THE EFFECT OF OXYGEN AND CARBON DIOXIDE BATHS ON THE SUBCUTANEOUS TISSUE GAS TENSIONS

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THE physiological action of baths of all kinds, water baths, artificial and natural carbon dioxide baths, salt-water baths, mud baths, mustard baths and air baths, has been investigated at various temperatures. Hill and Flack (1909) showed that in a hot-water bath an increased pulse rate, a lowered blood pressure and a notable fall in alveolar carbon dioxide and rise in oxygen pressure were obtained. This was confirmed by Bazett and Haldane (1921) for temperatures of 37° C. and above; they suggested that heat made the respiratory centre more sensitive to carbon dioxide. They found respiration unaffected with baths below 37° C. Bazett (1924) found similar effects in a hot room. Landis, Long, Dunn, Jackson and Meyer (1926) found that hot baths may produce such hyperventilation as to lead to carbon dioxide deficiency. In comparing the metabolism of men at different effective temperatures (dry-bulb temperature corrected for humidity and air movement), McConnel and Yaglou (1924) found lowered metabolism at 23·8–28·3° C.; above 32·2° C. metabolism was slightly increased. Bazett (1924) suggests that these deductions are not warranted, as chemical equilibrium is not attained. Youngsberg and Finch (1926) found no seasonal variation in metabolism with temperature. Much other work has been done along the same lines, and need not be referred to here. With regard to the effect of temperature on blood gases, Goldsmidt and Light (1925, p. 127) showed that in blood taken from the anticubital region with temperatures differing by 2° C. the oxygen saturation was 81·3 per cent. at the higher temperature and 58·7 per cent. at the lower. These authors (*ibid.* p. 146) also give many references to researches which show that the rate of the blood flow is increased by warmth and decreased by cold. With baths below 18° C. the skin takes on a pink hyperaemia, the oxygen saturation of the haemoglobin increases and the carbon dioxide content decreases in blood taken from veins in the anticubital fossa. They suggest that this is caused by a depression in the gaseous exchange between the blood and the tissues, due either to (1) depression of the oxidation, or (2) reduction in the dissociation of haemoglobin, or to both factors. Bazett and McGlone (1928) show that the acidity of the blood varies with temperature; that taken from a leg immersed in a warm bath shows a greater acidity than that taken from one immersed in a cold bath. Bazett and Sribyatta (1928) also showed the effect of local change in temperature on gas tensions in the tissues. They find that

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increase in temperature of an arm immersed in water increases carbon dioxide tension. In the case of oxygen tensions a minimum value is shown at about 22° C., after which a rise occurs with increasing temperature. Schott (1928) showed that when rabbits are almost completely immersed in Nauheim effervescent carbon dioxide baths the tissue carbon dioxide tensions decrease in all, while in 50 per cent. of the experiments the oxygen tensions increase. Plain-water baths of the same temperature and duration did not show these effects. Groedel and Wachter (1929) and Groedel (1907) have investigated the action of natural and artificial carbon dioxide baths; differences were noted. Their method was to investigate the respiratory quotient.

The object of the present investigation was to determine whether saponine foam baths have any effect on the carbon dioxide and oxygen subcutaneous tissue tensions. Winternitz (1902) has stated that in carbon dioxide baths the output of carbon dioxide is increased and the respiratory quotient rises to a value greater than unity; he concluded that carbon dioxide must be absorbed through the skin. Liljestrand and Magnus (1922) showed that in man this result is due to washing of carbon dioxide from the body by the increase of respiration caused by the bath. On the other hand there is the well-known vaso-dilatory action of moist carbon dioxide. This is considered by Lewis (1927). One question we wished to decide was whether carbon dioxide or oxygen diffuses from the bath through the skin in sufficient quantities to effect the subcutaneous tissue gas tensions.

The foam bath equipment consists of a bath in which is laid a board in the form of a grid with fine holes. On connecting this board to a source of positive air pressure, air escapes from the grid in fine streams. The board is just covered with warm water at 43–46° C. and an appropriate amount of saponin solution added. On passing the air a fine foam is formed and this rises and fills the bath. If the air supply to the grid is changed to an oxygen or carbon dioxide supply these gases can be used instead of air, and their loss is prevented by the previously formed foam acting as a cover. The technique of the treatment consists, then, of placing the patient in the bath so that he is surrounded by foam except for the head, and passing in through the grid either carbon dioxide or oxygen. The foam acts as an efficient heat insulator preventing loss of body heat except by the respiration and by radiation and convection from the face. A general rise in body temperature is usually obtained.

ESTIMATION OF OXYGEN AND CARBON DIOXIDE SUBCUTANEOUS TISSUE TENSIONS

To measure the tissue carbon dioxide and oxygen tensions the method of J. Argyll Campbell (1932) was employed. Air or nitrogen or a mixture of nitrogen, oxygen and carbon dioxide was injected into the subcutaneous tissues and left to reach equilibrium with the tissue gases. Then a sample was removed and analysed. Knowing the barometric pressure the tensions of oxygen and carbon dioxide in the tissues may then be calculated. For injection a hypodermic needle and syringe barrel, connected to a mercury manometer and to a rubber bag containing the gas mixture at a pressure of about 20–30 mm. of mercury above atmospheric pressure, were used. All parts of the syringe and needle were kept sterile and a loose plug of sterile cotton-wool placed in the barrel of the syringe. The rubber bag was filled from a cylinder of the gas mixture. The site of the injection was the inside of the forearm. A lightly applied bandage round the wrist prevents the injected gas from spreading to the hand, and another just below the elbow prevents it from spreading up the arm and to the rest of the body. A volume of 5–10 c.c. was injected subcutaneously. After equilibrium had been obtained, as a rule only a small volume of gas could be removed, and for its analysis a micro-method had to be used. To remove a sample of the gas a piece of rubber tubing was tied round the wrist just above the lightly applied bandage mentioned above and rolled up the arm towards the elbow. This localises some of the gas, and a sample was removed in a 1 c.c. hypodermic syringe fitted with a 26 G½ needle, the dead space of which was filled with the mixture of slightly acidified 80 per cent. glycerol and 20 per cent. sterile distilled water. As a rule the bubble removed was between 0·07 and 0·12 c.c. in volume. For analysis of the bubble Campbell's (1932) modification of Krogh's (1908) microtonometer as described by Campbell and Taylor (1935) was used.

Experimental results

Determinations were carried out on presumably normal controls in order to confirm the figures of 40 mm. of mercury for carbon dioxide tissue tensions and 40–43 mm. of mercury for oxygen tissue tensions. We confirmed these figures which, since they are in agreement with those generally accepted (Campbell, 1931), will not be further discussed. Determinations were also carried out to confirm the time taken for our gas mixture to reach equilibrium in the tissues. It was found that with a mixture of gases 5 per cent. carbon dioxide, 5 per cent. oxygen and 90 per cent. nitrogen, carbon dioxide reached equilibrium in a quarter of an hour or less and oxygen in about forty-five minutes. An example will make this clear:

	CO_2 %	O_2 %
On injection	5·00	5·00
Quarter of an hour later	5·60	5·45
Half an hour later	5·55	5·74
Three-quarters of an hour later	5·70	5·90
One hour later	5·50	5·88

The determinations were carried out as follows. Some of the gas mixture was injected as described and left in the arm for three-quarters to one hour, and some of it removed for analysis. This gives us the normal value for this particular patient. The patient is then immersed in the foam bath for three-quarters to one hour, and after this some of the gas removed and analysed.

The effect of the bath on the gaseous tissue tensions can then be determined. On each patient at various times the effect of carbon dioxide and oxygen foam baths is determined. It is probable that the values obtained for the oxygen tensions whilst the patient is in the bath are not the correct values, since there is always a time lag between the tension in the tissues (which may be continually changing) and that in the injected gas. The figures obtained will, however, be approximate. The patient's temperature is taken by mouth at the commencement and at the end of the bath. Table I gives the experimental results.

Table I

Patient	Normal tensions mm. Hg		CO_2 bath tensions mm. Hg			O_2 bath tensions mm. Hg		
	CO_2	O_2	CO_2	O_2	Body temp. rise ° F.	CO_2	O_2	Body temp. rise ° F.
1	36·2	45·6	36·9	38·0	0·6	33·0	47·0	1·4
2	45·2	36·9	24·2	56·4	2·6	32·0	73·4	1·6
3	29·9	29·9	38·1	46·4	0·8	36·0	56·4	1·2
4	41·6	43·2	31·7	45·3	1·0	26·0	58·0	1·0
5	39·0	46·2	32·2	49·9	2·0	—	—	—
6	45·9	60·4	35·0	64·4	1·6	25·2	58·8	1·6
7	39·2	40·1	25·3	64·3	2·2	35·0	66·1	1·0
8	41·2	45·4	30·7	61·4	0·8	—	—	—
9	36·0	46·0	31·4	49·4	1·6	30·4	51·8	1·0
10	34·3	46·8	39·0	45·1	0·8	27·9	60·0	1·2
11	36·9	42·0	36·0	48·2	1·0	32·5	57·1	1·0
12	39·7	46·4	23·0	57·6	1·8	28·0	57·3	1·2
13	45·0	48·7	25·2	48·7	2·2	35·5	61·2	2·0
14	43·5	46·8	42·1	48·2	1·2	32·7	57·2	1·4
15	39·1	44·3	30·0	60·0	2·0	28·8	57·4	2·2
16	26·8	51·0	37·2	47·0	2·0	26·5	79·3	1·6
17	41·5	45·9	31·6	50·0	1·0	32·0	51·0	1·6
18	49·0	34·0	20·3	52·5	1·0	33·4	51·7	1·0
19	38·0	47·0	30·6	62·2	1·6	33·1	62·2	1·4
20	48·9	45·3	36·3	62·7	1·0	26·7	65·8	0·8
21	37·2	45·0	36·3	51·7	0·6	35·2	51·1	0·4
22	38·9	44·3	32·6	52·2	2·0	30·0	57·3	1·4
23	25·0	63·3	30·7	63·2	1·0	28·2	56·4	1·0
24	44·0	45·9	42·2	60·4	0·8	38·0	52·0	0·6
25	44·4	41·3	31·8	57·9	1·2	30·6	52·0	1·4
26	34·0	42·0	33·9	52·2	2·3	39·4	61·6	2·1
27	42·1	37·6	25·6	60·0	2·0	27·7	65·3	1·0
28	42·0	45·0	25·3	52·5	1·2	28·0	52·6	1·0
Averages	40·9	44·1	32·2	54·0	1·4	31·2	58·5	1·3

It will be noticed that the average carbon dioxide and oxygen subcutaneous tissue tensions in the case of oxygen and carbon dioxide baths are nearly the same. The conclusion to be drawn is that sufficient gas does not diffuse through to the subcutaneous layers to affect the tissue tensions in that region (Campbell, 1929). It appears from this point of view that the effect of these baths is to raise the body temperature and thus to increase the respiration, leading to a fall in tissue carbon dioxide and a rise in tissue oxygen tensions, and to a greater flow of blood through the skin capillaries, this having the same effect. An incidental feature upon which not too much stress is laid, is that most of the patients were obese and suffering from hypertension. The normal values of these patients lie within the limits of 40 mm. mercury for carbon dioxide and 40–43 mm. mercury for oxygen. This seems to indicate that hypertension is not associated with capillary stasis, since under this condition a rise in carbon dioxide and a fall in oxygen tissue tensions would be expected.

Summary

1. A method is described for estimating subcutaneous tissue oxygen and carbon dioxide tensions in man.

2. Measurements were carried out before and at the end of carbon dioxide and oxygen saponin foam baths. These baths decrease the carbon dioxide and increase the oxygen subcutaneous tissue gas tensions. No appreciable differences were found between carbon dioxide and oxygen baths.

3. We conclude that gases do not diffuse through the skin in sufficient quantities to affect the subcutaneous tissue gas tensions.

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