Transmission of sound generated by sternal percussion

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Bohadana, Abraham B., and Steve S. Kraman. Transmission of sound generated by sternal percussion. J. Appl. Physiol. 66(1):273-277, 1989.—We indirectly determined the transmission path of sound generated by sternal percussion in five healthy subjects. We percussed the sternum of each subject while recording the output audio signal at the posterior left and right upper and lower lung zones. Sound measurements were done during apnea at functional residual capacity, total lung capacity, and residual volume both with the lungs filled with air and with an 80% He-20% O₂ (heliox) gas mixture. Three acoustic indexes were calculated from the output sound pulse: the peak-to-peak amplitude, the peak frequency, and the mid-power frequency. We found that the average values of all indexes tended to be greater in the upper than in the ipsilateral lower lung zones. In the upper zones, peak-to-peak amplitude was greater at total lung capacity and residual volume than at functional residual capacity. Replacing air with heliox did not change these results. These experiments, together with others performed during Mueller and Valsalva maneuvers, suggest that resonance of the chest cage is the predominant factor determining the transmission of sternal percussion sounds to the posterior chest wall. The transmission seems to be only minimally affected by the acoustic characteristics of the lung parenchyma.

Lung sound transmission; lung volumes; chest cage

SINCE THE DESCRIPTION of pectoriloquy by Laënnec (9), clinicians have been aware of the fact that changes in the characteristics of voice and breath sounds transmitted through the chest are often related to abnormalities in lung tissue density and, hence, are useful indicators of lung disease. Common examples of such clinical signs include the faint vesicular sound easily detected in patients with advanced emphysema, the association of absent vocal fremitus with dullness to percussion found in patients with large pleural effusions, and the presence of bronchial breathing and bronchophony which, together with pectoriloquy, are characteristically found over areas of lung consolidation (5, 15). The factors that affect the passive sound transmitting properties of the lung have not been well defined. The classic approach to this problem consists in introducing an input sound at some point in the respiratory system and analyzing the output sound at one or more sites over the chest. This has been done by several investigators (1, 4, 6, 7, 10, 12) although in most such studies, the question of transmission did not constitute the main objective. Comparing these studies with one another is difficult because of differences involving both the input and output sound as well as the populations studied. For instance, in some studies the input sound was an electronically generated pure tone (2-4) or colored noise (7, 12) and in others it was a sound generated either by the vibration of a tuning fork applied to the sternum (10) or by percussion of the chest (1, 6). In some studies, the output sound was analyzed (presumably) only at a single point anteriorly and/or posteriorly over the chest wall (1, 3, 10), whereas in others it was analyzed at various points anteriorly (12), posteriorly (2, 6), or both anteriorly and posteriorly (7). Thus, the amount of information regarding the sound-transmitting properties of the lungs, especially of healthy individuals, is incomplete and confusing.

We attempted to better define the factors affecting sound transmission through the chest by investigating the effects of lung volume and gas density variations on the characteristics of sternal-percussion-generated sound (reported here) and of sounds introduced at the mouth (reported separately) (8).

MATERIALS AND METHODS

We examined the pattern of transmission of sound generated by gentle finger percussion of the sternum. This maneuver forms the basis of auscultatory percussion, a clinical test that has been purported to detect intrapulmonary lesions (6). We chose this procedure because it is noninvasive, easy to perform, and, in contrast with other methods of studying passive sound transmission, it does not require the patient’s cooperation. Moreover, in a preliminary study, we found its intrasubject variability to be acceptable (coefficient of variation between 4.8 and 20.6%) for the indexes described here (unpublished observations).

The study was approved by the Institutional Review Board and informed consent was obtained from the subjects. The subjects were five male lifetime nonsmokers 22-41 yr of age. Sound recordings were done by using four identical electret microphones, flat in free-field frequency response between 10 and 10,000 Hz. Each microphone was glued to the top of a plastic chest piece 14 mm diam and 3 mm deep. Four small holes drilled through each chest piece led from the cavity to the active element of the microphone. The cavity interiors were kept at atmospheric pressure by a 1.0-cm length of 22-gauge needle. The microphones were fastened to the skin by using double-sided tape rings. The unfiltered output of each of the four microphones was amplified and recorded simultaneously by a four-channel FM tape recorder (model 3964 A, Hewlett-Packard) at tape speed of 9.525 cm/s. For each subject, the microphone gains...
were made equal at a point just below saturation at the location of greatest sound output (determined by preliminary testing). Once adjusted, these were kept constant throughout the experiments.

Sound measurements were done in the upright posture at four sites over the chest posteriorly; two microphones placed at the right and left interscapular regions, 5 cm from the fourth thoracic vertebra (T4), and two placed at the right and left basal regions, 5 cm below the scapulae. Each microphone was placed at the same location throughout the course of the study and labeled as follows: microphone LUZ at the left lower zone, microphone LUZ at the left upper zone, microphone RLZ at the right lower zone, and microphone RUZ at the right upper zone.

The percussion maneuvers were done by one observer (ABB) who was well practiced. With the subject in the upright posture, the observer tapped gently but firmly over the manubrium with the distal phalanx of the right middle finger. In a preliminary study we had found that these maneuvers could be performed consistently (coefficient of variation 4.8% for frequency index and 20.6% for amplitude index) by the same examiner (unpublished observations). Forty taps were done during an apnea at each of three lung volumes: functional residual capacity (FRC), total lung capacity (TLC), and residual volume (RV), in that order. Because most subjects experienced some discomfort while trying to maintain a long apnea at RV, at this volume we performed two series of 20 taps each, separated by ~1 min of normal breathing. These were easily reproducible lung volumes for trained subjects to reach, so no objective control of the volume points was attempted. After completing the percussion maneuvers while the subjects breathed air, they then breathed a low-density gas mixture (80% O2-20% He, heliox) for 10 min, after which the same percussion protocol was repeated.

The recorded percussion sounds were digitized at 2,000 Hz by using a 14-bit digital wave form analyzer (model 6000, Data Precision). The output audio signals were stored and analyzed individually in 256 ms signal segments. The percussion wave forms were analyzed according to three steps. In the time domain (step I), we measured the peak-to-peak amplitude of the impulse. Next (step II), each record was submitted to frequency analysis by a 512-point fast Fourier transformation from which we derived the peak frequency corresponding to the frequency at which maximum amplitude occurred. Finally, the power spectrum was integrated with respect to frequency (step III), allowing the measurement of the median power point, indicating the frequency which separated the power spectrum into two equal areas.

For each acoustic index, we determined the significance of differences between homologous upper vs. lower lung zones and right vs. left lung zones by using the Student’s unpaired t test. For a given lung zone, the differences due to changes in lung volume (FRC vs. TLC and FRC vs. RV) and in the resident gas were assessed by the Student’s paired t test. For all statistical analyses, \( P < 0.05 \) was considered significant.

## RESULTS

A typical waveform of the output signal is shown together with its corresponding power spectrum in Fig. 1. The former usually consisted of two or more damped oscillations generally initiated by a negative deflection. The power spectrum was, in all cases, typical of a damped resonant tone. The data from the five subjects were grouped for analysis. The average values of all acoustic indexes, measured at all lung volumes both after breathing air and heliox, are shown for all microphone locations in Fig. 2, A and B. The main findings displayed in Fig. 2 can be summarized as follows. 1) In general, all three index values tended to be higher in the upper zones compared with the ipsilateral lower zones, irrespective of the lung volume considered. However, this was statistically significant only at TLC and RV. 2) For a given index, no significant differences were observed between the values observed over homologous right and left lung zones regardless of the lung volume and resident gas considered. 3) In the upper zones, a "V" pattern in the peak-to-peak amplitude with changing lung volume was noticed. This pattern was characterized by statistically significantly higher values at TLC and RV than at FRC and occurred both with the lungs filled with air and with heliox. 4) For all indexes, the values observed after breathing heliox were not significantly different from, and matched almost perfectly, those seen after breathing air regardless of the lung zone and lung volume considered.

## DISCUSSION

Our results show that during sternal percussion both the amplitude and frequency of the output sounds over the posterior chest were greater over the upper lung zones compared with the ipsilateral lower zones. Moreover, these indexes tended to be greater at the extremes of lung volume compared with FRC. This was especially true of the amplitude index. These regional patterns of changes were, within the limits of this study, independent of the nature of the resident gas in the lungs. In order to interpret these findings the possible paths of sound transmission from the sternum to the microphones must be considered. It is tempting to envision a direct path from the site of percussion to the microphones through the bulk of the lung parenchyma, a hypothesis which has been previously suggested and claimed to be useful for clinical purposes (6). Such a direct path has been dem-

![FIG. 1. A typical waveform of the output percussion note recorded at the left lower zone (left) of subject 2 is shown along with its corresponding power spectrum (right).](http://jap.physiology.org/)
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FIG. 2. A: average changes in percussion sound indexes with changing lung volumes at 4 lung zones after breathing air. Arrows indicate where mean values were significantly different from those measured at functional residual capacity (FRC, paired t test, \( P < 0.05 \)). Symbols represent placement of microphones. ⌂, Left lower zone (LLZ); ⌟, left upper zone (LUZ); ⌣, right lower zone (RLZ); ⌟, right upper zone (RUZ). Vertical bars represent standard deviation. B: same measurements as shown in A, after breathing heliox. Average values were not significantly different from those observed after breathing air regardless of the acoustic index and lung volume considered. Because of the similarity with the data shown in A, the significance between the values at different lung volumes is not shown. ⌂, LLZ; ⌟, LUZ; ⌣, RLZ; ⌟, RUZ. TLC, total lung capacity; RV, residual volume; PKPK, peak-to-peak; PF, peak frequency; QFZ, midpower frequency.

... demonstrated in excised animal lungs. In experiments designed primarily to determine the sound speed in pulmonary parenchyma, Rice (14) measured the translobar transmission of a sound of initial frequency range of 5–30,000 Hz applied to a point on the pleural surface. He found that, apart from being strongly filtered by the lung parenchyma, the sound waves behaved as if they propagated as compression waves through the bulk of the lung parenchyma along a direct pathway.

Another potential acoustic route is through the chest cage. Such a possibility cannot be discarded a priori because the sternum and the ribs are anatomically linked, semirigid structures that are probably similar to one another in acoustic impedance. Therefore, one could expect that the sound introduced at the sternum would spread through the clavicles and ribs with little impairment, causing the chest cage to "ring." Some evidence exists that such may be the case. Michelson (10) placed a vibrating tuning fork on the sternum and a stethoscope alternately in the right and left sides of the chest of two patients with unilateral hydropneumothorax. Because he sensed no differences in the intensity and duration of the sound heard over the two sides of the chest, he concluded that the sound vibrations were actually not transmitted through the lungs but rather through the ribs. Bishop et al. (1) percussed anterior ribs of normal subjects and recorded the sound over the back of the chest. They found the transmitted sound to contain higher frequency components over the percussed rib than over other ribs indicating a direct path along the rib. They also percussed sheep thoraces with and without the lungs within, and found only minor changes attributable to the presence of the lungs. They concluded that the character of the transmitted percussion sound was determined by "cage resonance," which was only slightly modified by the presence of the lungs.

We believe that our results are consistent with those of Bishop et al. (1). We propose that the sternal percussion note heard at the upper location represented transmission through the chest wall which behaved as a resonant cavity, partially damped by the thoracic contents. Over the lower chest, the vibration or "ringing" of the chest wall was impaired due to the more intense damping effect of the adjacent, dense abdominal contents and relatively pliant diaphragm (compared with the thoracic skeleton). At high and low lung volumes, the muscle contractions stiffened the chest cage, improving the transmission and raising the resonant frequency of the upper chest. This explains the increased amplitude and frequency at RV and TLC over the upper chest. Because
the physical properties of the gas within the lungs would play little role in such a system, replacing the air with heliox would be predicted to have a negligible effect as was the case. To corroborate whether the peculiarities of our findings, especially the increased amplitudes at TLC and RV over the upper chest, were due to changes in chest stiffness, we performed an additional experiment. A healthy individual, experienced in performing respiratory maneuvers, was examined on two occasions. First, the sternum was percussed and the output sound recorded at the previously described four sites over the posterior chest while the subject performed apneas at TLC, FRC, and RV. Then the percussion was repeated while he performed first a Mueller and then a Valsalva maneuver at FRC. During these two maneuvers the chest cage is submitted to stiffening forces similar to those observed at TLC and RV, respectively, without concomitant changes in lung volume. The results of these iso-volume experiments (Fig. 3) were similar to those seen during actual lung volume changes supporting our contention that chest wall stiffness is the predominant factor determining the character of the transmitted percussion note.

Some concern should be given to the potential effect of muscle noises. Muscle noises were noticeable at RV and TLC, but we do not believe that they biased our results because their effect on frequency would have been to drive the output frequency down because of their low predominant frequency [≈15 to ≈25 Hz, (11, 13) compared with the mean frequency of the percussion impulses (≈70 Hz, Fig. 2, A and B)]. Instead, the output frequency remained constant or increased at the extreme lung volumes. Muscle noise could not have contaminated the peak-to-peak amplitude either because the percussion notes were visually monitored and were always greater in amplitude than the muscle noise. Because the peak-to-peak amplitude only involved the highest amplitude component (the percussion note), muscle sound could not have affected this index.

Theoretically, the results of this study could have been influenced by the tapping force used during sternal percussion. We do not believe this has happened because, as part of a preliminary study, we performed experiments intentionally using different levels of tapping force and found little difference between the acoustic indexes unless the force was strong enough to cause pain. Also, we averaged the indexes over a high number of measurements (n = 40).

In conclusion, these data suggest that the characteristics of percussion-generated sound transmitted to the posterior chest from the sternum are principally determined by the chest cage. The acoustical characteristics of the lung apparently have little effect on this sound.

![FIG. 3. Additional experiments performed by a healthy subject experienced with respiratory maneuvers. Open symbols indicate measurements obtained at TLC, FRC, and RV. Closed symbols indicate measurements done during apnea (A), Mueller (M), and Valsalva (V) maneuvers at FRC. See Fig. 2 legend for definition of abbreviations.](http://jap.physiology.org/)
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