

Effects of Two Years' Intermittent Stay at High Altitudes on the Pulmonary Blood Volume in Man*

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Pulmonary vascular response to high altitude hypoxia in natives and in temporary residents has been the subject of several studies (Rotta *et al.*, 1956; Peñaloza *et al.*, 1962; Vogel *et al.*, 1962; Pugh, 1964; Banchemo *et al.*, 1966), but few estimates of pulmonary blood volumes are available. Rotta *et al.* (1956) found the total blood volume increased at high altitudes, and postulated theoretically a concomitant increase in the pulmonary blood volume. Monge *et al.* (1955) estimated the latter from the last slope of the dye dilution curve, and reported it to be disproportionately higher in natives of Peruvian Andes than in residents at sea level. Roy *et al.* (1965c) measured this volume by double dye dilution curves, and found it to be higher in convalescents from high altitude pulmonary oedema than in those convalescing from pulmonary hypertension. The present study was undertaken to measure the pulmonary blood volume in Indian soldiers exposed to high altitudes intermittently for over two years.

SUBJECTS AND METHODS

The clinical material consisted of 26 male volunteers from the defence service who had stayed at altitudes of over 4270 metres (14,000 feet) intermittently for over two years, and did not suffer from high altitude pulmonary oedema or hypertension. They were between 19 and 50 years of age, average 25 years. To assess if the altitude *per se* had any effect on the response of the pulmonary blood volume, they were divided into two groups; group A consisted of 13 subjects who were stationed permanently at 4422 metres (14,500 feet), and group B of 13 subjects who camped at the same altitude but shuttled every day by truck to 4880 metres (16,000

feet) or higher. The total duration of stay and the last continuous stay at the high altitude of the two groups outlined in the Table are comparable.

The subjects were studied at Delhi (height, 198 metres (650 feet)) within 48 hours of their departure from the high altitude station. Details of the catheter procedures were explained to them, and written consents were obtained before the study. Right heart catheterization was performed by positioning a No. 7 cardiac catheter in the pulmonary artery just beyond the valve. The left atrium was entered by the percutaneous transseptal method, as practised in this laboratory (Roy, Bhatia, and Guleria, 1963). The right brachial artery was cannulated to obtain arterial blood pressures and dye curves. Consecutive dye dilution curves were obtained directly on a polyviso channel through a continuous recording densitometer (Colson) by injecting cardio-green dye into the main pulmonary artery and then into the left atrium. The difference in the mean transit times of the two resulting curves was taken as pulmonary transit time. The cardiac output was measured from the dilution curves by the formula of Hamilton *et al.* (1932). The volume of blood between the pulmonary artery and the left atrium was obtained by multiplying the pulmonary mean transit time by the average cardiac output and represented the pulmonary blood volume. Similarly, the volume of blood between the pulmonary and the brachial arteries was measured by multiplying the pulmonary artery to brachial artery mean transit time by the average cardiac output, and this gave the central blood volume. Details of the technique have already been reported (Roy, Bhardwaj, and Bhatia, 1965a). The intracardiac and brachial arterial pressures were recorded through Statham P23AA strain gauge manometers on a 4-channel single gun photographic system. The baseline for all pressure measurements was taken as half the chest thickness at the second costal cartilage, with the patient supine (Roy, Gadboys, and Dow, 1957).

RESULTS

Continuous Stay, Blood Volume, and Cardiac Output. When the pulmonary blood volume was related to the duration of the last continuous stay at

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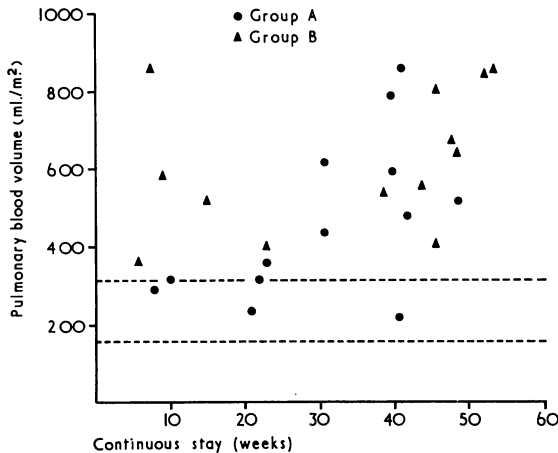


FIG. 1.—Relation of pulmonary blood volume (PBV) of 26 subjects to the duration of their continuous stay at high altitude. The solid circles comprise 13 cases of group A stationed at 4422 metres, and solid triangles represent 13 subjects camped at 4422 metres but shuttled daily to 4880 metres (16,000 feet) or higher. While increase in the PBV is seen after 30 weeks' stay in both the groups, three cases in group B show increases after 7, 9, and 15 weeks of stay. The broken lines (145–310 ml./m.²) give the range of the normal PBV.

high altitude (Fig. 1), the increase in this volume in group A subjects was apparent after 30 weeks. The increases in group B subjects were of two types: (1) in the majority of them the pattern was similar to that of group A, and (2) in three subjects the volume increased early (7, 9, and 15 weeks). The central

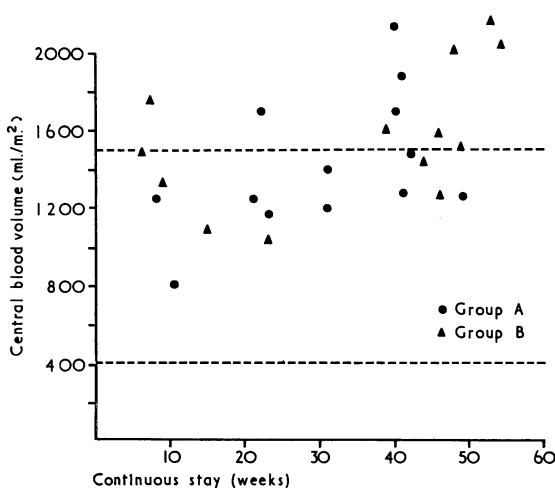


FIG. 2.—Relation of the central blood volume (CBV) to duration of continuous stay at high altitude showing a significant increase of CBV in both the groups after 38 weeks' stay at high altitudes. Two cases in group B showed increases after 6 and 7 weeks of stay.

blood volume and cardiac output of both the groups showed a significant increase only after 38 weeks of stay, but here again in two subjects in group B an early peak was seen within 6 and 7 weeks of their stay (Fig. 2 and 3). The extrapulmonary quota of central blood volume (i.e. central blood volume less the pulmonary blood volume) could not be related to the duration of stay, nor was any significant difference apparent between the values of the two groups (Fig. 4).

Total Stay, Blood Volumes, and Cardiac Output. As outlined in the Table, the average pulmonary blood volume of group B subjects was 35 per cent higher and the central blood volume was only 10 per cent higher than that of group A. But the central minus the pulmonary value was the same in the two groups. The average cardiac output was about 37 per cent higher in group B subjects.

Total Stay and Ventricular Pressures. No difference was seen in the right and left ventricular pressures of the two groups as shown in the Table.

DISCUSSION

Pulmonary blood volume estimated in 25 normal healthy men of comparable age and occupation in this laboratory ranged between 145 and 310 ml./m.² with an average of 210 ml./m.² (Roy *et al.*, 1965a). The 25 normal volunteers were studied before their ascent to the high altitude to obtain baseline haemodynamic data as a part of a prospective study; the 13 subjects comprising group A are part of the 25 volunteers. The average pulmonary blood volume values recorded in the present study in both the groups are significantly higher than our normal values. Further, the pulmonary blood volume values recorded here are much higher than the average value of 309 ml./m.² estimated in 12 convalescents from high altitude pulmonary oedema (Roy *et al.*, 1965c). As the convalescents were studied several days after their arrival at Delhi, the two sets of data are not comparable. The average pulmonary blood volume of 625 ml./m.² in group B subjects approaches the average value of 670 ml./m.² of 10 male natives of Peruvian Andes studied at a height of 4544 metres (14,900 feet) by Monge *et al.* (1955). However, the present data are to be interpreted guardedly as the volume was not measured at high altitudes, but at a height of 198 metres (650 feet). Roy, Bhatia, and Guleria (1965b) reported that the process of deacclimatization of the circulatory changes due to high altitude hypoxia started within the first few days of arrival at sea level and was completed by the second or

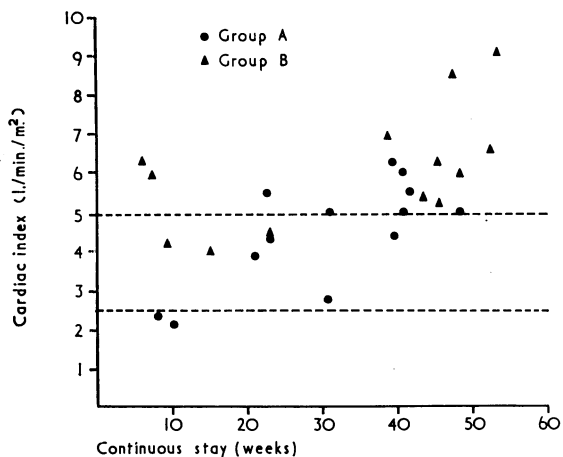


FIG. 3.—Relation of the cardiac index to duration of continuous stay at high altitude. An increase in the cardiac index of both the groups is seen after 38 weeks of stay. The same two cases of group B which showed increased CBV after 6 and 7 weeks of stay also show similar increases in cardiac indices.

the third week of stay at sea level. As the pulmonary blood volume was estimated within 48 hours of their departure from high altitudes, and as the data of both the groups were obtained under similar conditions, the difference in the values obtained in the two groups appears significant.

Of particular interest are two observations on the response of the pulmonary blood volume of group B subjects: (1) an average of 25 per cent greater increase than group A subjects, and (2) an early increase in a few subjects. Though subjects of both the groups were stationed at a comparable height of 4422 metres (14,500 feet), the group B

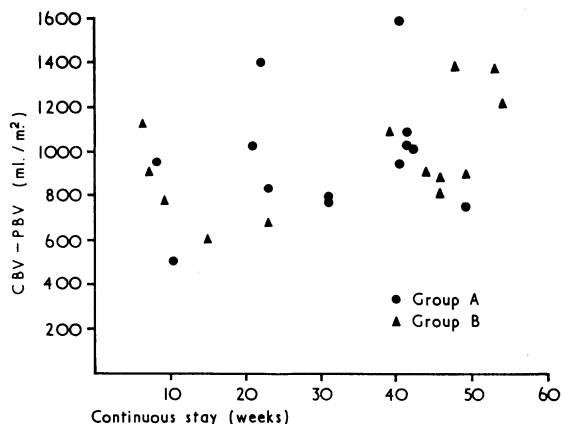


FIG. 4.—There is no correlation between extrapulmonary quota of the central blood volume (CBV-PBV) and the duration of stay at high altitude in either group, and no difference between the values in the two groups.

subjects, in addition, shuttled to 4880 metres (16,000 feet) every day. Whether the difference in the response of the pulmonary blood volume in the two groups could be due to exposure to different heights remains debatable as no comparable data are available.

This, however, does not explain why a few subjects in group B had increased pulmonary blood volumes within the first few weeks of stay at the high altitude. This could not be explained on the basis of total duration of stay irrespective of the last continuous stay because, (1) the group A subjects did not show similar response in the early weeks, and (2) even group B subjects between 15 to 30 weeks did not show any increase. A possible

TABLE

RANGE AND AVERAGES OF AGE, LENGTH OF TOTAL AND LAST CONTINUOUS STAY AT HIGH ALTITUDE, AND CIRCULATORY RESPONSES OF SUBJECTS IN GROUPS A AND B

Range	Group and numbers	Age (yr.)	Total stay (wk.)	Last continuous stay (wk.)	Time of study after leaving altitude (hr.)	Cardiac index (l./min./m. ²)	Blood volumes (ml./m. ²)			Ventricular pressure (mm. Hg)			
							Central	Pulmonary	Central minus pulmonary	Right		Left	
										Systolic	Diastolic	Systolic	Diastolic
Range	A (13)	21-29	104-129	8-49	46-48	2.2-6.3	827-2173	215-864	508-1575	20-29	1.0-7.5	109-146	2.5-10.0
Average		24	117.3	30.7	47.3	4.6	1442	463	979	26.0	4.6	122	6.8
Range	B (13)	21-50	108-142	6-54	23-48	4.1-9.5	1078-2217	371-855	608-1369	16-48	1.5-7.0	100-132	2.0-11.0
Average		27	122.5	33.7	35.2	6.3	1597	625	972	22.0	4.9	115	7.0
Range	Normal* (25)	19-31	—	—	—	2.5-5.0	407-1473	145-310	233-1296	13-30	1.0-6.0	110-130	2.0-11.0
Average		24	—	—	—	4.1	960	210	750	21.0	3.7	120	4.0

* Normal values were obtained by studying 25 healthy subjects of comparable age and occupation.

theory may be one of homeostasis, whereby in some subjects when suddenly exposed to high altitude the volume increases from the very beginning; then after a few weeks the extra volume of blood shifts away from the pulmonary circuit, to reappear again after 30–38 weeks in an attempt to maintain a homeostatic balance between the pulmonary and the extrapulmonary circuits.

This hypothesis is indirectly supported by the fact that the pulmonary blood volume of group B subjects was 37 per cent higher whereas the central blood volume was only 10 per cent greater and the extrapulmonary quota of central blood volume of both the groups was the same, indicating that the increase in the central blood volume is due to the increase in pulmonary volume and that the response of the latter is independent of the central volume. If the homeostasis theory is true, then it is also possible to explain, in part, the role of increased pulmonary blood volume in high altitude pulmonary oedema, which occurs only in the first few days after arrival at high altitudes.

SUMMARY

Data on the response of the pulmonary blood volume to two years' intermittent stay in 13 subjects stationed at an altitude of 4422 metres (14,500 feet) (group A) and in another 13 subjects who camped at this altitude but shuttled daily to 4880 metres (16,000 feet) or higher (group B) are given.

Average pulmonary blood volumes of both the groups were grossly increased, (A) 463 ml./m.² and (B) 625 ml./m.², as compared with the normal value of 210 ml./m.². The relatively greater increase in group B subjects might have been due to their daily shuttle to higher altitudes. The increase in the central blood volume was found to be dependent on the increase in pulmonary blood volume, but response of the latter was found to be independent of the former.

It is postulated that the triphasic response, i.e. early increase for the first 10 to 15 weeks, normal values from 15th to 38th week, and thereafter significant increase of the pulmonary blood volume, as seen in a few subjects of group B, may represent a homeostasis mechanism between the pulmonary and the extrapulmonary circuits.

It is a pleasure to record our deep appreciation to Lt. General T. R. Pahwa, Director General, Armed Forces Medical Services, and his staff for their kind and ungrudging help at all stages of the study. We also

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REFERENCES

- Banchero, N., Sime, F., Peñaloza, D., Cruz, J., Gamboa, R., and Marticorena, E. (1966). Pulmonary pressure, cardiac output, and arterial oxygen saturation during exercise at high altitude and at sea level. *Circulation*, **33**, 249.
- Hamilton, W. F., Moore, J. W., Kinsman, J. M., and Spurling, R. G. (1932). Studies on the circulation IV. Further analysis of the injection method and of changes in hemodynamics under physiological and pathological conditions. *Amer. J. Physiol.*, **99**, 534.
- Monge C., C., Cazorla T., A., Whittombury M., G., Sakata B., Y., and Rizo-Patron, C. (1955). A description of the circulatory dynamics in the heart and lungs of people at sea level and at high altitude by means of the dye dilution technique. *Acta physiol. lat.-amer.*, **5**, 198.
- Peñaloza, D., Sime, F., Banchero, N., and Gamboa, R. (1962). Pulmonary hypertension in healthy man born and living at high altitudes. *Med. thorac. (Basel)*, **19**, 449.
- Pugh, L. G. C. E. (1964). Cardiac output in muscular exercise at 5,800 m. (19,000 ft.). *J. appl. Physiol.*, **19**, 441.
- Rotta, A., Cánepa, A., Hurtado, A., Velásquez, T., and Chávez, R. (1956). Pulmonary circulation at sea level and at high altitudes. *J. appl. Physiol.*, **9**, 328.
- Roy, S. B., Bhardwaj, P., and Bhatia, M. L. (1965a). Pulmonary blood volume in mitral stenosis. *Brit. med. J.*, **2**, 1466.
- , Bhatia, M. L., and Guleria, J. S. (1963). Percutaneous transeptal left heart catheterization. *Indian Heart J.*, **15**, 255.
- , —, and — (1965b). Circulatory adaptation at high altitude and the effects of deacclimatization. Symposium on Problems of High Altitude. Armed Forces Medical College, Poona 16th–19th February, p. 24.
- , —, Singh, I., and Khanna, P. K. (1965c). Pulmonary blood volume in high altitude pulmonary oedema. *ibid.*, p. 49.
- , Gadboys, H. L., and Dow, J. W. (1957). Base line for left heart catheterization. *Amer. Heart J.*, **54**, 753.
- Vogel, J. H. K., Weaver, W. F., Rose, R. L., Blount, S. G., and Grover, R. F. (1962). Pulmonary hypertension on exertion in normal man living at 10,150 feet (Leadville, Colorado). *Med. thorac.*, **19**, 461.

ADDENDUM

After submitting this article we had the opportunity of studying three natives who were born at high altitude, i.e. over 4270 metres (14,500 ft.) and whose forbears had lived there for three generations. Their average age was 28 years. The pulmonary blood flow was 7.8 l./min. m.²; central blood volume 2154, and pulmonary blood volume 830 ml./m.²; pulmonary arterial pressure (systolic) 33 mm.Hg, and left atrial mean pressure 7 mm.Hg; pulmonary vascular resistance 1.3 units.

It is noteworthy that natives of high altitude have higher pulmonary flow and central and pulmonary blood volumes, and slightly higher pulmonary arterial pressures.