THE ALVEOLAR PLATEAU AS A MEASURE OF REGIONAL ASYNCHRONOUS VENTILATION OF THE LUNGS

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Regional lung concentrations and the concentration curve of Xe-133 in the expired air were investigated in 18 persons inhaling this test gas at various times of inspiration.

The terminal part of the alveolar plateau is raised during inhalation of Xe-133 in the initial stages of inspiration from the level of its residual volume and lowered if Xe-133 is administered at the end of inspiration.

The change in concentration of the test gas in later expiration samples is the result of regional asynchronous ventilation of the lungs. The more the preinspiratory volume differs from the mean physiological level, the more marked the asynchronous ventilation of the lungs.

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The respiratory dead space has been investigated since 1963 by the use of Fowler's principle [7], by recording the concentration curve of xenon-133 (Xe-133) in the expired air during a single expiration synchronously with the expired volume. The principle described is the obtaining of the alveolar plateau, indicating the development of a uniform Xe-133 concentration from the lungs [3]. It was occasionally observed that the terminal part of the alveolar plateau is raised or lowered, indicating an increase or decrease in concentration of the test gas in the mixed alveolar air. Such changes in the terminal part of the alveolar plateau have been observed by several workers [6, 8, 11].

The object of the present investigation was to determine the nature of concentration changes in the terminal part of the alveolar plateau.

EXPERIMENTAL METHOD

Xe-133 (1-2 mCi/2-3 ml air) was injected into the inspired mixture in different preinspiratory volumes determined by an electrospirograph of the writer's own design. The Xe-133 concentration in the inspired and expired mixtures was recorded by a scintillation counter in a special collimator placed in the subject's mouth. Changes in activity of Xe-133 in the expired mixture were determined by a fast-acting radiometer with time constant 0.2 sec and transmitted to the vertical axis of a two-coordinate self-writing instrument designed by the writer on the basis of a multi-channel oscilloscope. The electrospirograph signal was fed synchronously on the horizontal axis of the instrument. In this way the two-coordinate instrument recorded the integral expiratory curve of Xe-133 activity as a function of expired volume. The time constant of the two-coordinate self-writer was less than 0.1 sec. The shape of the expiratory concentration curve and the alveolar plateau were recorded by this method.

Meanwhile the regional Xe-133 concentrations were recorded by four scintillation counters located extrathoracically over the dorsal surface of the right lung. The counters were arranged at regular dis-

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tances along the long axis of the lung from above down (all investigations were carried out with the patients in the sitting position). Xe-133 activity was measured by fast-acting NC-106 radiometers, and regional radioactivity levels were recorded on a type N-320 self-writing instrument.

The regional concentration of Xe-133 was determined by the method of Ball and co-workers [5], with measurement of the primary counting speed and the counting speed after the period of equilibration:

$$K_{reg} = K_{spir} \times \frac{C_{reg}}{C_{eq}},$$

where K_{reg} is the regional Xe-133 concentration; K_{spir} the Xe-133 concentration in the spirograph after the period of equilibration, C_{reg} the regional primary counting speed; C_{eq} the regional counting speed after equilibration.

The technique of this investigation and the equipment used have been described previously [1, 2, 4].

Xe-133 was injected by a syringe into the airway in four preinspiratory volumes: 0-10% of the VCL* (residual volume), 20-30% of the VCL, 40-50% of the VCL (functional residual capacity), and 60-70% of the VCL. Inhalation began from the level of the residual volume and continued up to the VCL. Expiration during which the expiratory concentration curve of Xe-133 and the alveolar plateau were recorded continued down to the level of the residual volume.

Altogether 18 subjects aged 24-39 years with no evident pathology of the respiratory and circulatory systems were investigated. All subjects received preliminary training in performance of the essential respiratory procedure without the use of Xe-133.

EXPERIMENTAL RESULTS

The frequency of changes in the terminal part of the alveolar plateau is shown in Table 1 in relation to the preinspiratory volume at which Xe-133 was injected. The rise or fall of the plateau at the end of inspiration was regarded as significant only if the Xe-133 concentration in the final part of the plateau differed from the general level of the plateau by more than 10%. In these cases the name "plateau" is, of course, conventional in character.

The results given in Table 1 and Fig. 1 demonstrate that the test gas concentration in the last samples taken during expiration are definitely dependent on the preinspiratory volume at which the test gas was injected. Consequently, the behavior of the terminal part of the alveolar plateau is usually not random but regular, and the mechanism of this relationship requires explanation.

The regional distribution of Xe-133 in the same patients, given in Table 2, can now be considered. Table 2 shows that during inspiration from the level of the residual volume, to begin with, it is the upper portions of the lungs which are mainly filled. Filling of the lower lung segments begins to predominate only when the lungs have been filled to the extent of about one-third of the VCL. Injection of Xe-133 at

* Vital capacity of the lungs.

TABLE 1. Terminal Part of Alveolar Plateau following Inhalation of Xe-133 at Different Moments of Inspiration

Plateau at end of expiration	Preinspiratory volume (in percent of VCL)			
	0—10	20—30	40—50	60—70
Rise of plateau (increase in Xe-133 concentration)	12	2	1	1
No change	2	14	7	4
Fall of plateau (decrease in Xe-133 concentration)	2	2	6	10
Total number of subjects	16	18	14	15

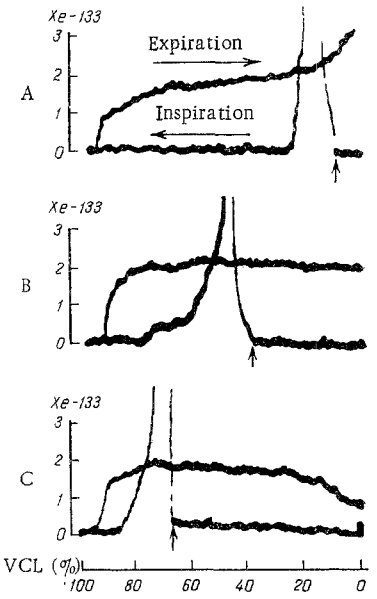

Fig. 1. Alveolar plateau after inhalation of test gas at different moments of inspiration (concentration curves as a function of volume plotted by two-coordinate integrating self-writers for subject Z., aged 38 years). Abscissa, volume; ordinate, Xe-133 concentration (in thousands of pulses/sec). A) Injection of Xe-133 at preinspiratory volume of 10% of VCL; B) 67% of VCL. Vertical arrows denote times of injection of Xe-133.

TABLE 2. Regional Concentrations of Xe-133 following its Inhalation at Different Moments of Inspiration (M ± t)

Counter	Preinspiratory volume (in percent of VCL)			
	0—10	20—30	40—50	60—70
I	120,3±2,48	91,7±1,76	84,7±1,34	87,0±1,87
II	117,9±0,64	112,2±0,78	105,6±0,73	100,7±0,63
III	76,2±1,75	114,8±0,63	133,5±2,01	121,0±0,65
IV	56,8±4,21	95,8±1,37	145,0±1,14	148,1±1,05

Note. Counters I-IV were located in order from the apex to the base of the lung.

different preinspiratory volumes thus confirms the asynchronous filling of the lungs segments, described as successive ventilation of the lungs [9]. Although the existence of asynchronous ventilation of the lungs has been known since 1902 [13], it was measured for the first time only in 1959 by Koler and co-workers [10], who used labor bronchospirometry for this purpose. Asynchronous ventilation of the lungs was demonstrated by Read [12] by the use of a more refined technique using inert gases.

By inhalation of Xe-133, the existence of asynchronous regional ventilation of the lungs under abnormal conditions of respiration, i.e., with extremely small or large preinspiratory volumes, can be reliably confirmed.

If regional Xe-133 concentrations and the characteristics of the alveolar plateau are confirmed for identical conditions of respiration (Tables 1 and 2), a more precise idea can be obtained of both regional asynchronous ventilation of the lungs and the mechanism of the change in concentration of the test gas in the final samples of expiration. The alveolar plateau at the end of expiration is raised if Xe-133 is inhaled at the beginning of inspiration (i.e., it enters mainly the upper segments) and lowered if the test gas is inhaled at the end (i.e., it enters mainly the lower segments of the lungs). It is thus evident that during maximal expiration it is gases from the upper segments of the lungs which are expelled. A similar relationship probably must exist also for the alveolar plateau obtained with other foreign test gases.

The relationship described was obtained only under conditions of lung ventilation outside the mean physiological limits. However, if it is remembered that function tests based on determination of mean concentrations of alveolar gas are frequently carried out at maximal expiration, corrections must be introduced when the results of these tests are analyzed.

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