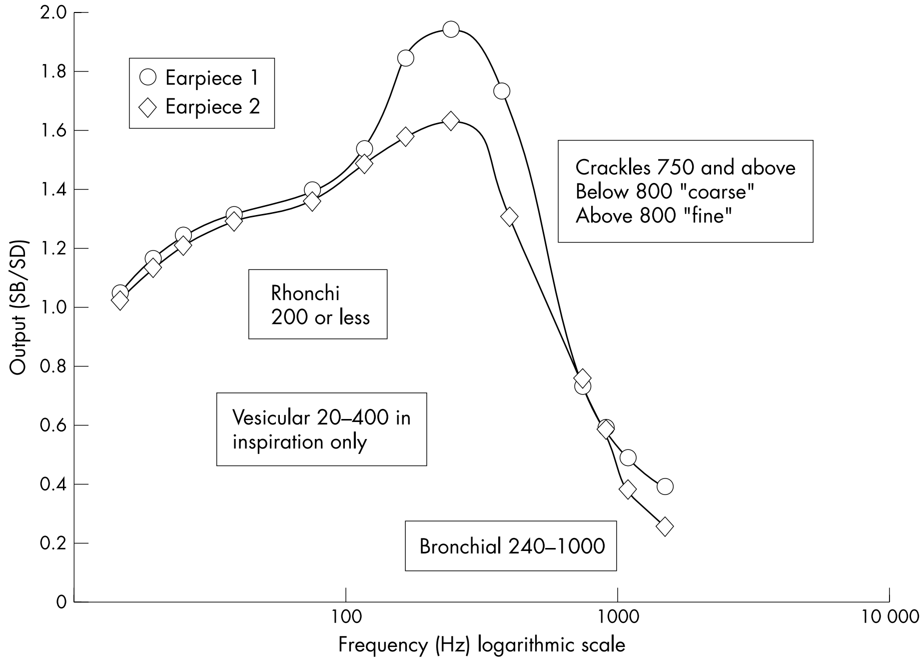

Figure 2 Performance of the stethoscope bell and stethoscope diaphragm as measured at both earpieces. The crossover point is about 400 Hz (the differences in plots derived from the two earpieces may indicate that the microphone and preamplifier combination serving one were relatively less sensitive at higher frequencies than that serving the other).

Input signal frequencies included those contained in breath sounds, ranging from 20–1280 Hz. Outputs for the bell and diaphragm were measured at each earpiece. The outputs of the bell were divided by the corresponding diaphragm output to produce a ratio comparing performance, a technique which also cancelled out artefactual interferences.

Selective hearing

To investigate "selective hearing" 21 volunteers aged 20–25 had their pure tone audiometry thresholds determined. They were then told to expect a *high* pitched sound, were asked to report when they first heard any sound, and were then presented with a *low* frequency sound (250 Hz) at their auditory threshold. The volunteers were then told to expect a *low* pitched tone, were asked to report when they first heard any sound, and were then presented with a *high* frequency tone (8000 Hz).

RESULTS

Teaching practice

Two textbooks recommended bell,[14 15] three the diaphragm,[16–18] and three the bell and/or diaphragm.[6 19 20]

Forty eight respiratory tutors (all consultants or professors) were sent questionnaires; 32 replied. Seven taught use of the bell, 15 the diaphragm, and 10 the bell and/or diaphragm. Fifty seven doctors working on respiratory wards were sent a questionnaire; 36 replied. Nine used the bell, 19 the diaphragm, and eight bell and/or diaphragm.

Stethoscope properties

The output from the bell divided by the output from the diaphragm at each frequency is shown in fig 2. Outputs were equal at the 400 Hz level.

Selective hearing

Forty two volunteers each heard 8000 Hz and 250 Hz played at their auditory threshold when given correct prior warning of the pitch but 26 (62%) did not hear 250 Hz when played at their previously determined auditory threshold for that frequency when falsely advised that the tone would be of high pitch, and 18 (43%) did not hear a high tone when played at their previously determined auditory threshold for that frequency when falsely advised that the tone would be of low pitch.

DISCUSSION

Teaching practice

Although our surveys were not comprehensive, they illustrate the marked contradictory diversity of teaching and use of the stethoscope bell and diaphragm. It is obvious that both teaching and use of stethoscope bells and diaphragms is non-uniform.

Stethoscope properties

Since stethoscope bells provide louder output than diaphragms at the low frequencies associated with the main energy of respiratory breath sounds, it has been suggested that stethoscope bells outperform diaphragms.[21] Stethoscope bells would perform better in the detection of normal breath sounds since the main energy is in the low frequency range. However, provided that breath sounds are audible in the first place, it is high frequencies and harmonics that are required for characterisation and localisation. As low frequency sounds mask high frequency sounds, it makes sense to limit the low frequency sounds as much as possible, particularly when there is cardiac and muscular interference at precisely these low frequencies. Stethoscope diaphragms will detect but limit these low frequencies so that the high pitched sounds will be less masked. *Use of the bell is thus superfluous.*

The performance of the human ear is astonishing. How does the ear amplify sounds and analyse their frequency? The traditional view is the "place code", which suggests that different frequencies enter the cochlea and cause particular regions of the basilar membrane to vibrate, with high notes causing vibration at the base, and low notes at the apex. When the basilar membrane vibrates it causes deflection of stereocilia on top of sensory inner hair cells and stretches tip links that link stereocilia. Hair cells then send impulses to the brain where the frequency of the stimulus can be derived from the location of the hair cells firing most rapidly.[22]

However, the place code is a rather coarse mechanism to account for such acuity (we can distinguish two tones that differ by a fraction of a percent when played successively,[23] and it is now known that hair bundles contain motile systems, which generate oscillations at a particular frequency. When one of these non-linear dynamical systems is on the verge of vibrating it is very sensitive to disturbances at frequencies close to its characteristic frequency. In other words the cochlea is thought to contain ''many voices, each of which is ready to sing along with any incoming sound which falls within its own range of pitch''.[23] Such an ability to set our inner hair cells to await stimulation would allow the ear to focus on particular pitches of sound. The outer hair cells of the cochlea, with their own motor intervention (about 20% of auditory nerve fibres are efferent) may be involved in sensitivity and tuning of the inner hair cells. This would perhaps allow the ear to compensate for the poorer bell qualities in practice.

Selective hearing

Why do some clinicians prefer to use the bell despite its poorer performance in practice? The false expectation results that reveal ''selective listening'' probably explain why some clinicians advocate using the bell. They can compensate for inferior delivery from the stethoscope bell by choosing what they want to hear—their hair cell stereocilia were being tuned to a brink of oscillation for an expected incoming sound of particular frequency. They would be better advised to use this skill in enhancing the appreciation of input from the stethoscope diaphragm.

CONCLUSIONS

The teaching concerning the use of stethoscope bells and diaphragms is in some disarray. A student will learn to use stethoscope bell and/or diaphragm depending on which book they read, or which tutor they are taught by rather than which is technically optimal. The stethoscope bell could be used to detect breath sounds, but the diaphragm can detect normal breath sounds without enhancing lower pitched masking sounds and can also be used to characterise and more accurately localise both normal and abnormal breath sounds. Use of the stethoscope bell for pulmonary auscultation is both superfluous and deleterious and should not be taught as the preferred mode of pulmonary auscultation. We are aware that this evidence based message may fall on deaf ears connected to closed minds.

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