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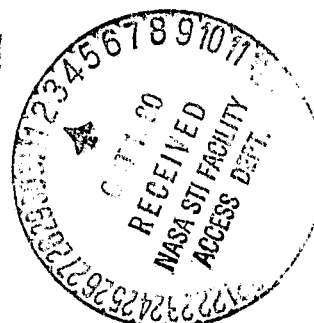
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BLOOD FILLING AND FLOW IN LUNGS DURING CHANGE IN
BODY POSITION IN SPACE

A. S. Pogodin and B. I. Mazhbich

Translation of "Krovenapolneniye i krovotok v legkikh
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16. Abstract In the horizontal position (supine and lateral), in the upright position (head up and head down) and during change of the cat body position in space, quantitative responses of regional blood volume and blood flow in the lung (ml/100 cm ³) revealed presence of the gradient in the gravitation direction. Blood volume and blood flow of different lung portions changed qualitatively and quantitatively in different ways. These changes occurred only in the direction producing the equality of regional hydrostatical and hemodynamic loads in the lungs at either horizontal level.			
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BLOOD FILLING AND FLOW IN LUNGS DURING
CHANGE IN BODY POSITION IN SPACE

A. S. Pogodin and E. I. Mazhbich*

Due to the development of the concept of nonuniformity in the functions of the lungs [13, 15, 16] the interest in studies on regional pulmonary circulation has noticeably intensified recently. It is evident that without consideration for regional nonuniformity in pulmonary functions many questions of the physiology and pathology of pulmonary circulation and respiration cannot be completely understood [3, 12, 13, 15]. As is known, the main cause of regional nonuniformity of pulmonary hemodynamics is the effect of the gravity force. Blood flow and filling of different sections of the lung change considerably with a change in the amount or direction of the gravity force [3, 15]. These changes develop on the background of shifts in general hemodynamics, in which all the links of the cardiovascular system and its regulating mechanisms are involved [1,4,11]. The regional nonuniformity of the pulmonary functions is influenced also by a number of other factors: hypoxia, physical load, certain types of pulmonary pathology, thoracotomy, etc. [3, 13, 14]. However, until now many questions of the regional hemodynamics of the lungs have not been sufficiently studied [2], and this refers first of all to the studies of regional blood filling which is linked to the difficulties in determining this important index [8, 11], especially in animals with intact thoracic cage. /555**

In accordance with what has been said, the purpose of this work was to study the condition of blood filling and blood flow in the lungs with different body

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**Numbers in margin indicate pagination in original foreign text.

positions and redistribution of these hemodynamic indices at the moment of change in the body position in space.

Technique

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The experiments were conducted on 37 adult cats weighing 3.5-5.2 kg that were narcotized with nembutal (60 mg/kg, intraperitoneally) with artificial ventilation using listenone. Surgical preparation of the animal only consisted of tracheotomy.

A study of the distribution of blood filling and blood flow in the lungs was made in a horizontal (lying on back and lateral), vertical (head upwards) and reversed vertical (head downwards) body position, as well as at the moment of change in the body position in space. The study employed the method of regional electroplethysmography [5,6] that makes it possible to quantitatively evaluate the blood filling and blood flow (in ml per 100 cm³ of organ volume) of individual pulmonary sections [5,10]. For such type of research we especially developed a new design of electroplethysmographic sensor [7], whose use prevents a possible shift in the sensor in relation to the studied section of the organ with a change in body position.

A change in body position of the animal in space was implemented with the help of a turning table of an x-ray apparatus, whose angle of incline could be smoothly altered from 0 to 90°. Artificial ventilation at the moment of change in body position was disconnected.

In order to compare the study results in the lungs the following zones or regions were conditionally separated: apical, medial and basal, among which the dorsal and ventral sides were distinguished. According to this plan, 1 or 2 electroplethysmographic sensors were introduced into the lungs under fluoroscopic control, and the electroplethysmograms were recorded on a self-recorder.

Results of Study

The table presents the results of a study to determine the blood filling and flow in the lungs in a horizontal (lying on back) and vertical (head upwards and head downwards) body position. In any of the indicated positions the

CERTAIN INDICES OF REGIONAL PULMONARY HEMODYNAMICS WITH DIFFERENT BODY POSITIONS IN SPACE

Body position	Studied pulmonary zones	B ml/100 cm ³	MV ml/100 cm ³	DI of B	DI of MV	Up/down	
						B	MV
Horizontal (lying on back)	Ventral	11.0±0.5	258±16	0.87	0.85	0.78	0.73
	Central	12.7±0.3	294±17	1.01	0.97		
	Dorsal	14.1±0.4	355±18	1.12	1.18		
Vertical	Apical	4.8±0.3	88±8	0.55	0.41	0.39	0.28
	Medial	9.4±0.3	240±15	1.07	1.12		
	Basal	12.2±0.4	313±16	1.40	1.46		
Reversed Vertical	Basal	12.5±0.4	323±26	0.89	0.96	0.77	0.90
	Medial	13.2±0.5	321±20	0.94	0.96		
	Apical	16.3±0.8	360±35	1.16	1.07		

Note: B--blood filling, MV--per-minute volume of blood flow, DI--distribution index.

gradient of blood filling and blood flow was found according to the direction of the gravity force. In a horizontal (lying on back) position this was the ventrodorsal gradient. Blood filling of the ventral zone of the lungs averaged 22% lower, and blood flow 27% lower than the dorsal. The relative characteristics of regional nonuniformity of blood filling and blood flow for these zones were also close, the ratio "up/down" and the distribution index (see table). The apical-basal gradient both for blood filling and for blood flow was not found in the horizontal position.

The vertical body position (head upwards) is characterized by the greatest regional nonuniformity of blood filling and blood flow of the lungs (see table). For the apical zones, all the indices are considerably lower than for the basal. Differences in blood filling average 61%, for blood flow--72%. The deviation from the uniform distribution for blood filling is 45% for the apical zone and 59% for blood flow. For the basal zone the corresponding indices are 39 and 46%. No asymmetry in the hemodynamic indices between the same sections of the right and left lungs was found in the vertical position. /557

With the reversed vertical body position, a trend is found towards the opposite distribution of blood filling and blood flow in the lungs, i.e., the blood filling and flow of the apical zones is higher than the basal, although /558

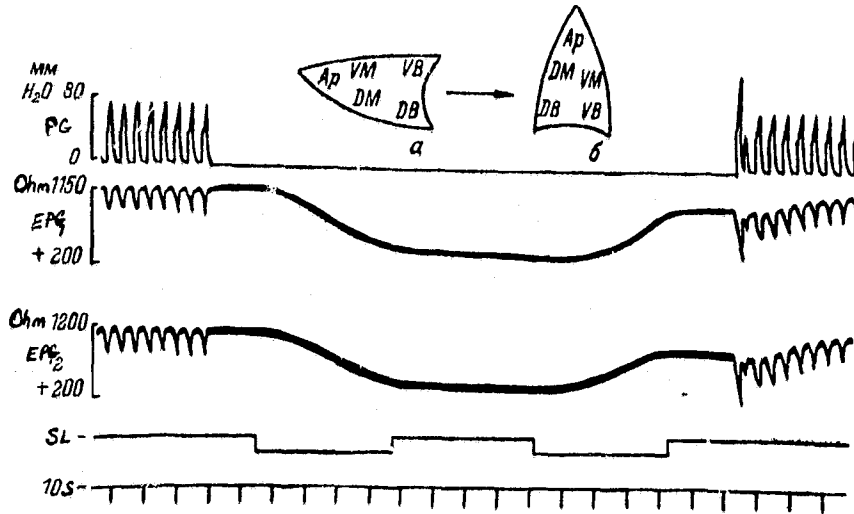


Figure 1. Change in Blood Filling of Symmetrical Dorsobasal Sections of Right and Left Lung during Change in Body Position from Horizontal (Lying on Back--a) to Vertical (b) and Again to Horizontal
 PG--pneumogram; EPG₁ and EPG₂--electroplethysmogram of right and left lung; SL--signal line; time marker--10 s; Ap, VM, DM, VB and DB--apical, ventromedial, dorsomedial, ventrobasal, dorsobasal lung zones. First bracket on signal line--transition to vertical, second--transition to horizontal position.

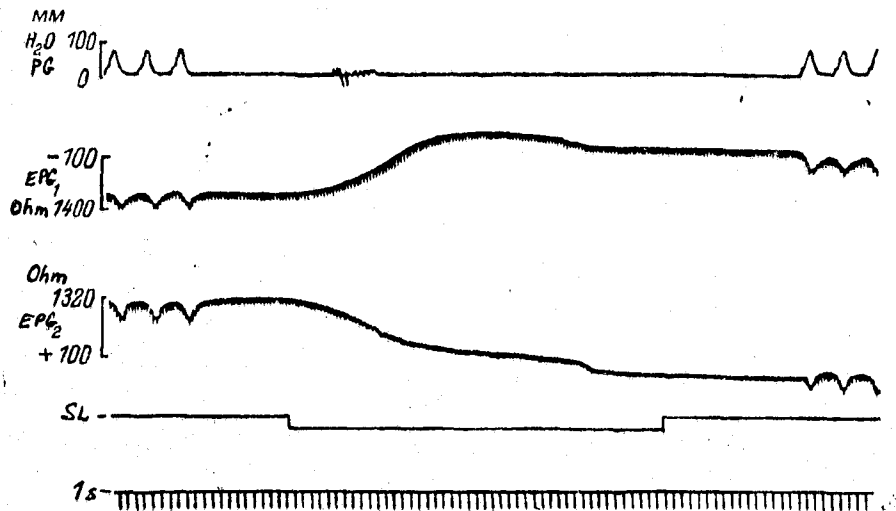


Figure 2. Different-Direction Changes in Blood Filling of Ventrobasal and Dorsobasal Sections of Right Lung during Change in Body Position from Horizontal to Vertical.
 PG--pneumogram, EPG₁ and EPG₂--electroplethysmogram from ventrobasal and dorso-basal sections; SL--signal line; time marker--1 s. Bracket on signal line--transition to vertical position.

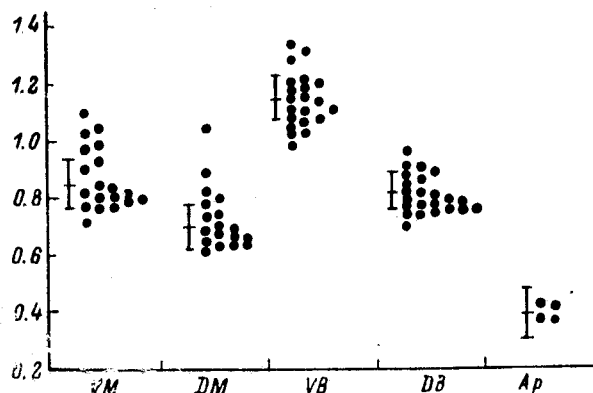


Figure 3. Relative Changes in Blood Filling of Different Pulmonary Sections with a Change in Body Position from Horizontal to Vertical
 VM, DM, VB, DB, Ap--ventromedial, dorsomedial, ventrobasal, dorsobasal, apical lung zones.

statistically the reliability of the differences is confirmed only in a comparison of the blood filling of the basal and apical zones; for the latter it is 30% higher in this position.

In a study of the distribution of blood filling of the lungs in animals that were in one of the lateral positions, differences were detected between the higher- and lower-arranged sections of the lungs for both positions. These differences average 16%, and the deviation from the uniform distribution--±7%.

A study of the redistribution of blood filling in the lungs at the moment of change in body position in space demonstrated that the relative blood filling of different pulmonary zones changes differently not only in a quantitative, but also in a qualitative respect. Figure 1 presents the electroplethysmograms with symmetrical sections of the right and left lung that were recorded during the transition of the animal from the horizontal position to the vertical, and again to the horizontal position. It is apparent that the blood filling of both sections here is changed practically the same.

Figure 2 presents the electroplethysmograms that were obtained from the dorsobasal and ventrobasal sections of the right lung with a change in the body position from the horizontal to the vertical; here the amount of relative blood filling in the indicated pulmonary sections changes in the opposite directions. The blood filling of the dorsobasal section drops, while the ventrobasal rises.

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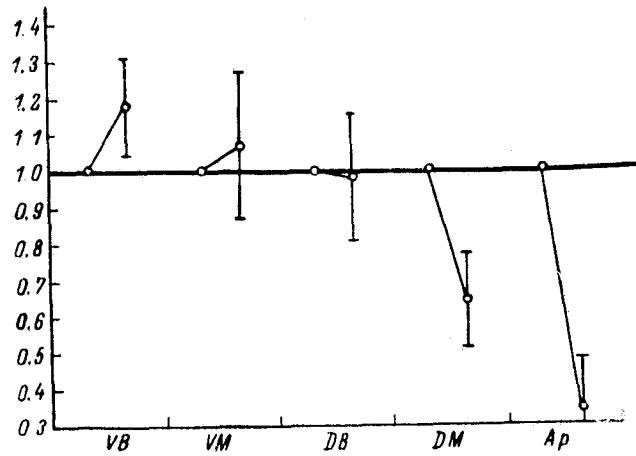


Figure 4. Relative Changes in Blood Flow Through Different Pulmonary Sections with Change in Body Position from Horizontal to Vertical

VB, VM, DB, DM, Ap--ventrobasal, ventromedial, dorsobasal, dorso-medial, apical pulmonary zones

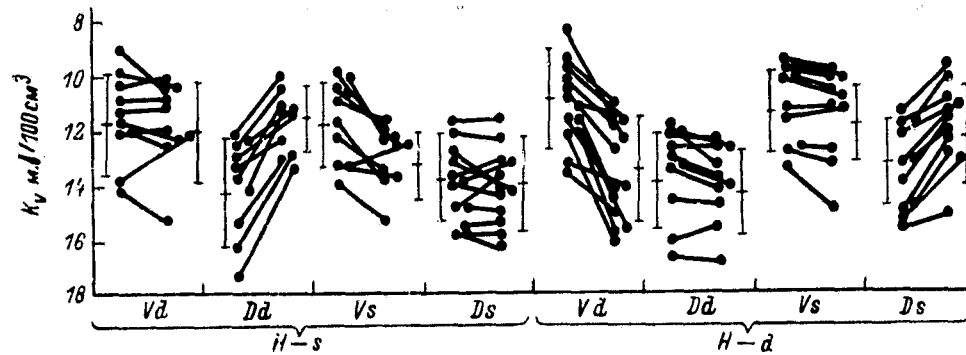


Figure 5. Changes in Blood Filling of Different Pulmonary Sections with a Change in Body Position from the Horizontal (Lying on back) to the Left or Right Lateral

Vd, Dd--ventral and dorsal zones of the right side; Vs, Ds--ventral and dorsal zones of the left side; H-s--transition to the left; H-d--transition to the right lateral position.

Figure 3 presents the results of a study on the postural effects of a change in blood filling of the lungs, expressed as the ratio of the amounts of blood filling of the pulmonary sections in a vertical (or reversed vertical) position of the animal to the amounts of blood filling of these sections in a horizontal (lying on back) position. As this figure shows, with a transition to the vertical position the blood filling of the apical zones changes (drops) most of all (by 62%), the blood filling of the ventromedial, dorsomedial and dorsobasal zones on the average is also reduced respectively by 16, 32 and 1%, although for these zones reactions of an increase in blood filling (20% of the cases for ventromedial and 10% for dorsobasal zones) are observed. Blood filling of the ventrobasal zone is increased (by 17%; $p < 0.01$), while on the whole the blood filling of the lungs is reduced. Analogous data were also obtained for blood flow (fig. 4) that is reduced through the apical zones by 68%, dorsomedial--by 36%, and through the ventrobasal zones is increased by 18%. For the ventromedial and dorsobasal zones the changes in blood flow are unreliable ($p < 0.05$). On the whole, the blood flow through the small circle during the transition to the vertical position is dropped.

In the transition from the horizontal position to the reversed vertical a trend is observed of the opposite nature, although the statistically reliable results ($p < 0.01$) were obtained only for the apical zones (increase in blood filling by 31% and blood flow by 28%).

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With a change in body position from the horizontal (lying on back) to the right or left lateral (fig. 5), the blood filling of certain pulmonary sections changed in the opposite directions. During a transition to the right lateral position it dropped by 14% in the dorsal left sections and increased by 20% in the ventral right sections. An analogous pattern was observed also in the transition to the left lateral position, i.e., blood filling of the ventral right sections increased by 12%, while that of the dorsal right was reduced by 16%. The average amount of relative blood filling during the transition from the horizontal position (lying on back) into one of the lateral positions did not change.

Discussion of Results

The findings on the whole agree well with the ideas on the regional non-uniformity in circulation in the lungs [3, 13, 15], according to which the gradient of blood flow in the lungs is determined by the effect of the gravity force and exists in all body positions.

The results of the experiments conducted in this study on the fine regional /560 level (with the help of the method of regional electroplethysmography of the lungs) and on comparatively small animals (cats) with intact rib cage also reflect the given law: both the absolute amounts of regional blood flow, and the relative characteristics of its distribution indicate the reduction in blood flow in the higher regions of the lungs as compared to the lower (see table). The distribution of blood filling of the lungs is analogous. With any position of the animal's body in space the higher regions of the lungs have lower blood filling than the lower. These differences are especially graphic with the vertical position of the animal and are characterized by fairly significant deviations of the blood filling of the apical and basal zones of the lungs from the uniform distribution. Here, the differences in the blood filling of the apical and basal zones on the average reach 60% (see table).

A change in body position in space is a fairly convenient approach to studying regional nonuniformity of the pulmonary hemodynamics [3,4,15], however, the transition from one position to another is accompanied by a change in the general indices of circulation and respiration: per-minute volume of the heart,

arterial pressure, cardiac contraction rate, as well as the volume of blood and air in the lungs [3,4,9], and the redistribution of blood filling and blood flow in the lungs occurs on the background of these changes. In this respect it is important to observe the regional postural reactions of the small circle directly at the moment of change in body position, which was done in the given work in relationship to the blood filling of the lungs (fig. 1-3). The findings demonstrated that blood filling of different pulmonary sections that are located even in the limits of one zone of the lungs, the basal, can change differently not only in a quantitative, but also in a qualitative respect (fig. 3). Analogous data were obtained in a study of the regional blood flow in the lungs in the horizontal and vertical body positions (see table). The nature of these changes depends on the original localization of the studied section in the lungs, but it occurs only in that direction that guarantees leveling of the hydrostatic and hemodynamic loads of the pulmonary sections located on one horizontal level. With a horizontal position of the ventro- and dorsobasal zones there is different blood filling, which is leveled during the transition to the vertical position; at the same time, the blood filling of the dorsobasal zone of the lungs is reduced, while that of the ventrobasal is increased (fig. 2 and 3). Different direction changes in the blood filling are also characteristic in the transition from the position of lying on the back to a certain lateral position (fig. 5). Such transitions are not accompanied by noticeable changes in the general parameters--per-minute volume of the heart, volume of the pulmonary blood and volume of air in the lungs [3], and these changes are not superimposed on the postural reactions of blood filling redistribution.

Analysis of the findings indicates that the amount and direction of the postural effects of the change in regional blood filling of the lungs are determined by the interaction of three simultaneously active mechanisms: change in the general volume of pulmonary blood, change in the volume of air in the lungs, and their intrapulmonary redistribution.

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