Measurement of tracheal lung sounds

To the Editor: A recent study of the spectral characteristics of tracheal lung sounds by Charbonneau et al. (1) illustrates the difficulties involved in the quantification of breath sounds in the frequency domain. These authors used a microphone coupled to the body surface through a small conic air chamber that was open in its sharper end. To test the frequency response of their microphone-coupler combination, they exposed it, in free air, to sounds at various frequencies and found a linear response in the range of interest (to ~1 kHz) and a wide resonance peak of over 20 dB near 1,500 Hz. I challenge the assertion that these specifications remain relevant when the microphone-coupler apparatus is attached to the skin. I also raise and support the possibility that the spectra of sounds presented by the authors represent the frequency characteristics of their transducer rather than those of the tracheal sounds themselves.

The resonance frequency \( f_0 \) of a hollow chamber with a circular orifice (Helmholtz resonator) is given approximately by (3)

\[
f_0 = \frac{1}{[2\pi \cdot (L \cdot C)]^{1/2}} = \frac{c}{2\pi \cdot (2r/V)^{1/2}}
\]

where \( L \) is the inerance of the gas passing through the orifice, \( C \) is the compliance of the gas in the chamber, \( c \) is the speed of sound, \( r \) is the radius of the orifice, and \( V \) is the volume of the compressible gas in the chamber. For the values given by the authors for the coupler, the calculated \( f_0 \) is close to the resonance peak of the transducer when tested in free air. When the orifice is occluded by a membrane of skin and underlying tissue, the inertia of the tissue at the orifice dominates the frequency characteristics of the transducer and the resonance frequency is reduced by a multiplying factor that is approximately equal to the square root of the ratio of air to tissue densities, \((\rho_{air}/\rho_{tissue})^{1/2}\). If we assume that the skin, subdermal and tracheal tissue, and the air inside the trachea have an effective mean density of 0.5 g/cm\(^3\), then the resonance frequency of the transducer is predicted to decrease to approximately 100–200 Hz.

The results support the possibility that the high peaks of power observed by Charbonneau et al. in the spectra of the sounds in the range of 100–200 Hz are a manifestation of the resonance frequency of the microphone-air chamber-tissue combination when exposed to the random noise generated by the trachea.

To verify this theoretical result I measured tracheal sounds with a microphone-coupler apparatus similar to that described by the authors. I compared the spectra of the tracheal sounds picked up with this transducer with those obtained with a Hewlett-Packard HP 21050 contact sensor. The latter has a relatively flat response from few to 2,000 Hz when tested under contact conditions.

Figure 1 shows the averaged spectra of expiratory tracheal sounds picked up by both transducers from the same subject. It is apparent that the air chamber apparatus accentuates the spectral content of the sounds near 100–200 Hz as predicted by the calculation above. The spectra of the sounds picked up by the contact sensor (linear and log presentation) conform to those presented by us in a previous communication (2), which is characterized by a spectral shape of a random noise with a cutoff near 1 kHz.

These results illustrate the need for careful selection and calibration of lung sound pickup transducers. It is apparent that contact-type transducers that are tested and calibrated under the same condition as during data acquisition have an advantage when information is sought about the frequency content of breath sounds.

![Figure 1](image-url)
REPLY

To the Editor: The comments raised by Dr. Gavriely have led us to offer the following explanations to exclude the hypothesis that spectra presented in our paper may simply reflect the frequency response of our transducer.

First, the resonance frequency $f_0$ of our transducer has a peak value around 1,500 Hz, and the theoretical value is

$$f_0 = \frac{c}{2\pi} \sqrt{\frac{2r}{V}} = 2,774 \text{ Hz}$$

with $r = 0.6 \text{ cm}$ and $V = 4.75 \text{ cm}^3$. So when the orifice is occluded by a membrane of skin, the resonance frequency would be

$$f = 1,500 \text{ Hz} \times \sqrt{\frac{\rho_{\text{air}}}{\rho_{\text{tissue}}}} = 76 \text{ Hz}$$

instead of 140 Hz if we take the theoretical value for $f_0$. We never observed a peak value around 76 Hz. Moreover, as $\rho_{\text{tissue}}$ appears as its square root, doubling the frequency would involve dividing $\rho_{\text{tissue}}$ by four.

Second, our results show a strong variation in the peak location as well as in the bandwidth between asthmatics and normal people. This observation is inconsistent with the assumption that we measure the frequency response of the transducer.

Third, to understand the differences between our findings and those of Gavriely et al., we compared results obtained by picking up the sound with our system in two different locations: their location on the side of the neck (1) and ours just above the sternal notch (see Fig. 1). We obtained a spectral shape similar to that observed by Gavriely et al. when we picked up the sound at the same location. Thus it seems that differences in the location induce significant differences in the frequency spectral shape.

We suggest the following explanation of this effect. When we take the sound near the top of the trachea, it is possible that the acoustical properties of the vocal track interfere with those related to the airways. The vocal track is known to present three main resonances. The first varies, depending on the geometrical conditions, between about 300 and 1,000 Hz. This resonance may amplify breath-sound frequency components in this frequency range.

