GATED REGIONAL SPIROMETRY (GRS)


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ABSTRACT

A new non-invasive procedure to assess the regional distribution of the lung ventilation is described. 133 Xenon is used as a radioactive tracer. The radioxenon distribution within the thorax is measured during resting and forced respiratory cycles using a LFOV scintillation camera and a dedicated minicomputer. The program used to produce the images of the regional spirometric values is explained. Patterns of the distribution of these physiological parameters in normal males and females are presented.

INTRODUCTION

There is a need for a sensitive, precise, and non-invasive method to measure the ventilation and respiration of the different lung segments and subsegments. Conventional spirometric techniques and flow-volume measurements are capable of making accurate evaluations of the total ventilatory function of the lungs. Similarly, their respiratory efficiency can be assessed through arterial blood gas measurements. However, there does not currently exist a non-invasive procedure which can give precise information of regional ventilation.

Ventilation lung scans with 133 Xenon or radioaerosols, as performed in most nuclear medicine clinics, are useful in determining the presence of gross ventilation/perfusion mismatches in the absence of obstructive bronchial disease. In addition, it has been demonstrated, that the ventilation lung scan is a very sensitive test for the early detection and qualitative evaluation of chronic obstructive pulmonary disease (COPD). However, it is not capable of accurate detection of segmental or subsegmental ventilation/perfusion mismatches in patients with COPD. It is also limited in its ability to quantify regional ventilatory changes during the natural history or treatment of a lung disease.

The regional uncertainty of the ventilation lung scan is due to the fact that information is inferred only from washin or washout of the radioactive gas. Actual volume changes are not measured because of the low count rates observed in the serial images. This limitation can be overcome by creating a representative respiratory cycle by summing corresponding parts of several cycles using a gated acquisition program.

Previous application of the gating technique to the study of the regional ventilation has been carried out using an electrical trigger signal derived from a spirometer. We are presently using a simpler procedure which involves no hardware triggering device and is based solely on the post collection processing of the collected data. To date 14 normal volunteers (Table I) have been studied and the regional distributions of the lung volumes are presented.

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METHOD

The subject rebreathes in a closed system in order to achieve a uniform concentration of Xe-133 within the air in the lungs and within the inspired air. The closed system consists of a constant supply of oxygen, a CO₂ absorber, a 10 liter rubber and nylon bag, a volumeter, a bacterial filter, a mouth piece, a nose clamp and connecting tubes (Fig. 1). In order to insure accurate registration of the anterior and posterior views a special repositioning device was constructed (Fig. 2). Once the patient has become accustomed to rebreathing in the system the 133 Xenon is introduced. After equilibrium is achieved, data acquisition is started. Data are recorded during 1 to 2 minutes (approximately 20 cycles) of resting respiration and for 7 to 10 forced ventilation cycles. Acquisition is performed in frame mode with a temporal resolution of approximately 20 frames per cycle. The frame duration is calculated for each patient depending upon the respiratory frequency. Several measurements of the tidal volume are performed using a volumeter during the period of resting respiration. Similarly vital capacity is measured during the forced ventilation cycles.

Processing of the acquired data consists of the following steps:

A) Using an area of interest including both lungs, time-activity curves are obtained for the resting and forced ventilation time periods.

B) By adding the frames corresponding to the peaks and valleys on each curve as shown in Fig. 3, the following images are formed:

- Image A = Resting Maximal Inspiration
- Image B = Resting Maximal Expiration
- Image C = Forced Maximal Inspiration
- Image D = Forced Maximal Expiration

C) By adding the frames corresponding to 1 sec. after the peaks of forced ventilation a fifth image is obtained.

- Image E = 1 sec. after maximal inspiratory effort

D) A background value of counts per picture element (BKG) is determined from the counts in Axilar region. This is used as described below to correct for activity due to Xenon absorbed in the fat of the soft tissue.

E) Images of the topographical distribution of lung volumes are obtained from these 5 initial images by using the following equations:

- Image C - BKG = Image of the Total Lung Capacity (TLC)
- Image D - BKG = Image of the Residual Volume (RV)
- Image C - Image B = Images of the Vital Capacity (VC)
- Image A - Image B = Image of the Tidal Volume (VT)
- Image B - BKG = Image of the Functional Residual Capacity (FRC)
Representative resting and forced cycles are created by dividing the activity curve of each cycle into 12 equal height segments and adding the corresponding frames.

A conversion factor to transform counts in each image into units of volume is derived by equating the tidal volume as measured with the volumeter to the difference in counts between the maximum inspiration and maximum expiration images.

For the analysis of the normal patterns, images of the lung volumes are divided into 25 equal segments along the vertical axis using the posterior TLC image as reference. The activity per slice in each lung is then plotted as a vertical profile. Average profiles for each lung are determined separately for normal males and females (Fig. 4 to 7).
DISCUSSION

The technique of gated regional spirometry (GRS) provides information on the regional distribution of lung volumes within the thorax during resting and forced respiration. It is non-invasive, simple, fast and does not require any sophisticated instrumentation or special skills. As is the case with any test of pulmonary function, a certain degree of patient cooperation is required. The average study time including the time needed to teach the patient to rebreathe in the closed system is approximately 20 minutes. Most of this time is spent in training the patient to rebreathe in the system. In spite of the limited depth response of the detector caused by the attenuation of the $^{133}$Xenon photons (81 KEV), the results have been found to be satisfactory. In this regard, $^{127}$Xenon (200 KEV) offer advantages over $^{133}$Xenon. However, its longer half life increases the risk of contamination of the laboratory equipment and personnel. Once it becomes available for routine use, $^{81m}$Krypton (190 KEV) may become the ideal radiopharmaceutical for this procedure, provided a correction for radioactive decay can be made.

The profiles of distributions of the lung volumes in the posterior view showed no significant difference between males and females (Fig. 4 and 5). The differences in lung volumes between the left and right lungs at the base, are the result of the presence of the heart in the left hemithorax. The profiles of the anterior images (Fig. 6 and 7) are different in females and males. The downslope observed in the third-fifth of the profiles of the anterior images, seen in females but not in males, is produced by the absorption of the Xenon gamma rays in the mammary glands. Disregarding the artifact produced by the breast, the relative height of the second fifth of the curve is larger in the tidal volume and vital capacity images of females than males. This difference should be interpreted as the manifestation of a relatively greater anterior expansion of the upper thorax in females.

GRS, as with any other procedure which measures regional ventilation using radionuclides, determines the changes in different thoracic regions, but does not measure the volume change of specific lung regions. The very high values of tidal volume and vital capacity in the lower portion of the thorax are mainly produced by the lung displacement during total lung expansion. The technique offers the possibility of measuring the gravitational center of the lung ventilatory function. The simultaneous measurements of the gravitational centers of the ventilation and the functional pulmonary blood flow (as determined from radioactive microsphere distribution images) will be a significant advance in the assessment of the respiratory function in such conditions as emphysema, pulmonary fibrosis, thoracic deformities, etc.

It is our opinion that the cine display of the representative cycles and the forced expiratory volume image may prove to be specific and sensitive tests for determining bronchial obstruction. We are in the process of evaluating the GRS for this purpose.

REFERENCES


This research was sponsored by a grant of the Tennessee Lung Association.

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