SELECTIVE DISTRIBUTION OF CAVAL BLOOD WITHIN THE LUNGS

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The distribution of many pulmonary diseases appears to be highly selective and topographically characteristic. Thus, tuberculosis usually begins in the upper lobes, whereas pulmonary infarctions mainly affect the lower lobes. This rather constant localization of disease processes in the lungs is difficult to explain on the basis of qualitative or quantitative changes in pulmonary ventilation.

In contradistinction, variations in pulmonary perfusion seem to explain these observations more easily. Thus, if we assume that little mixing occurs in the right heart between the two blood streams carried by the superior and inferior vena cavae, and that the flow in the pulmonary artery is of the laminar type; we would expect on the basis of the direction of flow in the right heart that the former stream would reach mainly the upper lung zones, whereas the stream of the inferior vena cava would be distributed mostly to the lower lobes.

The aim of the present work is to test the validity of these assumptions, i.e., the occurrence of streamlined flow in the pulmonary artery in man, with distribution of the superior vena caval blood to the upper pulmonary zones and the inferior vena caval blood to the lower pulmonary field.

MATERIALS AND METHODS

The present report deals with the findings obtained in 30 individuals: 21 males and 9 females. Their ages ranged from 11 to 62 years. They were selected after thorough examination to exclude any cardiac and/or pulmonary disease.

In each case, the distribution of radioactivity was measured twice following the intravenous injection of 0.5 ml ^{131}I-macroaggregated human serum albumin suspension (MAA)*. In the first instance, approximately 20 μCi of MAA were injected into a vein on the dorsum of the foot or into the femoral vein itself. Without any change in the position of the patient or the placement of the detectors, the second measurement was done after the injection of double the first dose of MAA into an antecubital vein which is known to drain via the superior vena cava.

Radioactivity was detected by a pair of well-matched, properly shielded scintillation detectors. The collimators used had straight bores with 1½-in.-wide aperture, the crystal being recessed 3 in. from the surface. The information collected by these detectors was measured by two synchronized rate meters, with a time constant of 1 sec, and recorded on a dual strip-chart recorder moving at a rate of 3 in./min.

Radioactivity accumulating in the upper lobe was determined by centering the detector over the second intercostal space in the mid-clavicular plane. Information from the lower lobe was obtained by focusing the detector over the eighth intercostal space in the scapular line.

In ten subjects, the test was performed in the sitting position, whereas in the remaining 20 persons it was done while they were lying on their backs. In this recumbent position, the lower lobe was reached by aiming the detector through a hole in the examination table.

RESULTS

In order to avoid the effects of chest wall differences and variations in the pulmonary tissue thickness in the upper and lower lung fields, the results are presented as a ratio between the radioactivity of the upper and lower pulmonary zones.

Recumbent position. The results obtained from studying 20 subjects in the recumbent position are presented in Table 1. It can be seen that in 13 individuals (65% of the 20 cases examined) the ratio between the level of radioactivity in the upper lobes

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to that in the lower lobes (UL/LL) increased significantly when the radioactive material was injected via the tributary of the superior vena cava as compared with what was obtained when the injection was performed via a branch that drains through the inferior vena cava. The magnitude of this increase in the ratio of the level of radioactivity in the upper lobes as compared with that in the lower lobes ranged from 11 to 164%, with an average of 49.4%.

Of the remaining seven subjects, four (20% of the group) showed no significant difference in the distribution of radioactivity between the upper and lower pulmonary lobes whether the injection was done through the leg or arm veins. The difference was considered insignificant when the degree of change was 5% or less.

In contradistinction, in the remaining three cases (15% of the subjects tested) the ratio of radioactivity in the upper lobes to that in the lower lobes decreased when the radioactive material was injected through the antecubital vein as compared with the situation when the injection was done through the leg veins.

Sitting position. The test was applied to ten subjects in the sitting position and the results are summarized in Table 2. In eight cases (80%) the distribution of radioactivity between the upper and lower pulmonary fields showed no significant difference whether the MAA particles were injected through the leg or arm veins.

In contrast, one of the remaining two individuals showed an increase, whereas the other showed a decrease in the ratio of radioactivity between the upper and lower lung fields when the injection was repeated through the arm vein after the first which was performed through one of the leg veins.

DISCUSSION

The flow of viscous fluids in tubes is either streamline or turbulent. In the case of streamline, which is also called laminar flow, the fluid moves in parallel layers with no cross currents and the fluid particles move in parallel paths or laminae. In contrast, when the velocity of the fluid exceeds a certain level (critical velocity), the flow of the fluid becomes turbulent, i.e., random and irregular eddies develop throughout the fluid with resultant mixing between its laminae.

The critical velocity (V_c) above which turbulence occurs, was found to depend upon the viscosity (v) and density (d) of the fluid, as well as upon the radius of the tube (r) measured in centimeters. This relationship is described by the equation

$$V_c = \frac{kv}{dr},$$

where k is a constant called Reynolds number. For blood, k equals 1,000, v is 0.04 poises, and d is 1 gm/ml.

TABLE 1. RESULTS OBTAINED IN 20 SUBJECTS STUDIED IN THE RECUMBENT POSITION

				Level of radioactivity (cpm)				Ratio of radioactivity between UL/LL		Magnitude of change
				Injection via IVC		Injection via SVC				
Serial No.	Sex	Age	Lung	UL	LL	UL	LL	IVC	SVC	(%)
1	M	15	Left	800	1,300	2,000	3,800	0.61	0.53	− 13
2	M	40		650	1,600	2,400	5,000	0.41	0.48	+ 17
3	M	43		2,700	500	4,800	900	5.40	5.33	− 1
4	M	30		1,200	1,400	2,000	2,100	0.86	0.95	+ 11
5	F	36		2,700	600	4,200	900	4.50	4.50	+ 4
6	M	17		1,650	200	10,900	500	8.25	21.80	+164
7	M	14		4,200	350	14,100	700	12.00	20.14	+ 68
8	M	22		2,850	800	9,400	2,100	3.56	4.48	+ 26
9	M	28		3,500	200	12,000	1,500	17.50	8.00	− 54
10	F	37		1,400	2,800	3,800	6,400	0.50	0.59	+ 18
11	F	20	Right	2,200	3,100	17,000	11,000	0.71	1.54	+117
12	M	48		12,900	3,000	27,600	24,000	4.40	1.15	− 73
13	F	30		9,000	2,200	17,400	3,600	4.09	4.83	+ 18
14	M	40		6,400	6,500	13,800	13,500	0.98	1.02	+ 4
15	M	25		2,500	700	8,800	1,950	3.57	4.51	+ 26
16	M	34		2,250	2,400	4,500	2,900	0.94	1.55	+ 63
17	F	20		600	450	4,800	3,000	1.25	1.60	+ 28
18	M	32		2,700	1,600	7,800	4,800	1.69	1.62	− 4
19	M	22		9,600	2,400	25,000	5,400	4.00	4.63	+ 16
20	M	43		1,700	300	60,000	6,200	5.67	9.68	+ 71

UL: upper lobe.
LL: lower lobe.
IVC: inferior vena cava.
SVC: superior vena cava.

TABLE 2. RESULTS OF STUDYING 10 SUBJECTS IN THE SITTING POSITION

Serial No.	Sex	Age	Lung	Level of radioactivity (cpm) Injection via IVC UL	LL	Injection via SVC UL	LL	Ratio of radioactivity between UL/LL IVC	SVC	Magnitude of change (%)
1	M	37	Right	4,100	3,400	24,000	19,500	1.21	1.23	+ 2
2	M	17		700	500	5,100	3,600	1.40	1.42	+ 1
3	F	22		5,000	9,200	16,100	31,200	0.54	0.52	− 4
4	M	40		300	900	1,200	3,600	0.33	0.33	0
5	M	40		5,000	9,200	15,000	32,000	0.54	0.47	− 13
6	F	52	Left	1,300	1,000	4,800	3,200	1.30	1.50	+ 15
7	M	60		5,100	9,100	16,600	31,000	0.56	0.54	− 4
8	M	62		6,700	6,700	14,500	15,000	1.00	0.97	− 3
9	F	45		4,300	3,500	25,000	19,700	1.23	1.27	+ 3
10	F	25		2,700	1,600	7,900	4,800	1.69	1.65	− 2

UL: upper lobe.
LL: lower lobe.
IVC: inferior vena cava.
SVC: superior vena cava.

Throughout the whole circulation the critical velocity of the blood is never exceeded except, perhaps, at the root of the aorta and pulmonary artery for a brief period during the maximal ejection phase of early cardiac systole (*1*).

The two caval veins drain into the right atrium, the superior vena cava is 2 cm wide whereas the width of the inferior vena cava is 2.5 cm (*2*). Since the velocity of the blood flow in the two caval veins during the recumbency is much lower than the critical velocity of the blood, no turbulence is expected to occur in the right atrium and the streams of the two caval systems remain separated (Fig. 1).

In the right ventricle, no change is expected during diastole and the two streams thus remain separate. During ventricular systole, the right ventricle pumps the blood into the pulmonary artery. Consequently, the velocity of the two streams is greatly augmented. However, the blood stream coming from the superior vena cava should logically have a higher initial velocity than the stream of the inferior vena cava due to the difference in their cross section. Furthermore, the stream of the superior vena cava forms a shorter and more acute curve in the right ventricle. Accordingly, on the basis of the physical rules of hydraulics, when this stream is pumped into the pulmonary artery, it forms a wider curve at the site of the bifurcation of this artery into its two main branches. It then continues in those branches, occupying a higher position than the other stream coming from the inferior vena cava (Fig. 1). Therefore, blood drained by the superior vena cava tends to pass to the upper lobar arteries, whereas the blood reaching via the inferior vena cava is mainly distributed to the lower arteries.

The momentary and transient turbulence that occurs in the root of the pulmonary artery at the onset of ventricular systole cannot lead to complete mixing of the blood. This is explained by the counter effects played by the pulsatile nature of the flow in the pulmonary artery (*3*) together with the occurrence of the bifurcation of the pulmonary artery in its two main branches at a right angle (*4,5*).

In the sitting and erect positions, the hemodynamic situation is completely different. Under such circumstances, the central venous pressure is lowered, together with diminution in the venous return from the abdominal and lower limb veins, in spite of the absence of change in the state of contraction of the veins (*6*). As a result, the velocity of the blood flow in the inferior vena cava is expected to be diminished. In the meantime, the velocity of the blood in the superior vena cava is increased due to the effect of gravity. This discrepancy between the velocities of the blood in the two streams could lead to turbulence and mixing of blood due to the jet action of the stream entering through the superior vena cava.

The validity of these theoretical speculations appears to be supported by the results of the present work. Thus, in 65% of our 20 patients who were examined in the recumbent position, the level of radioactivity was higher in the upper lung fields when the MAA particles were injected through an arm vein that drains via the superior vena cava than when the injection was performed through a leg vein. The results obtained in the remaining seven subjects could be explained by the effects of the momentary and transient turbulence that occurs in the root of the pulmonary artery at the onset of ventricular systole. This might have been helped in two of these subjects by the presence of anemia which tends to encourage

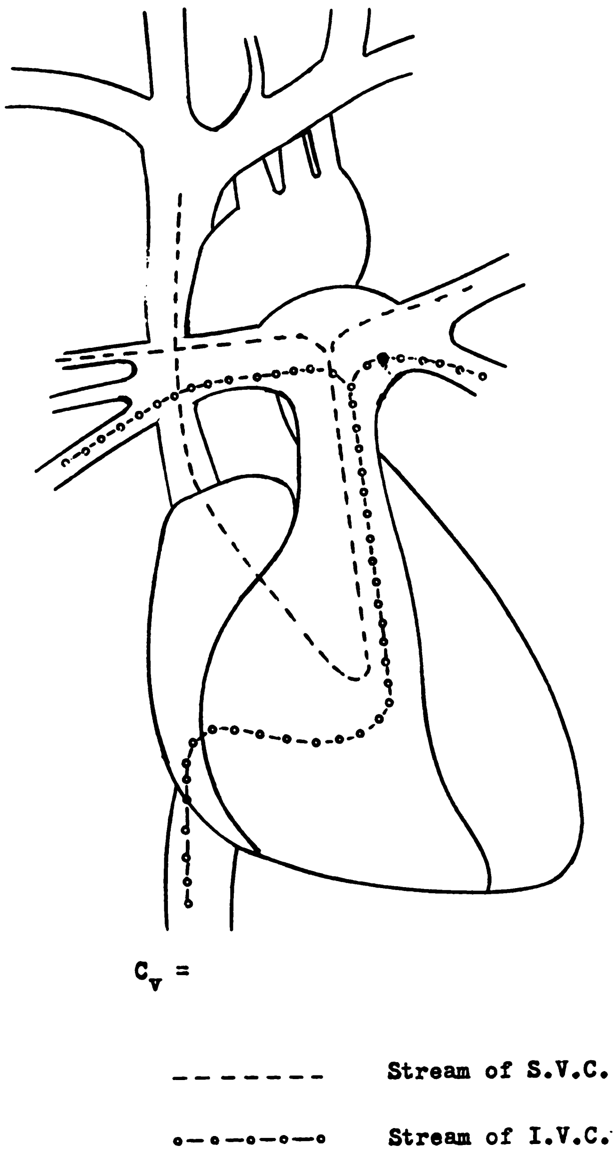

FIG. 1. Schematic representation of pathways of streams of blood through right heart and pulmonary arteries.

turbulence by decreasing the blood viscosity and increasing its velocity.

In the sitting position, there was no special distribution of caval blood between the upper and lower lung fields in the subjects tested.

The presence of streamlined flow in the pulmonary artery with selective distribution of the superior vena caval blood to the upper lung zones and the inferior vena caval blood to the lower lobes in the recumbent position might explain many baffling points in the pathogenesis and localization of some pulmonary diseases of hematogenous origin.

In this respect, it was found by previous workers that the most common source of pulmonary emboli is venous thrombosis in the pelvic and lower limb veins (*7,8*) which drain into the inferior vena cava. Furthermore, many of the patients who develop pulmonary embolism are usually recumbent. Consequently, according to the suggested selective distribution of caval blood, most of the emboli should reach the lower pulmonary lobes. This is exactly what happens both experimentally and clinically (*9,10*).

In contradistinction, post-primary pulmonary tuberculosis has a special predilection for the upper lobes (*11,12*). This might be explained on the basis of the suggestions of previous investigators (*11,13*) by the fact that in the course of the primary tuberculous infection of the lungs, the hilar and mediastinal lymph nodes are affected. Similarly, the mesenteric lymph glands suffer the brunt of the primary tuberculous infection of the intestines. These lymph nodes are believed to harbor viable tubercle bacilli that are dormant (*13*). Since the drainage of these glands via the right lymphatic and thoracic ducts ultimately passes into the superior vena cava, the upper lobes should be bombarded by tubercle bacilli via the superior vena caval stream, especially during recumbency.

The suggested zonal distribution of the caval blood in the lungs can also explain the basal occurrence of the primary amebic lung affection in the absence of manifest hepatic amebiasis (*14*). This is easily understood if we remember that the amebae which harbor the large intestine could reach the lungs via the inferior vena caval system.

SUMMARY AND CONCLUSIONS

Using macroaggregated human serum albumin tagged with ^{131}I (MAA) the ratio of radioactivity accumulating in the upper pulmonary lobes to that in the lower lobes was determined by external monitoring. In each subject this determination was done twice. In the first instance, the radioactive particles were injected into one of the leg veins that ultimately drain via the inferior vena cava. The second measurement was performed following the injection of the MAA into an antecubital vein which is known to drain via the superior vena cava.

Out of the 20 subjects examined in the supine position, 13 showed a significant increase in the ratio of radioactivity accumulating in the upper lung fields as compared with that in the lower pulmonary lobes when the radioactive particles were injected via a tributary of the superior vena cava instead of the leg veins. The magnitude of this increase amounted to an average of 49.4%.

In contrast, in the ten individuals studied in the sitting position there was no special distributional pattern for radioactivity between the upper and lower pulmonary fields whether the radioactive particles were injected via the arm or leg veins.

The selective distribution of the superior vena caval blood to the upper lung zones and the inferior vena caval blood to the lower lobes could be explained by the separate streams followed by the superior and inferior vena caval blood in the right heart, together with the streamline flow of blood in the pulmonary artery.

On the basis of this selective pulmonary perfusion, one can explain the frequent occurrence of pulmonary infarctions and primary amebic lung abscess in the basal regions. It can also explain the special predilection of post-primary pulmonary tuberculosis for the upper lobes.

REFERENCES

1. Rushmer RF: *Cardiac Diagnosis.* London, Saunders, 1962, p 1955

2. Davies DV, Davies FD: *Gray's Anatomy,* 33rd ed. London, New York, Toronto, Longman's Green, 1962, pp 890, 901

3. Comroe JH, Forster RE, Dubois AB, et al: *The Lung. Clinical Physiology and Pulmonary Function Tests.* 2nd ed, Chicago, Year Book, 1962, p 72

4. Milne-Thomson LM: *Theoretical Hydrodynamics.* 3rd ed, London, Macmillan, 1968, p 155

5. Hammad YH: Personal communication

6. Gregg DE: In *The Physiological Basis of Medical Practice,* 8th ed, Best CH, Taylor NB, eds, Baltimore, Williams and Wilkins, 1966, pp 647, 787

7. Henderson EF: Fatal pulmonary embolism. *Arch Surg (Chicago)* 15: 231–236, 1927

8. Miller R, Berry JB: Pulmonary infarction. A frequently missed diagnosis. *Amer J Med Sci* 222: 197–206, 1951

9. Abernathy RS, Smith GB: The apical localization of reinfection pulmonary tuberculosis. II. Selective localization of pulmonary emboli. *Amer Rev Tuberclosis* 70: 557–569, 1954

10. Wagner HN, Sabiston DC, McAfee JG, et al: Diagnosis of massive pulmonary embolism in man by radioisotope scanning. *New Eng J Med* 271: 377–384, 1964

11. Smith DT, Abernathy RJ, Bondurant S: The apical localization of reinfection pulmonary tuberculosis. I. The stream flow theory. *Amer Rev Tuberculosis* 70: 547–556, 1954

12. Sabri YY, Mahmoud ME, Hussein DK: The prevalency of pulmonary tuberculosis on the right side. *Med J Cairo Univ* 38: 51–52, 1970

13. Schwartz P: The role of the lymphatics in the development of bronchogenic tuberculosis. *Amer Rev Tuberculosis* 67: 440–452, 1953

14. Abdel-Hakim M, Higazi AM: Bronchopulmonary amebiasis. Diseases of the chest. *J Amer Coll Chest Physicians* 34: 607–620, 1958