ACOUSTIC IMPEDANCE METHOD FOR DETECTING LUNG DYSFUNCTION

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ABSTRACT

The acoustic impedances of seven rat lungs were measured at frequencies between 100 and 6400 Hz. Rats were divided into two groups: a silica exposed group (N=3) and a control group (N=4). The silica exposed group was injected intratracheally with silica solution. Three of the control group were intratracheally injected with saline. Between four and six weeks after the injections, all lungs were excised and degassed. Lungs were suspended in a pressure chamber, with the trachea canula attached to the end of a tapered impedance tube. The lungs were subjected to transpulmonary pressures between -30 cm H_2O and 6 cm H_2O to simulate deflation and inflation. With transpulmonary pressure being held constant, the impedance tube was excited with random noise. A dual channel analyzer calculated $H_{12}(f)$, the transfer function between the two microphones. This function was used to calculate the lung's impedance at that pressure. The impedance magnitude spectra of both groups typically had peaks at 2000, 3500, and 5500 Hz. Statistically significant differences (90% confidence level or greater) between the two groups occur at the 3500 Hz peak at transpulmonary pressures of 20, 8, 6, 4, and 2 cm of H_2O. This fact seems to confirm that this method can detect lung disease. Further research will indicate whether this method will be able to detect the onset of coal worker's pneumoconiosis.

INTRODUCTION

One of the first studies of impedance of the human lung were conducted by DuBois et al.[2] using the forced oscillation technique. This technique, however, was limited to frequencies below 30 Hz. Further studies by Van Den Berg[6] revealed that the lung reflected higher frequency sounds (100–10,000 Hz), instead of behaving as an anechoic termination. This discovery has lead to several studies of the acoustical properties of both human and animal lungs at high frequencies.[3,4,5]

Ishizaka et al.[4] measured the input impedances of laryngectomized human subjects using a two microphone technique. This study reported peaks in the impedance magnitude at 640, 1400, and 2100 Hz. Fredberg et al.[3] used a transient forced oscillation technique to measure the input impedance of excised canine lungs for frequencies up to 10,000 Hz. Jayaraman and Frazer[5] used a two microphone technique in combination with transmission matrix theory to study changes in the acoustic impedance of excised rat lungs during deflation and inflation.

This study's focus is to determine the differences in the acoustic impedance of excised silicotic and healthy rat lungs. Seven Long Evans Hooded rats, weighing between 200 and 250 g, were divided into two groups. The silica-exposed group (N=3) were intratracheally injected with a silica-saline solution to induce silicosis. Three rats of the control group (N=4) were given a sham exposure of saline. During a

period four to six weeks after injection, all lungs were excised and degassed.

METHODS

Figure 1 displays a block diagram of the impedance tube facility used in this study. An excised lung is attached to the end of a tapered tube within a plexiglass pressure chamber. Random noise, produced by a Bruel and Kjaer 2032 dual channel analyzer, is amplified and introduced into the tube via a side-mounted speaker driver (University, type ID-30C-8). The standing waves thus formed in the impedance tube are measured by two Bruel and Kjaer 4136 pressure microphones mounted 2.3 cm apart in a plexiglass cylinder. The signals of these microphones are the inputs to the dual channel analyzer, which calculates the transfer function between the two microphones, H_{12}, and its inverse Fourier transform , h(t). Following Jayaraman and Frazer's example,[5] exponential weighting is applied to h(t) and transmission matrix theory applied to the resulting transfer function to yield the input impedance of the excised lung.

The plexiglass chamber's pressure is controlled by a variable speed pump to produce transpulmonary pressures between 30 and -6 cm of H_2O. The difference between chamber pressure and atmospheric pressure is monitored by a water manometer. A lung is first inflated to 30 cm of H_2O, then deflated to -6 cm of H_2O, pausing at several pressures for impedance measurements. Once fully deflated, the lung is inflated to 30 cm of H_2O, again stopping at various pressures for measurements.
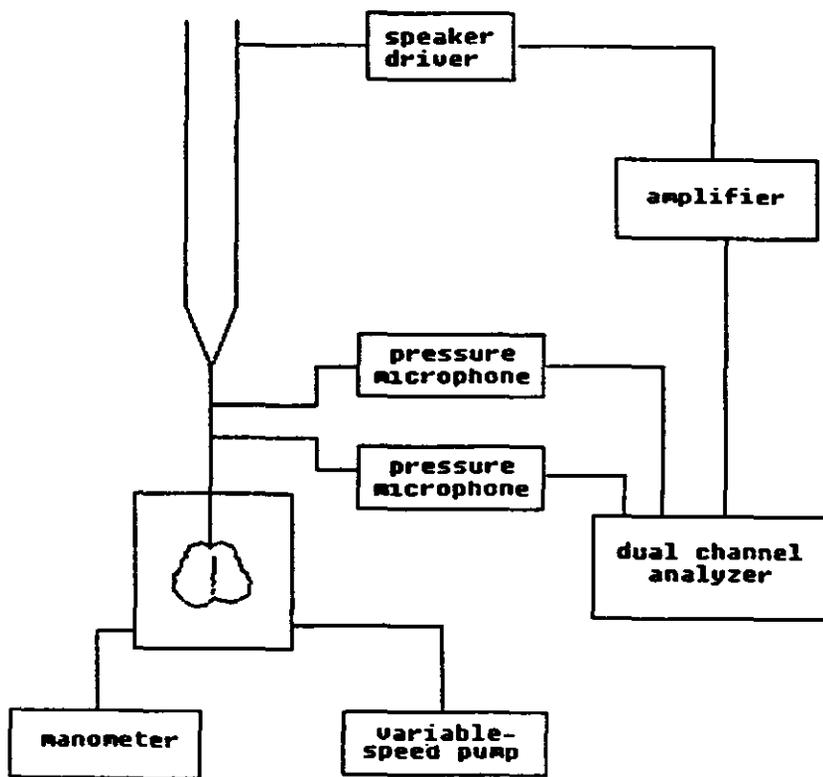
Figure 1. Block diagram of impedance measurement facility.

RESULTS

The average magnitude spectra of the silica and control groups are presented in Figures 2, 3, and 4 for transpulmonary pressures of 30, 8, and 2 cm of H_2O, respectively.

DISCUSSION

The impedance magnitude spectra of all rats have been computed for transpulmonary pressures of 30, 20, 10, 8, 6, 4, 2, 0, and -2 cm of H_2O. Typical rats in both groups had

Figure 2. Comparison of average impedance spectra of silica and control groups. Deflation 30 cm H₂O.

peaks at 2000, 3500, and 5500 Hz. The placement of these peaks compare favorably with the study of Jayaraman and Frazer,[5] with the exception that in this study, no peak occurred at 600 Hz.

Significant differences between the silica and control groups occurred at the peak at 3500 Hz. T-tests performed on the peak magnitudes at this frequency showed that the silica group had significantly higher impedance (90% confidence

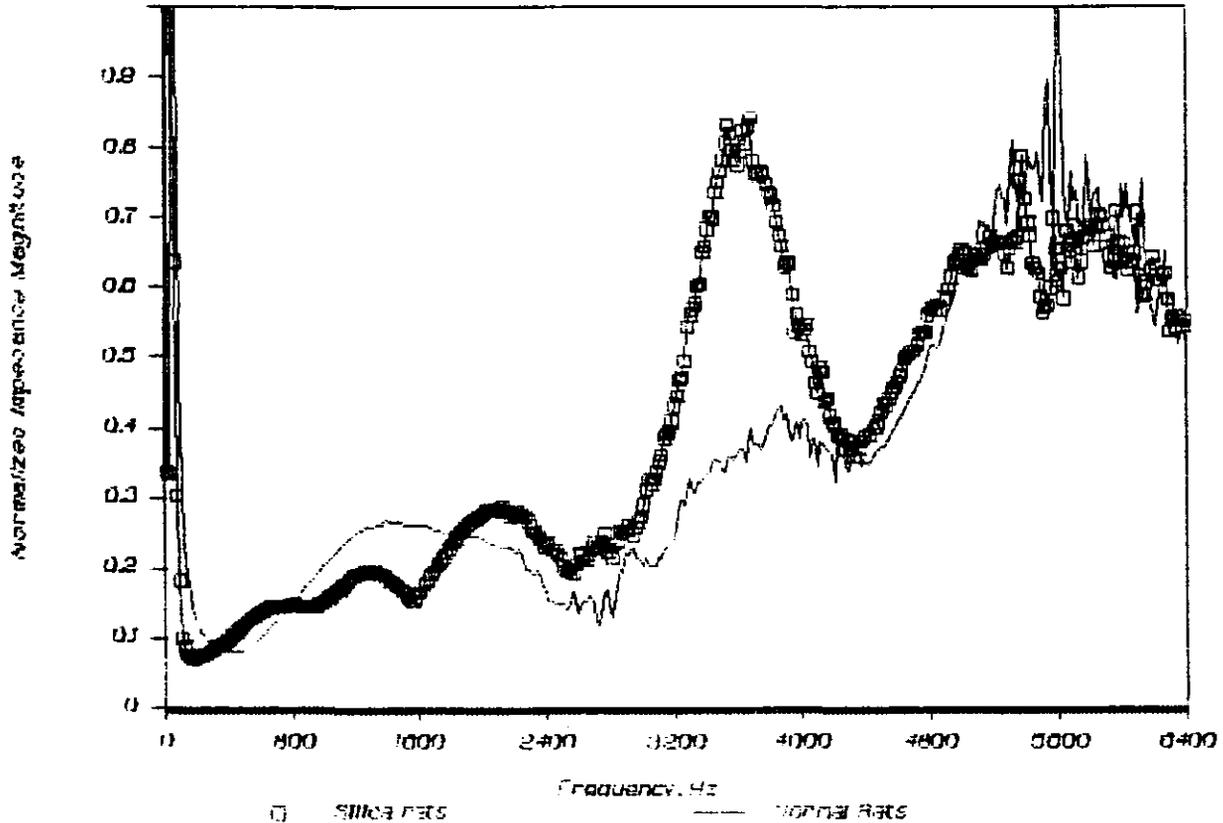## Comparison of Normal and Silica Rats

Deflation 8 cm H2O

Figure 3. Comparison of average impedance spectra of silica and control groups. Deflation 8 cm H₂O.

level) at transpulmonary pressures of 20 and 8 cm of H₂O during deflation. The silica group also had significantly higher impedance (98% confidence level) at 3500 Hz at pressures of 6 and 4 cm of H₂O during deflation. These findings show that changes in the mechanical properties of lung tissue and the closure of airways occurred at higher pressures in the silica group than with the control group. This finding agrees with the work of Chvalova et al.[1] which found that the pressure-volume curve of silicotic rats was shifted to higher pressures compared to normal rat lungs.

CONCLUSIONS

The above findings indicate that silicosis in rat lungs can be detected by measuring the lung input impedance. The key indicator thus far is the impedance magnitude of the peak at about 3500 Hz. Further studies will determine the effectiveness of the method in detecting the development of lung diseases and if the measurement of acoustic impedance can be an effective clinical tool for the treatment of lung diseases.
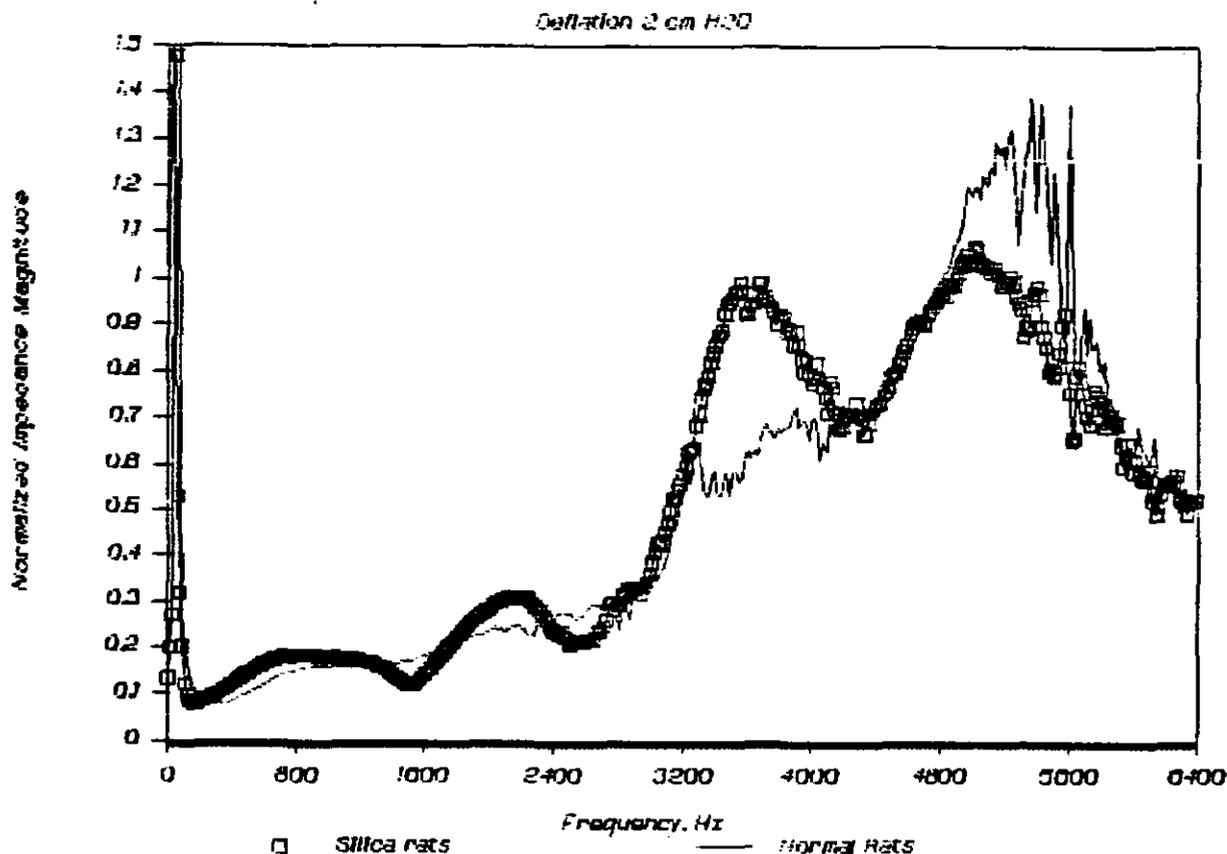
Figure 4. Comparison of average impedance spectra of silica and control groups. Deflation 2 cm H_2O.

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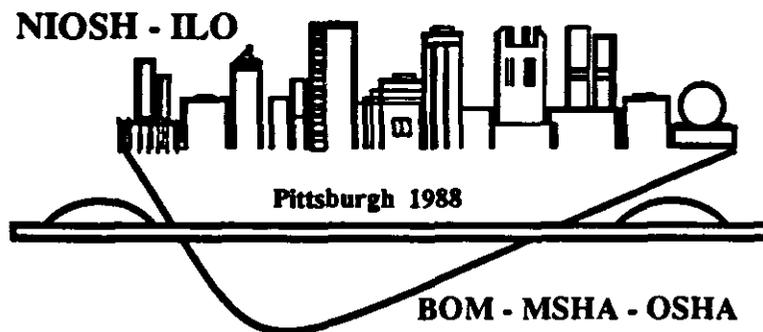
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