SOUND SPEED IN THE LUNG MEASURED BY SOUND INJECTION INTO SUPRACLAVICULAR SPACE

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BACKGROUND AND PURPOSE

The speed of sound in the lung changes with changing tissue properties and thus measurement of sound speed has the potential to help in non-invasive diagnosis. Introduction of sound at the mouth for this purpose can be difficult in certain clinical situations such as in the comatose or intubated patient. Accordingly we were interested in a method of measurement speed of sound in the lungs that avoided this problem.

METHODS

- Twenty one subjects with no history of lung disease.
- 82.5% of lung sound analyzer or STET
- Microphone locations

METHODS - Input Sound

- Monophonic sounds from 50Hz to 60Hz, (Sounds with frequency below 70Hz and above 140Hz were transmitted poorly.)
- Cycle frequencies were varied in the following pattern (in Hz, cycles 1 through 14): 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 140.
- The sound was played in a loop every 200 ms yielding 80 transmission "images" over 20 s of the recording.

RESULTS - Transit time analysis - Figure 4

An example of the transit time analysis through the right chest of the polysounds sound, with frequencies of 70 to 140Hz is shown in figure 4A. The sound was recorded at the speaker (Reference) sound on the top and the sound recorded at channel 6 is shown on the bottom. Using the time interval between corresponding peaks of twosounds to yield an approximation of transit time, the sound recorded from channel 6 is delayed by 14.9ms as compared to the reference. In figure 4B, the transit time analysis was refined by cross-correlating the two sounds. The cross-correlation shows a peak clear (arrow) corresponding to an arrival time difference of 14.9ms between the reference and channel 6. The correlation coefficient at the peak of the cross-correlation function was 0.93.

RESULTS - Transit time analysis - Figure 5

- There was a progressive increase in this transit time from the microphones on the apical sites to the microphones over the basal sites. Transit time varied over the chest from 6.0ms at the apical sites to 13.9ms at the basal sites.

RESULTS - Relationship of transit time to lung volume - Figure 6

- Transit time was shorter the bigger the lung volume.
- At all lung volumes the transit time was minimal at the apical sites (channels 1 and 9).
- There was a strong tendency for the transit time to increase gradually the further away the microphones were from the apices.
- In all chest locations the transit time varied inversely with lung volume.

RESULTS - Comparison between experimental and theoretically predicted speed of sound

The theoretically predicted speed of sound in a homogeneous two-phase system is shown in figure 7 as a function of the volume fraction of air in the lungs (\(v\)). The minimum speed of sound (\(24.8\text{m/s}\)) occurs when air occupies half of the lung volume. In the theoretical case when only air is present, \(v = 1\), the speed of sound increases to 34.6m/s. When no air is present, \(v = 0\) the speed of sound increases to 146m/s.

The experimental data from the normal subjects are superimposed on the theoretical curve. The leftmost data point corresponds to lung residual volume that was assumed to be 0.25L. The rightmost data point corresponds to vital capacity in which volume was assumed to be 7L. For simplicity the tissue volume was assumed to be constant 0.8 liters. The leftmost data point corresponds to a lung residual volume (RV) that was assumed to be 1L. The rightmost data point corresponds to a vital capacity (VC) that was assumed to be 5.5 liters. Volume of air in airways was assumed constant at 0.15L. Volume of air in the lung parenchyma (Vp) was calculated by subtracting volume of air in airways from lung volume. The tissue volume (Vt) was assumed to be 0.38 liters at RV linearly increasing to 1.7 liters at VC. These assumptions yielded fraction of air by volume (\(v\)) in the lung parenchyma 0.05 at RV and 0.76 at VC. This range of fraction of air by volume is close to that measured in dogs 0.53-0.83.

Discussion - Comparison to sound input at the mouth

- There was a tight distribution of transit times among the diverse population of subjects.
- The standard deviation of the average transit time data was approximately 10% compared to 30% when sound was injected through the mouth.
- The transit time dependence on the lung volume was strongest at the central sites and weaker at the peripheral sites similar to the results obtained with sound injection through the mouth.
- The average decrease in the transit time from vital capacity to residual volume was 0.8ms with both methods of sound injection.
- Transit time was shorter on the left than on the right when sound was injected through the mouth. Transit times did not vary significantly between left and right channels when the sound was injected into supraclavicular space.
- Calculated sound speeds were approximately half as fast when the sound was input through the supraclavicular space compared with sound input through the mouth.
- Experimentally determined speed of sound 22 +/- 2.4m/s to 34 +/- 2.9m/s is very similar to that predicted by the equations 1 and 2 at a fraction of air 0.5 - 0.8.

CONCLUSIONS

- Sound injection into supraclavicular space provides a noninvasive method of examining sound speed in lung parenchyma.
- This method yields consistent and reliable results while reducing the need for patients cooperation.
- This improved method of studying the mechanism of sound transmission in the lungs may help in the development of noninvasive tools for diagnosis and monitoring lung diseases.