SEGMENTAL TOPOGRAPHY AND AERATION GRADIENTS OF THE HUMAN LUNGS

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The method of regional electroplethysmography of the lungs was used to study the segmental topography of the air volume when the total preinspiratory lung volume corresponded to the functional residual capacity. In subjects recumbent in the supine position, besides a distinct dorsal–ventral gradient, there is also an equally marked apical–basal gradient, the origin of which cannot be explained from the standpoint of a gravitational mechanism. The electroplethysmographic index of the air content in a part of the lungs can be converted into an index of the regional volume of air in the lungs, and it was also shown that, in principle, the regional total lung-capacity index can be calculated by electroplethysmography.

KEY WORDS: electroplethysmography; regional air volume of the lungs.

The concept of functional heterogeneity of the lungs has received fresh evidence with the introduction of radioisotopic methods of investigation into respiratory physiology [5, 15, 16]. In practice, however, these methods are unsuitable for the study of regional functions at the segmental level, which would allow a more adequate comparison of functional heterogeneity with morphological. The segmental principle is also of great practical importance in connection with the requirement of pulmonology and thoracic surgery.

Since no data on the segmental distribution of aeration of the lung could be found in the accessible literature, it was decided to study this problem by the method of regional electroplethysmography of the lungs.

EXPERIMENTAL METHOD

Tests were carried out on 25 men and 5 women from 19 to 47 years old. The electroplethysmogram was recorded during combined bronchoscopic investigation under intravenous thiopental anesthesia after atropine (1 mg) premedication. Artificial ventilation of the lungs was carried out with a semiopen circuit and passive expiration. Measurements were made in the period of transient apnea, and they related to parts of the lungs not exceeding the volume of an ellipsoid of rotation with hemiaxes of 17.5 and 11 mm. The location of the detector-probe of the electroplethysmograph was determined endoscopically and radiologically. The segmental topography of the lungs is described in agreement with the terminology of the bronchial tree and broncho-pulmonary segments adopted at the 6th International Congress of Anatomists in 1955 [7, 13].

The air content per unit volume of the organ in percent (the aeration) was calculated by the method of measurement and computation described previously [9, 11].

This paper gives an analysis of the results of investigations of patients found to be clinically healthy after clinical and radiological examination (7) and also of patients with monosegmental minor forms of tuberculosis (23), in whom the measurements were carried out on segments of the contralateral lung. The study of external respiratory function shows that, in agreement with criteria established by various workers [1, 3, 8, 12], neither group of patients had evidence of ventilatory insufficiency. Control oxyhemographic tests showed that the oxygen saturation of the arterial blood during the period of recording of the electro-

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plethysmograms deviated from its initial level by not more than ± 2 %. All measurements were carried out with the patients in a supine position.

EXPERIMENTAL RESULTS AND DISCUSSION

For conveinence of comparison of the index of regional aeration of the lungs obtained when the total preinspiratory volume corresponded to the functional residual capacity (FRC) with the results obtained by workers [5, 15] who calculated the regional air volume as a fraction of the regional maximal capacity of the lungs in percent, a calculation based on the following simple consideration was carried out [2, 10].

$$\frac{V_f}{V_t} = \frac{V_{bt}+B_f}{V_{bt}+B_t} = \frac{B_f\left(1+\frac{V_{bt}}{B_f}\right)}{B_t\left(1+\frac{V_{bt}}{B_t}\right)}; \quad a_f = \frac{V_{bt}}{V_f}; a_t = \frac{V_{bt}}{V_t};$$

$$a+b=1; \quad \frac{a_t}{a_f} = \frac{B_f\left(1+\frac{a_f}{b_f}\right)}{B_t\left(1+\frac{a_t}{b_t}\right)}; \quad \text{FRC reg \%} = \frac{(1-b_t)\,b_f}{b_t(1-b_f)}100\%;$$

where V and V_{bt} are the regional volume of the organ (in cm^3) as a whole and the regional volume occupied by blood and the tissue of the organ (in cm^3); B the regional volume of air (in cm^3); a and b the relative volumes of blood + tissue of the organ and air; f and t are indices of the functional reserve capacity and total capacity of the lungs; FRC_{reg} % is the regional functional reserve capacity, but with extrapolation for the lung segment, expressed in percent.

In order to calculate FRC_{reg} % it is thus necessary to know only the relative percentage of air in the segments studied for corresponding functional states of the lungs, and this can be found in principle on the basis of two successive measurements of the electrical resistance of that part of the lung. The possibility of determining it in any other functional state is of interest on its own account, for it enables the total lung capacity index, previously found on the basis of experiments on isolated human lungs [2], to be determined directly.

The results (Fig. 1) show that with the subject in the supine position a clear dorsal–ventral aeration gradient of the lungs exists ($P < 0.001$) on account of differences between the dorsal 10th segment and the group of ventral segments (3–5), which are very homogeneous in their air content. However, subjects in the same position also show an apical–basal gradient between segments 10 and 2, virtually on the same horizontal level.

It must be emphasized that the dorsal–ventral and apical–basal gradients, expressed by the ratio between the FRC_{reg} % indices, were closely similar in value (2.02 and 1.98). The mean values of the relative air content and the regional FRC in the lung segments are given in Table 1.

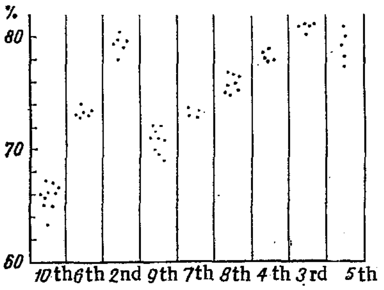

Fig. 1. Segmental distribution of air content in lungs. Abscissa, from left to right, nomenclature of segment from most dorsally to most ventrally situated; ordinate, air content in segment, in percent, when total preinspiratory volume of lungs corresponded to functional reserve capacity.

The apical–basal gradient found in the horizontal position is comparable in all respects with the same gradient determined by radioisotopic methods in subjects in the vertical position (Table 1). This gradient is usually regarded as gravitational in origin. However, such an interpretation is not valid for the apical–basal gradients in the horizontal position.

The most likely explanation is that it is largely determined by the different conditions of ventilation which, in turn, depend to a substantial extent on the morphological heterogeneity of the lungs. Segmental differences in differentiation of the alveolar parenchyma, the character of branching of the bronchi and blood vessels, and differences in the anatomical conditions for collateral aeration are implied [4, 6, 7, 14].

The results obtained for subjects in the horizongal position thus show that there is an apical–basal gradient of aeration as well as a dorsal-ventral gradient. Since these gradients, which from the gravitational point of view are mutually exclusive, are comparable in magnitude there is reason to suppose that other

TABLE 1. Mean Value of Air Content and Regional Functional Reserve Capacity in Lung Segments

Regional electroplethysmography			Xenon-133 [5]		
broncho-pulmonary segments	air content, percent	FRC_{reg}, [5]	zone of lung	FRC_{reg}, %, data from graph on page 159	Vertical apical-basal gradient
Infero-posterior (10th) Infero-lateral (9th) Cardiac (7th)	65,7±0,32 70,7±0,39 73,1±0,25	25,6 32,3 36,4	Inferior	30	
Infero-apical (6) Infero-anterior (8th) Lateral (4th)	73,2±0,23 75,7±0,32 78,2±0,2	36,6 41,7 48,0	Middle	43	1,83
Posterior (2nd) Medial (5th) Anterior (3rd)	79,1±0,39 79,1±0,58 80,7±0,15	50,7 50,7 56,3	Superior	55	

(nongravitational) factors play an essential role in the mechanisms of distribution of air in the lungs. Their investigations would probably help to elucidate more fully the mechanism of origin of regional differences in the air content in the lungs.

LITERATURE CITED

1. V. G. Boksha, Probl. Tuberk., No. 2, 50 (1972).
2. E. R. Weibel, Morphometry of the Human Lungs [Russian translation], Moscow (1970), pp. 51, 54.
3. A. G. Dembo, Proceedings of the 15th All-Union Congress of Physicians [in Russian], Moscow (1964), p. 25.
4. I. K. Esipova et al., in: Some Problems in Pathology of the Lungs in the Light of the Most Recent Data on Their Normal Structure, Development, and Regeneration [in Russian], Novosibirsk (1962), p. 39.
5. A. P. Zil'ber, Regional Functions of the Lungs [in Russian], Petrozavodsk (1971), pp. 13, 159, 169.
6. A. I. Klembovskii, in: Some Aspects of Pathology of the Lungs in the Light of the Most Recent Data on Their Normal Structure, Development, and Regeneration [in Russian], Novosibirsk (1962), p. 7.
7. F. Kovacs and E. Zhebek, Roentgenoanatomical Bases of Investigation of the Lungs [in Russian], Budapest (1962), pp. 75, 91, 115, 374.
8. J. Comroe et al., The Lungs. Clinical Physiology and Function Tests [Russian translation], Moscow (1961), pp. 15, 20.
9. B. I. Mazhbich, Byull. Éksperim. Biol. i Med., No. 3, 121 (1964).
10. B. I. Mazhbich, Izvest. Sibirsk. Otdel. Akad. Nauk SSSR, Ser. Biol., No. 12, 139 (1965).
11. B. I. Mazhbich, Electroplethysmography of the Lungs [in Russian], Novosibirsk (1969), pp. 53, 93.
12. M. Navratil, K. Kadlets, and S. Daum, The Pathophysiology of Respiration [Russian translation], Moscow (1967), pp. 50, 111.
13. K. V. Pomel'tsov, Vestn. Roentgenol., No. 6, 11 (1959).
14. A. G. Éingorn, Arkh. Pat., No. 2, 83 (1956).
15. J. J. Milic-Emili et al., J. Appl. Physiol., 21, 754 (1966).
16. J. B. West and C. T. Dollery, J. Appl. Physiol., 15, 405 (1960).