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Editorial

Some high pitched thoughts on chest examination

Observation reveals that about half of chest physicians use the stethoscope bell when auscultating the lungs and the other half use the diaphragm. None directly apply their ears. Despite extensive reading we have not encountered an evidence based answer to the question "Should normal mortals use the bell or diaphragm?" This unanswered question thus prompted an acoustical odyssey.

Historical note

Strangely the stethoscope was developed by René Théophile Hyacinthe Laennec not to enhance respiratory sounds but rather to avoid embarrassment! In 1816, he was called to a young lady "who presented the general symptoms of disease of the heart; the application of the hand to the chest, and percussion, afforded very little assistance, and immediate [meaning placement of his ear on the chest] auscultation was interdicted by the sex and *enbonpoint* [a euphemism for breasts] of the patient".[1]

In 1819, after various trials with materials of different density, Laennec found a cylinder of moderately light wood most convenient. After the publication of his thesis (L'auscultation mediate) in 1819 and its translation into English by the Edinburgh trained physician John Forbes in 1824, the stethoscope rapidly increased in popularity. In 1851, at the Great International Exhibition, the first binaural stethoscope was demonstrated by Dr Leared. In the *British Medical Journal* of 1884, E T Aydon Smith described the "ultimate instrument" that could be employed as a monaural, binaural, or differential stethoscope, an otoscope (using the chest piece) and the tubing could be used as an enema or oesophageal tube, a catheter, or a tourniquet![2] Diaphragm stethoscopes (often termed phonendoscopes) were first introduced at the end of the 19th century but it was not until 1926 that Howard Sprague of Boston described the combined bell and diaphragm chest piece of the modern stethoscope.[3] Although lacking the versatility of the "ultimate instrument", few modern stethoscopes show any significant acoustical improvement since the time of Laennec.[4]

It is thought that Laennec died from tuberculosis, but this could not have been an occupational disease caused by enthusiastic use of his invention because he had developed tuberculosis in 1814, five years before his invention.

The sound heard through the stethoscope depends on three main factors: sound (vibrations) present at the chest wall, perception of sound by the human ear (psychoacoustics), and acoustics of the stethoscope itself.

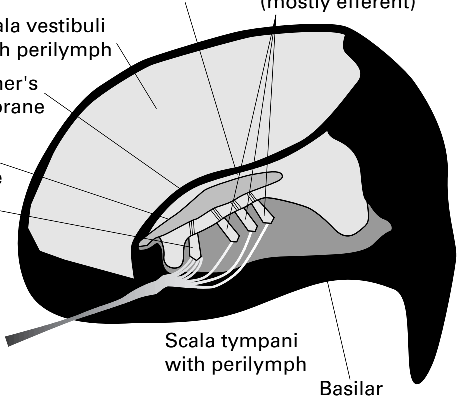

Figure 1 A diagramatic view of the cochlea.

Sound and its perception by the ear

All single tone sound vibrations can be described using four parameters: frequency, amplitude, starting phase, and duration.

Frequency refers to the fundamental frequency of the sound and is measured in Hertz (vibrations per second). The normal range of frequency detection for young people is 20–20 000 Hz. When pressure changes in the air reach the ear they are transmitted to the cochlea (a cross section of which is shown in fig 1). Pressure waves produced in the various lymphs induce vibrations of the basilar membrane which in turn induce shearing strains of the inner hair cells which abut onto the tectorial membrane. *Pitch* is the subjective perception of frequency. Pitch appreciation is derived from the position of the inner hair cells along the length of the cochlea with high frequencies being detected near the base and low frequencies at the apex. The inner hair cells of the cochlea have exclusively sensory (afferent) innervation. Most of the outer hair cells of the cochlea have motor (efferent) innervation and have a feedback function on the tectorial membrane enabling the sensory inner hair cells to be more sensitive and selective "focused". Frequency and pitch are usually within 5 Hz of each other.[5]

Amplitude is the degree of displacement of air molecules whereas *loudness* is the subjective perception of amplitude by the ear. The total amplitude range of sound audible by the ear ranges from the barely perceptible to the actually painful—a range of about one hundred billion (table 1). Because of this range, sound is measured in a logarithmic scale as decibels (named after Alexander Graham Bell, the inventor of the telephone). A 10 decibel difference reflects an increase in sound intensity of 10 times.

There is little published information about the loudness of respiratory sounds available at the chest wall. As an amateur musician PDW would grade sounds heard with his ear as *p* or *pp*, equivalent to 45–60 dB.[5]

The perception of sounds by the ear is highly complex. However, as far as auscultation is concerned three main aspects are important. Firstly, we can focus on particular frequencies (by both central and peripheral mechanisms). We should help students to focus upon and thus hear sounds by vocalising what we hear. Telling students "there is a low amplitude, high pitched sound to be heard" probably will not enable their outer efferent hair cells to be focused because the receiver of such verbal knowledge, unless possessing absolute pitch, could not consciously "tune in". Secondly, it is the presence of coexistent higher frequencies, particularly harmonics, which gives musical instruments and auscultated respiratory sounds their distinctive character (timbre). We normally hear the lowest note of a complex sound and, in musical terms, refer to this lowest perceived note as the fundamental pitch. An absent fundamental frequency can be often be inferred from its harmonics alone. In music this has been used in some compositions so that a third part is inferred and "heard" by the listener—a trio played by two flutes. Similarly it is often apparent that a concerto is in the key of A major even though the fundamental A is not played continuously.[6] We suspect that characterisation of lung sounds is probably similar. Thirdly, low frequency components of a complex sound usually mask out higher frequency components.[7 8]

Progressive masking of high frequencies by lower frequencies occurs as amplitude rises (one reason why the base component of musical recordings predominates if the volume is turned up—music should be reproduced at the volume that it was originally recorded in order to achieve fidelity).

Presbyacusis causes progressive deterioration of hearing but this usually affects frequencies above 3000 Hz, which is considerably above the frequency of sounds needing to be heard via a stethoscope (and also above the spectrum of a number of stethoscopes). So older doctors may not be at much of a disadvantage. But (and this is a big but) the elderly have poorer speech (and probably also stethoscope derived) discrimination relative to their single frequency audiograms because their cochleas are more linear (presumably caused by their straighter basilar membrane) with resulting loss of harmonic cues.[5]

Table 1 The (logarithmic) decibel scale

Decibels	*Human equivalent*	*Intensity ratios*
0 dB	The auditory threshold for the average human ear at 1000 Hz	1
30 dB	A soft whisper	1000
50 dB	Quiet conversation	100 000
70 dB	Normal conversation	10 000 000
100 dB	Shouting at close range	10 000 000 000
140 dB	A loud rock band	100 000 000 000 000

Respiratory sounds at the chest wall

By respiratory sounds we mean sounds over the lungs arriving via, or being created in, the lungs. We will not address their mechanism of production or their functional significance.

NORMAL RESPIRATORY SOUNDS

Respiratory sounds present at the chest wall are the result of the sound generated within the lung, together with the transmission characteristic of the lung and chest wall. There is much evidence that breath sounds originate from broadband frequency sound produced by turbulent airflow in larger airways. Lung tissue itself behaves like a low pass filter (that is, attenuates higher frequencies)[9] and frequencies below 300 Hz are differentially coupled to the parenchyma further enhancing the low frequency spectrum of breath sounds.[10] These factors explain why normal respiratory sounds recorded by microphones on the chest wall are found between 37.5–1000 Hz (fig 2) with the main energy below 100 Hz (where it is mixed with muscle and heart sounds). Sound intensity drops sharply between 100 and 200 Hz leaving little energy above 400 Hz. However, with sensitive transducers sound can still be detected up to 1000 Hz. High frequency sounds do not spread as widely or retain as much amplitude across the chest wall as do low frequency sounds. This is important for localisation.

ABNORMAL RESPIRATORY SOUNDS

The most common abnormal breath sound heard at the chest wall is bronchial breathing. In 1955 McKusick *et al* showed that bronchial breathing contained much higher frequency components than normal breath sounds.[15] The most likely explanation for this is the alteration of the low pass filtering characteristics, which occur in consolidated lung tissue.[10] This allows transmission of the higher frequencies of central airway sounds to the chest wall (a positive effect), in addition it is also possible that consolidated lung absorbs lower frequency sounds which unmasks higher frequencies (a negative effect). However, the acoustic transmission characteristics of the respiratory system in health and disease are complex and still not fully understood.[10]

Over consolidated lung a spoken "E" sounds like an "A" despite the fact that the fundamental frequencies of a spoken "A" and "E" are similar. This may occur because the lower frequency of the "E" is absorbed, leaving the higher frequency harmonic characteristics of an "A" to emerge.[16]

To demonstrate increased vocal fremitus or vocal resonance over consolidation logic suggests that, if one is interested in the differential emergence of high frequency sounds caused by absorption of lower frequencies, then one ought to ask patients (particularly female patients) to say a *low* frequency sound—perhaps the onomatopoeic "deep" would fulfil both these functions rather than the traditional "one, one, one" or ninety nine". Similar considerations apply to whispering pectriloquy when production of a high pitched sound is requested of the patient. The examiner should perhaps demonstrate to patients what is desired by vocalising a high pitched "herr" (as in heavy breathing). Both "deep" and "herr" would provide increased discrimination between normal and abnormal lung.

In summary, detection that there is *any* sound depends on the amplitude of the sound (as perceived through the stethoscope) whereas characterisation and localisation depends more on the higher frequency harmonics.

ADVENTITIOUS SOUNDS

Breath sounds contain a relatively wide range of frequencies, are devoid of peaks, and are not musical.[10] In contrast

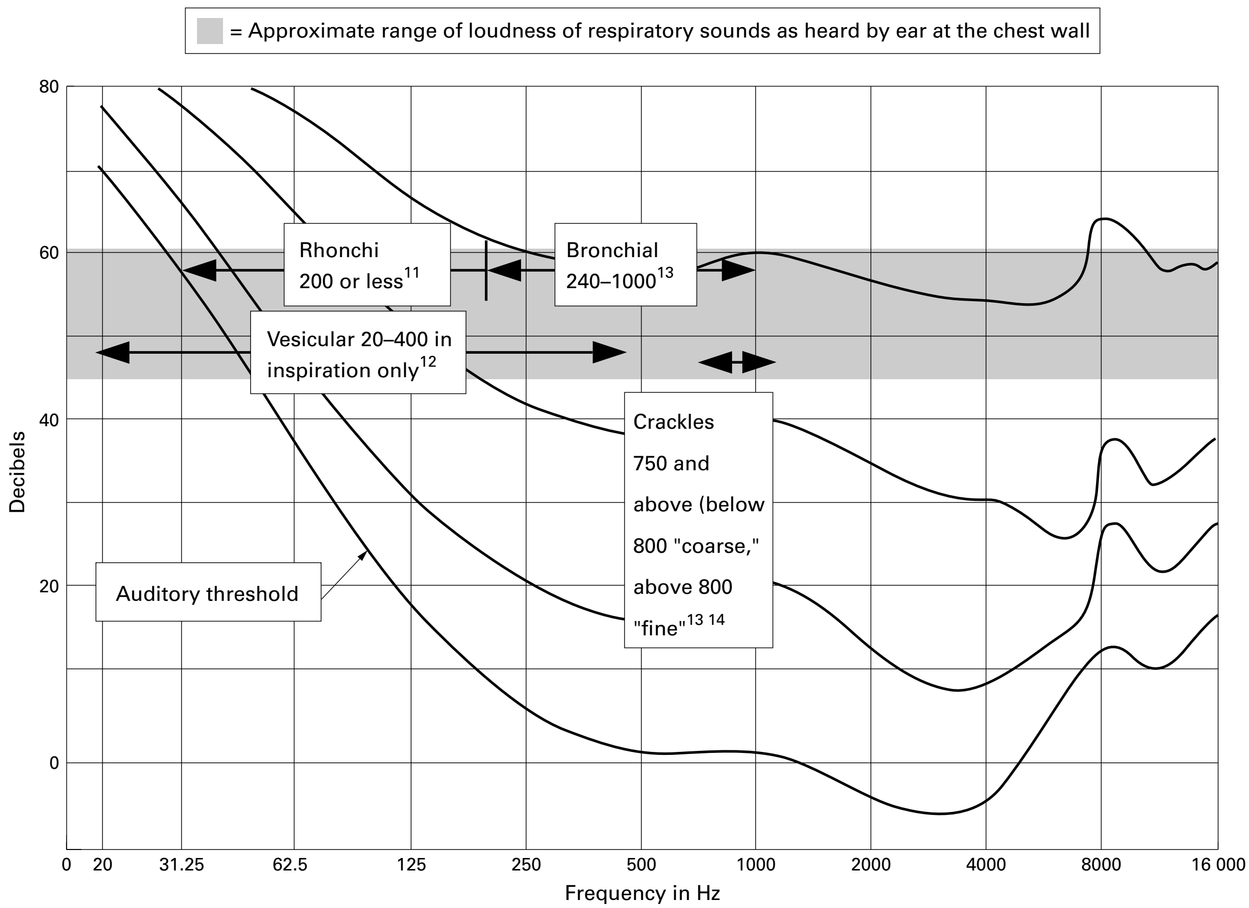

Figure 2 Equal loudness curves and frequency of respiratory sounds.

adventitious sounds always show strong peaks of energy and are divided into continuous *musical* sounds (wheezes and squeaks) with frequencies from below 100 Hz to 1000 Hz and discontinuous explosive non-musical sounds (crackles).

Acoustics of the stethoscope

Abella *et al* in a comparison of six popular stethoscopes found that sounds in the range 37.5–112.5 Hz were usually amplified (because the stethoscope functions as an acoustic filter and impedance transformer) by about 5–10 dB by stethoscope bells and attenuated by the stethoscope diaphragms.[12] In general "bells consistently outperformed diaphragms" *by increasing the amplitude* of sounds, producing amplification of up to 12 dB in the range 37.5–112.5 Hz,[12] but the corollary is that stethoscope diaphragms were consistently better at reducing the amplitude, in particular the amplitude of the lower frequencies. Most studies, including those of Ertel and Lawrence,[4] report on the fate of single "pure" frequencies and ignore the important contribution of harmonics.

Abella *et al* judged that bells outperformed diaphragms using the criteria that the bell provides better amplification.[12] But, *providing that the sounds are audible in the first place we do not need enhancement of lower frequency sounds* because the amplitude of the sound may be less important than the ability to hear higher pitched sounds, particularly harmonics. A 10-fold increase in amplitude at lower frequencies as provided by most stethoscope bells will mask precisely those higher frequencies required for characterisation, and in addition will accentuate low pitched interfering noise from intercostal muscles, chest wall movements, and the heart. Diaphragms reduce the amplitude of the masking low frequency sounds more than bells (but not below levels at which the sounds we are interested in are inaudible) and thus allow better characterisation and thus identification of the sound by appreciation of higher frequency harmonics. Admittedly there is a trade off between *detection* (best with the stethoscope bell) and characterisation (best with the stethoscope diaphragm).

Attenuation of lower frequencies is produced by increasing pressure of the stethoscope bell or diaphragm on the chest wall which allows "unmasks" higher frequency sounds.[13] Use of the diaphragm is also essential when occlusion of the bell by chest wall skin is impossible, as it may be in thin people or in auscultation of the supraclavicular fossa. In fact it is difficult to hear good low frequency transmission with stethoscope bells of less than two inches in diameter. Thus a clear cut separation in frequency response between the usual 1–1.5 inch stethoscope bell and their combination diaphragms cannot be expected.[13] Our obstetric colleagues, who are interested in the detection but not characterisation of (fetal) heart sounds, do use such large bells.

Conclusions

The stethoscope bell can be used if listening to normal lung or to *detect* abnormal lung. The diaphragm can be used to both detect and characterise abnormal lung (the bell can be saved for listening for low frequency heart sounds). You should ideally be young and apply the stethoscope firmly (or listen with your ear and ensure that your defence union subscription has been paid!).

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