Influence of altitude on the cutaneous circulation of residents and newcomers[1]

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IT IS WELL KNOWN that high altitude induces an increase in pulmonary vascular resistance, but little has been written on the changes taking place in the peripheral circulation. In order to obtain more data on this point, the effects of altitude have been studied on the cutaneous circulation of both residents and sojourners.

TECHNIQUE AND MATERIAL

The circulation in the right hand was chosen as an example of a cutaneous vascular bed. Blood flow, volume, and venous pressure were measured simultaneously: the pressure directly in a superficial vein, the flow and volume by use of a water-filled plethysmograph specially built to obtain distensibility curves by altering the hydrostatic pressure inside the plethysmograph (from −25 to +25 cm of water), according to a technique described elsewhere (13). Measurements were made at the same room temperature (23 C) but at different local temperatures, i.e., at different temperatures of the water filling the plethysmograph (from 7 to 43 C) in order to explore the cutaneous circulation in different physiological states.

Subjects have been studied comparatively at low and high altitude as shown in Table 1.

RESULTS

1) Blood flow in the hand (Fig. 1) was found to be lower at high altitude than at sea level and this was true both for high- and lowlanders. Differences were statistically significant only when local temperature was above 33 C ($P < 0.001$ at 43 C), i.e., when local blood supply was high, and grew larger when local temperature was increased. After residing 1 month at high altitude, sojourners still had a larger blood flow than highlanders. There was no significant difference in values obtained in highlanders residing at 3,750 m or at 4,800 m; but a further and significant reduction in blood flow was obtained in sojourners when measurements were made at the highest altitude ($P < 0.001$ at 43 C) (Fig. 2).

Reduction in blood flow appeared immediately at arrival at high altitude. There was no significant difference between the value obtained in sojourners 4 days and 30 days after their arrival at high altitude.

Since no change in arterial blood pressure has been observed, reduction in perfusion can be interpreted as an increase in cutaneous arteriolar resistance.

2) The average superficial venous blood pressure was increased by high altitude, but the modifications were more pronounced when the local temperature was either elevated ($P < 0.012$ at 43 C) or low ($P < 0.010$ at local temperature below 11 C); and the venous pressures were identical in the middle part of the explored zone (Fig. 3). The results obtained in residents and newcomers do not differ significantly.

TABLE 1. *Number of subjects of each group studied in different places**

	Low Altitude		High Altitude	
	Paris, 50 m	Santa Cruz, 400 m	La Paz, 3,750 m	Chorolque, 4,800 m
Lowlanders				
Caucasians	7		7	3
Indians		5		
Highlanders, Indians		5	15	6
			6°	
Mean barometric pressure, mm Hg	759	725	480	405

* The same lowlanders were studied both in Paris and in La Paz and three of them had also measurements made at higher altitude (Chorolque). The highlanders were different subjects in the three places. The 6° subjects have been studied in La Paz where they usually lived, but the study took place a few days after they had arrived from low altitude where they had resided for at least 5 months.

3) Volume changes of the hand obtained by a given increase or decrease of transmural pressure were smaller at high than at low altitude ($P < 0.005$) (Fig. 4). This

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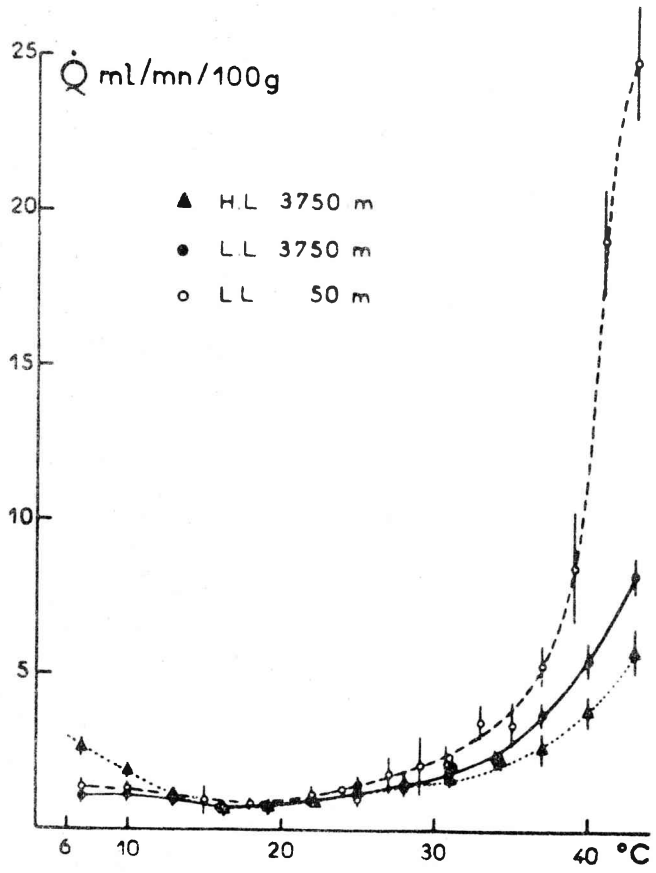

FIG. 1. Blood flow in the right hand ($\dot{Q}$) plotted against local temperature (°C) in high-altitude residents (HL ▲) and in lowlanders (LL) at sea level (○) and after 1 month of acclimatization to altitude (●). Mean values and standard errors.

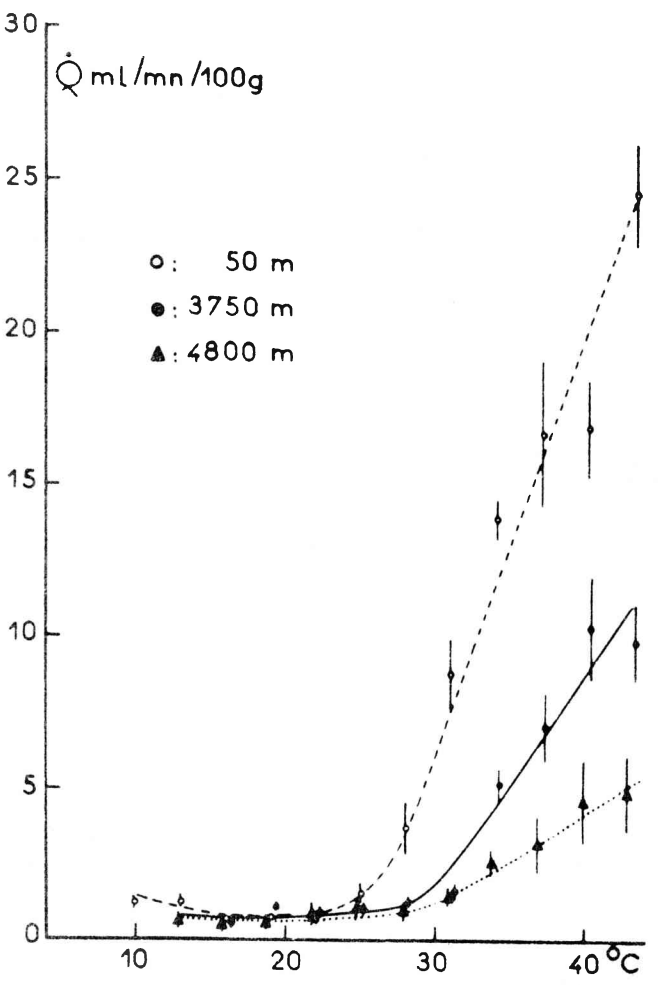

FIG. 2. Blood flow in the right hand ($\dot{Q}$) plotted against local temperature (°C) in three lowlanders at sea level (○) and after 6 days of acclimatization at 3,750 m (●) and 4,800 m (▲). Mean values and standard errors.

could have been due either to the presence of a larger volume of blood in the capacitance vessels, or to an active change of the mechanical properties of these vessels leading to a decrease of their capacitance.

In order to obtain more precise information on this point, it has been necessary to approximate an absolute figure for the cutaneous blood volume of the hand. This was done by increasing the pressure into the plethysmograph until no further reduction of volume of the hand could be obtained (Fig. 5). The pressure volume curves drawn in this way showed that the decrease in capacitance was associated with a decrease in local blood volume. Hence, this should be interpreted as the consequence of an active change in the mechanical properties of the capacitance vessels. Again modifications found at high altitude were more important when the local temperature was elevated, i.e., when the local blood volume was large.

As blood flow changes, the changes in distensibility appeared immediately after arriving at high altitude (Fig. 6) and they grew more pronounced with time, although the difference between the 4th and 30th day was not statistically significant ($0.25 > P > 0.20$). Nevertheless, even after 1 month distensibility of the lowlanders was still slightly larger than that of the highlanders ($0.10 > P > 0.05$).

A particular feature has been observed in six subjects who usually resided at high altitude but who had dwelt for several months at a lower level; when they came back to their native plateau, the recurrence of the cutaneous vascular pattern, characteristic of high altitude, was preceded by a marked over-shoot during the first few days (Fig. 7).

DISCUSSION

One generally agrees that blood flow in the hand, as measured by venous occlusion plethysmography represents mainly, if not only, the perfusion of the skin. As far as volume is concerned, measurements were made starting from "0" hydrostatic pressure to avoid collapse of the veins. Changes obtained by increasing or lowering the pressure around the hand probably only affect the distensible vessels (capillaries and veins) of superficial tissues, deep vascular beds in bones or muscles being

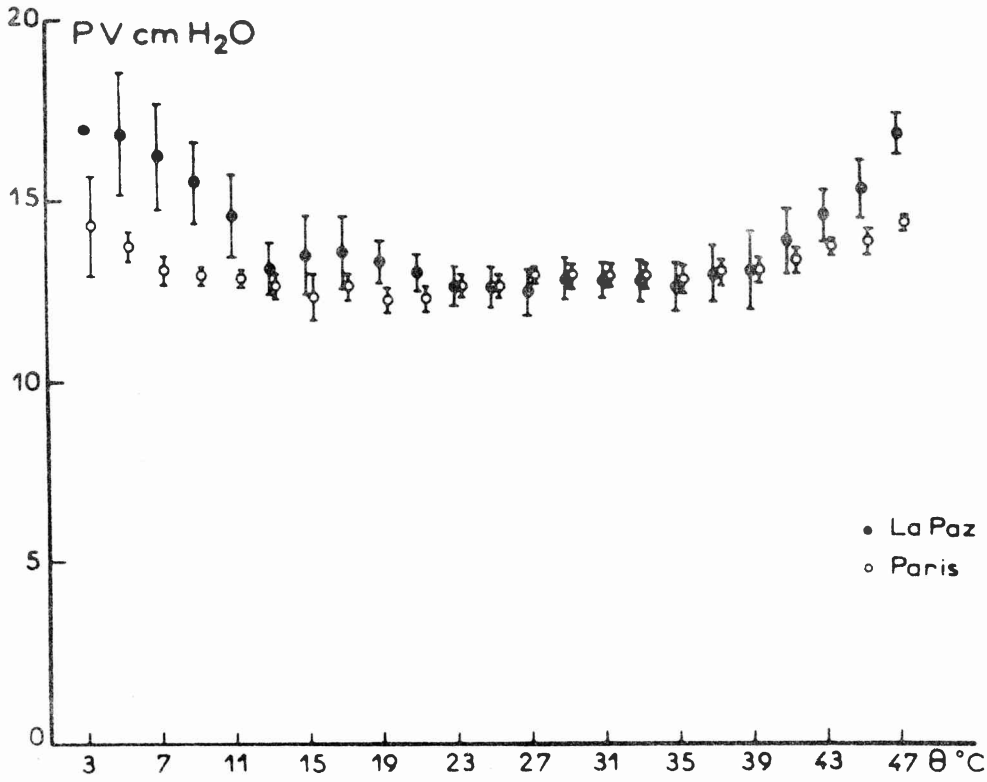

FIG. 3. Blood pressure in a superficial vein of the right hand (PV) plotted against local temperature (°C) in sea-level residents (○) and in high-altitude sojourners (●). Mean values and standard errors.

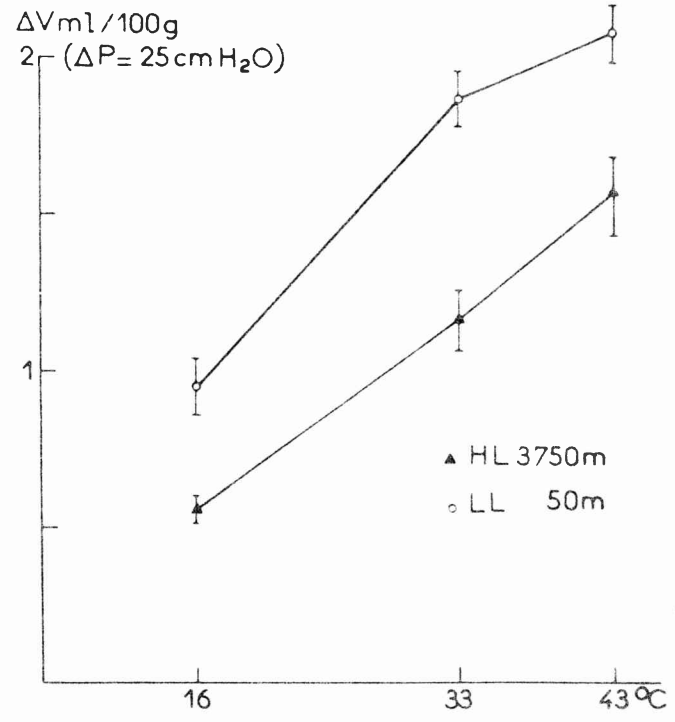

FIG. 4. Distensibility of capacitance vessels of the right hand, measured in lowlanders at sea level (○ LL) and in high-altitude residents (▲ HL), plotted against local temperature. The distensibility has been figured as the change obtained in the volume of the right hand (in percent) for a transmural pressure change of 25 cm of water. Mean values and standard errors.

protected from external pressure changes. It might be true that small arteries also are compressed or expanded, but this should not be significant in terms of volume since, first, the external pressures used were very small compared with the arterial pressure and, second, the volume in resistance vessels is negligible compared with the volume contained in capacitance vessels (3, 13, 17).

More questionable is the extrapolation of the data obtained to the whole integument since it is known that venous circulation is more reactive in the skin of the extremities than in other parts of the body (19) and up to now the figures given here should be considered as only an approximation.

The first work on the cutaneous circulation at high altitude, as far as we know, is the study made on visitors at Pikes Peak by Schneider and Sisco (16). Their results are contradictory to those reported here since they found an increased blood flow of the hand (measured by a calorimetric technique) and a decrease in peripheral venous pressure. Later on, Rotta (15) and Alarcon-Castillo (2) found that venous pressure was higher in high- than in lowlanders, while mean right atrial pressure did not exhibit any difference (14). The data of Elsner et al. (7) also suggest that the cutaneous blood flow in the lower limbs is smaller at high altitude.

There are many publications concerning the vascular changes induced by acute hypoxia when breathing low oxygen mixtures (1, 6, 8, 12, 13, 18), or by decompression (9). But the results obtained in these conditions show such a great variability that it is difficult to draw an

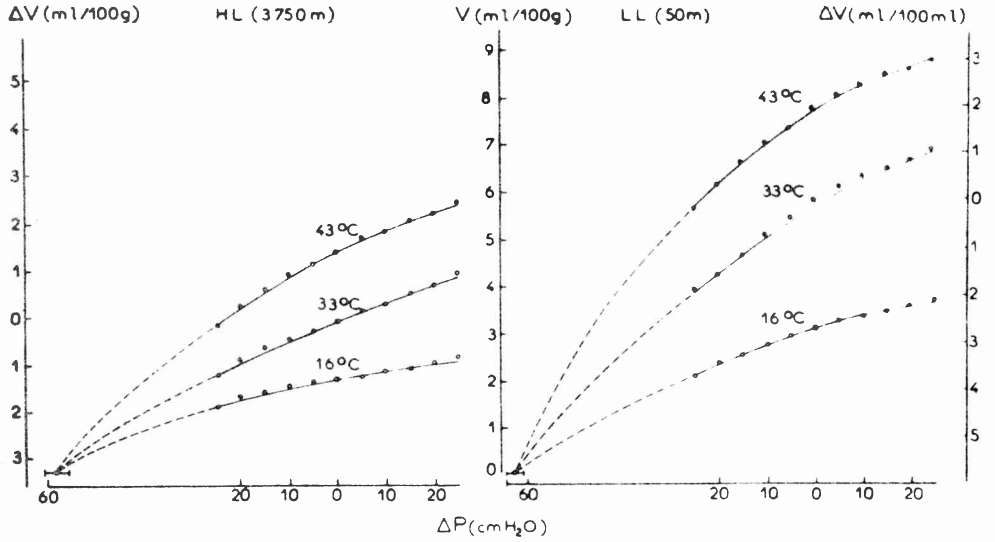

FIG. 5. Volume-pressure curves of capacitance vessels of the right hand in lowlanders (right side: LL) and in highlanders (left side: HL). Curves have been obtained for three different local temperatures 16, 33, and 43 C. In *abscissa* are figured the changes in venous transmural pressure (ΔP) and in *ordinate* volume changes of the hand (ΔV: right and left scales) or estimated blood volume (V: middle scale).

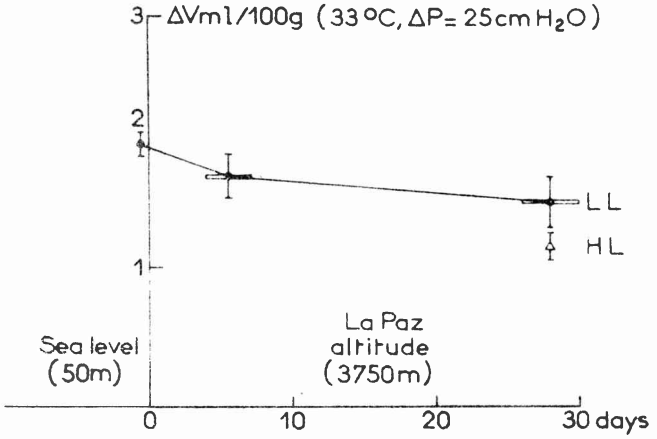

FIG. 6. Distensibility of capacitance vessels of the right hand plotted against time of acclimatization. Distensibility has been figured as the change obtained in the volume of the right hand (in percent) for a 25 cm of water transmural pressure change. Measurements have been made at the local temperature of 33 C. Values obtained in lowlanders (LL ●) are compared with those obtained in residents (HL △). Mean values and standard errors.

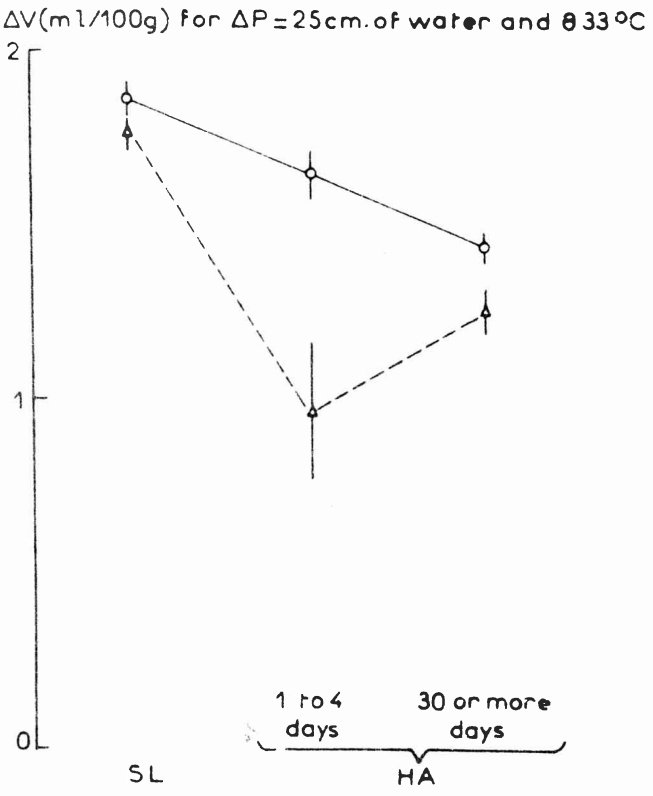

FIG. 7. Comparison of the reduction of cutaneous vascular distensibility during acclimatization at 3,750 m in sea-level residents (○) and in high-altitude residents coming back from sea level (△). Mean values and standard errors.

definite conclusion. The most we can say is that it seems that acute hypoxia, when it is marked, is accompanied by a cutaneous vasoconstriction and a muscular vasodilatation, and that hypocapnia probably plays an adjuvant role in both cases (4).

Provided that local temperature is high enough (above 30 C), the blood flow through the hand is always lower when measured at high altitude than at sea level. If these results are extrapolated to the whole cutaneous circulation, the economy of blood flow induced by high altitude is small in basal conditions (about 200 ml/min) and only becomes quantitatively important for skin temperature above 37 C, i.e., out of the physiological range.

The reduction in cutaneous blood volume at high altitude seems to be the most important physiological feature and this occurs even in basal conditions. If extrapolation from the hand blood volume to the total cutaneous blood volume is accepted, the change in volume when going from sea level to high altitude is about 300 ml.

Highlanders, returning to altitude from a sojourn at

sea level, occasionally exhibit a transitory overreduction of cutaneous vascular distensibility. It is appealing to think that this could be related to the high altitude pulmonary edema occurring in the same circumstances: pulmonary hypertension being favored by the blood shift toward the lungs, caused by a hyperreactivity of the cutaneous veins similar to the one known to affect the pulmonary vessels. But in the present study none of the subjects of this group showed any evidence of pulmonary edema and no conclusion can be drawn without further investigation.

In conclusion, at high altitude there is an increase in resistance and in elastance of the cutaneous circulation. The consequences are a reduction in blood flow and blood volume mainly in the skin, so that this circulation acts as a quantitatively important reservoir, participating in the blood volume redistribution during the cardiovascular adjustments induced by high altitude.

SUMMARY

Blood flow, pressure, and volume have been measured in the right hand considered as representative of a cutaneous vascular bed. Measurements have been made comparatively at sea level and at high altitude (3,750 and 4,800 m) on residents and newcomers. The results show an increase of the tone of both resistance and capacitance vessels at high altitude. The changes are more marked when the skin temperature is higher, that is, when the cutaneous circulation is increased. Extrapolating these results to the whole skin area, one can conclude that the cutaneous circulation acts as a blood reservoir during the circulatory adjustments caused by high-altitude hypoxia.

REFERENCES

1. Abramson, D. I., H. Landt and J. E. Benjamin. *Proc. Soc. Exptl. Biol. Med.* 4: 214, 1943.
2. Alarcon-Castillo, L. Tesis, Fac. Medicina, Lima, 1956.
3. Bargeton, D., J. Durand, J. Mensch-Dechene and J. Decaud. *J. Physiol., Paris* 51: 111, 1959.
4. Black, J. E., and J. C. Roddie. *J. Physiol., London* 143: 226, 1958.
5. Burch, G. E. *Digital Plethysmography*. New York: Grune & Stratton, 1954.
6. Eckstein, J. W., and A. W. Horsley. *J. Lab. Clin. Med.* 56: 847, 1960.
7. Elsner, R. W., A. Bolstad and C. Forno. In: *The Physiological Effects of High Altitude*, edited by H. Weihe. New York: Pergamon, 1964, p. 217.
8. Freeman, N. E., J. L. Shaw and J. C. Snyder. *J. Clin. Invest.* 15: 651, 1936.
9. Gilbert, C. A., and P. M. Stevens. *J. Appl. Physiol.* 21: 1265, 1966.
10. Goetz, R. H. *Am. Heart J.* 31: 146, 1946.
11. Grant, R. T., and E. F. Bland. *Heart* 15: 385, 1931.
12. Hintze, A., and H. L. Thron. *Arch. Ges. Physiol.* 274: 227, 1961.
13. Martineaud, J. P., S. Seroussi, C. Pannier, M. Massoum and J. Durand. *J. Physiol., Paris* 58: 687, 1966.
14. Peñaloza, D., E. Sime, N. Banchero, R. Gamboa, J. Cruz and E. Marticorena. *Am. J. Cardiol.* 11: 150, 1963.
15. Rotta, A. *Am. Heart J.* 33: 669, 1947.
16. Schneider, E. C., and D. L. Sisco. *Am. J. Physiol.* 34: 1, 29, 1914.
17. Thron, H. L., K. D. Scheppokat, A. Heyden and O. H. Gauer. *Arch. Ges. Physiol.* 266: 150, 1958.
18. Watson, W. E. *Brit. J. Anaesthesia* 33: 606, 1961.
19. Zelis, R., and D. T. Mason. *Federation Proc.* 27: 330, 1968.