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THE EFFECT OF ALTITUDE UPON THE BLOOD.

BY

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While making some prelimary investigations with respect to the blood in tuberculous subjects, the observation was made that the counts of red corpuscles are apt to be normal or above in numbers. Two explanations are given, either of which might account for the phenomenon observed. The high counts in red blood cells might be due to excessive toxin absorption as in advanced tuberculosis, cavity formation, etc., or they might be due to the effects of altitude. Of these two generally accepted principles, the latter seemed the more probable, for, in our cases altitude presents a constant and considerable factor. On the other hand, the toxin absorption hypothesis should apply to a limited number only. The latter did not seem to be true, and in order to form an intelligent estimate of the condition of the blood in tuberculosis, it appeared desirable to know the exact effect of altitude upon it. With this object in view, the present envestigation was undertaken.

The examination of the blood has become such a general practice that it will not be necessary to describe the process here. Suffice it to say, that in all important matters the methods given in our texts, especially Cabot and von Limbeck, have been closely followed.

For the sake of covenience and brevity, the cases are recorded by numbers and given in tabulated form only; but in our work the histories of the cases have in almost all instances been recorded, and these will be drawn upon when necessary.

Experimental Results.

Red Corpuscles or Arythrocytes.—As previously stated, the present work was suggested by an examination of the blood of a number of tubercular subjects, whose blood counts, contrary to expectation, were normal or above in numbers of red corpuscles. This fact is illustrated in Table I. below, in which ths tubercular cases are grouped together. By "tubercular cases" is meant persons suffering from tuberculosis at the time of the examination, the tubercle bacillus having been actually demonstrated, or all symptoms being such as to warrant the belief that the bacillus was present.

TABLE I.—Blood Counts of Tubercular Subjects (Not Cured.)

Case number.	Sex	Age	Date.	Residence in Albuquerque.	Number of Red Cells per Cu. mm,	Number of White Cells per Cu. mm.	Red Cells.	
							Above Normal.	Below Normal,
1	M	31	April 13, 1899	2 years	6,644,000	.....	1,144,000	.....
1	M	31	Oct. 6, 1899	2½ years	6,000,000	.....	500,000	.....
2	M	26	April 26, 1899	2 yrs 5 m	5,120,000	.....	.....	380,000
2	M	26	Sept. 9, 1899	2 yrs 9 m	5,120,000	.....	.....	380,000
4	M	adult	April 24, 1899	2 years	5,504,000	.....	4,000	.....
7	M	?	Oct. 5, 1899	6 weeks	5,515,000	.....	15,000	.....
10	M	?	Nov. 2, 1899	5 years	6,000,000	.....	500,000	.....
10	M	?	May 11, 1900	5½ years	6,072,000	.....	572,000	.....
10	M	?	May 21, 1900	5½ years	6,428,000	.....	928,000	.....
12	M	adult	Jan. 3, 1900	.....	6,720,000	.....	1,220,000	.....
13	M	23	.....	.....	5,833,000	.....	333,000	.....
14	M	44	Jan. 11, 1900	7 months	5,471,000	.....	.....	29,000
18	F	27	June 15, 1900	1 year	3,720,000	22,000	.....	1,280,000
21	M	?	June 20, 1900	2 years	6,242,000	35,000	742,000	.....
22	M	41	July 18, 1900	2 years	5,737,000	15,400	237,000	.....
25	M	adult	July 29, 1900	9 years	5,355,000	25,000	.....	145,000

The above table presents the blood counts of twelve persons, with sixteen examinations. Of these twelve cases, nine show the counts of red blood corpuscles as practically normal or above, while three are below that number. By "normal" we mean the commonly assumed figures of 5,500,000 red cells for man, and 5,000,000 for woman. Many physiologists assume somewhat lower numbers which would include as normal two of the cases we have given as below.

On comparing the above results with those obtained by Cabot *, we find them materially higher; for, out of forty-nine cases (53 counts) only six cases are above normal, and none of them reach 6,000,000 red corpuscles.

* Clinical Examinations of the Blood. 2nd Ed., page 220.

In this connection, we may quote Dr. Cabot regarding blood counts in tuberculosis: "The striking fact is the absence of such anaemia as we should expect, judging from the pallor of the patients and the nature of the disease... .... It is undoubtedly the fact that in most cases of tuberculosis, even in advanced stages, the count of red cells is approximately normal" *.

If we take the tubercular cases which have been "cured" i. e., arrested and in which *B. Tuberculosis* cannot be demonstrated, it appears that the counts of red cells are normal or slightly below, as is indicated in the following summary:

TABLE II.—Tubercular Subjects, or Presumably so, "Cured,"—i. e., B. Tuberculosis Not Present.

Case Number.	Sex	Age	Date.	Residence in Albuquerque,	Number of Red Cells per Cu. mm.	Number of White Cells per Cu. mm.	Red Cells.	
							Above Normal.	Below Normal.
3	M	28	April 19, 1899	3½ years	5,173,000	.....	Aver-	.....
3	M	29	Jan. 11, 1900	4 years	4,376,000	.....	age 3	666,000
3	M	29	June 16, 1900	4½ years	4,953,000	12,300	counts	.....
5	M	23	Sept. 15, 1899	2 days	5,520,000	.....	20,000	.....
5	M	24	Aug. 24, 1900	11 months	5,728,000	.....	228,000	.....
20	F	44	June 18, 1900	9 years	4,773,000	23,000	.....	227,000
23	M	?	July 18, 1900	4 years	5,437,000	18,000	.....	63,000
27	M	?	Aug. 5, 1900	.....	4,737,000	.....	.....	763,000
31	F	22	Aug. 3, 1900	5 years	3,422,000	8,000	.....	1,578,000
33	F	27	Aug. 3, 1900	1 year	4,147,000	8,600	.....	853,000
34	M	28	Aug. 4, 1900	18 months	3,640,000	9,200	.....	1,860,000
43	M	22	Nov. 21, 1900	2 years	5,154,000	.....	.....	346,000

It is true that the above counts of tubercular cases, active and cured, are not sufficiently numerous to warrant any positive conclusions being drawn. Still they seem to indicate a difference, and in the case of tubercular subjects, a variation from the normal which naturally provokes us to seek an explanation.

In seeking a cause for the high blood counts in these results, altitude seemed to furnish a possible explanation. That altitude does increase the number of red corpuscles in the blood is an hypothesis that has received quite general acceptance. The following table given by Koeppe† would seem to lend considerable strength to it:

* Clinical examinations of the blood. 2nd Ed., page 217.

† Munch. Med. Woch., 1890, No. 41.

Place.	Altitude (in feet.)	Red Cells.	Author.
Christiania	0	4,974,000	Laache
Goettingen	485	5,225,000	Schafer
Tuebingen	1,030	5,322,000	Reinert
Zuerich	1,358	5,755,000	Stierlin
Auerbach	1,394	5,748,000	Koeppe
Reiboldsgruen	2,296	5,900,000	Koeppe
Arosa	5,904	7,000,000	Egger
The Cordilleras	14,406	8,000,000	Viault

In view of these statements, it seemed desirable to make as correct an estimate of the altitude factor as possible. Such an estimate seemed absolutely essential to a satisfactory understanding of our ultimate problem.

A number of blood counts were next made of norma subjects residing in Albuquerque (altitude 5,000 ft.). The results of these examinations are given in the table below. It should be added that a number of these counts were made from the blood of students in the University of New Mexico. It is generally conceded that such cases should give a count normal or above, for students as a class enjoy excellent health.

TABLE III.—Blood Counts of Normal Subjects—Albuquerque 5,000 feet.

Case Number.	Sex	Age	Date.	Residence in Albuquerque.	Number of Red Cells per Cu. mm.	Number of White Cells per Cu. mm.	Red Cells.	
							Above Normal.	Below Normal.
6	M	22	Sept. 15, 1899	5 years	5,312,000	.....	.....	188,000
6	M	22	May 16, 1900	5½ years	5,738,000	.....	238,000	.....
6	M	22	May 23, 1900	5½ years	5,000,000	.....	.....	500,000
15	M	29	May 14, 1900	3 years	5,513,000	19,700	13,000	.....
16	M	28	May 18, 1900	2 years	6,062,000	9,500	562,000	.....
16	M	28	May 28, 1900	2 years	6,069,000	.....	569,000	.....
17	M	20	May 29, 1900	.....	4,647,000	10,800	.....	853,000
24	M	15	July 20, 1900	8 years Born in Colorado	5,404,000	17,900	.....	96,000
42	M	21	Nov. 21, 1900	1½ years	5,809,000	.....	309,000	.....
44	M	23	Nov. 22, 1900	Born in N Mex.	6,044,000	.....	544,000	.....
45	M	19	Nov. 23, 1900	Born in N. Mex.	6,600,000	.....	1,100,000	.....
45	M	19	Dec. 18, 1900	Born in N. Mex.	6,742,000	.....	1,242,000	.....
46	F	20	Dec. 5, 1900	Born in N. Mex.	5,320,000	.....	320,000	.....
47	F	adult	Dec. 6, 1900	1 year	4,613,000	.....	.....	387,000
48	M	43	Dec. 10, 1900	1 year	5,569,000	.....	59,000	.....
49	F	19	Dec. 19, 1900	4 years	5,124,000	.....	124,000	.....
51	M	24	Dec. 19, 1900	Born in N. Mex.	5,763,000	.....	263,000	.....

It is seen that the counts of red cells do not deviate materially from the normal, as we have assumed it, especially if allowance is made for seasonal variations. It is to be observed that the counts made in November and December are slightly higher than those of the summer months. That such a seasonal variation exists has also been pointed out by Mallassez.

Three of the above cases require comment:

Case No. 16 showing a considerable increase over normal, had been taking large quantities of purgatives immediately preceding the first examination. It is quite likely that these had the same effect as normal diarrhoea which concentrates the blood. A second examination ten days later, gave practically the same result. A third examination could not be obtained.

Case No. 17 has suffered in the past from slight asthma, but appeared quite free when the count was made.

Case No 45 shows a remarkable polycythaemia for which no apparent cause can be found. It is worthy of note that the case is native born and of Spanish decent; but case No. 51 presents the same history, though there is no remarkable variations from the normal.

These results seemed most remarkable, especially when taken in connection with Koeppe's table. Basing calculations upon the results of Egger* (7,000,000 for 5,900 ft. altitude), Albuquerque should show a blood count of 6,000,000 or 6,500,000 red cells. In fact however, the cases average about normal or only slightly above.

Being loath to accept the results obtained in Albuquerque, we determined to make a number of counts of persons residing at yet higher altitudes, heights that should show counts equal or above those of Egger. The Mountain resort, Camp Whitcomb, located 18 miles east of Albuquerque in the Sandia mountains, offered a favorable opportunity. A number of examinations were made there, the results of which follow:

* Verhandl. d. XII Congr. f. inn. Med. 1893,

TABLE IV.—Blood Counts of Cases Taken at Camp Whitcomb—Altitude 7,000 feet.

Case Number.	Sex	Age	Condition.	Date.	Time in mountains	Number of Red Cells per Cu. mm.	Number of White Cells per Cu. mm.	Specific Gravity.	Red Cells. Above Normal.	Red Cells. Below Normal.
26	M	44	Tuberculous. Bacilli, few.....	July 31, 1900	35 days	5,431,000	14,800	1052	.....	69,000
27	M	?	Tuberculous. Well.....	August 5, 1900	65 "	4,737,000	.....	.....	.....	763,000
28	M	25	Tuberculous.....	" 1, 1900	101 "	5,031,000	18,000	1060	.....	469,000
29	F	26	Tuberculous.....	" 2, 1900	22 "	4,360,000	14,800	1055	.....	640,000
30	M	?	Recovered from Pneumonia.	" 2, 1900	43 "	4,578,000	22,200	1055	.....	422,000
31	F	22	Weak Lungs. Tuberculosis(?)	" 3, 1900	31 "	3,422,000	8,000	.....	.....	1,578,000
32	F	22	Slight Pneumonia. Well.....	" 3, 1900	31 "	5,711,000	15,400	1057	711,000	.....
33	F	27	Tuberculous. Well.....	" 3, 1900	30 "	4,147,000	8,600	1055	.....	853,000
34	M	28	Tuberculous. Well.....	" 4, 1900	82 "	3,640,000	9,200	1055	.....	1,860,000
35	M	50	Normal.....	" 5, 1900	? "	4,462,000	.....	.....	.....	1,038,000
3	M	29	Tuberculous. Well 3 years...	" 7, 1900	12 "	5,147,000	.....	.....	.....	353,000
36	F	.....	Tuberculous Well (?).....	" 24, 1900	21 "	4,831,000	22,000	.....	.....	169,000
37	M	30	Normal.....	" 24, 1900	21 "	5,657,000	.....	.....	157,000	.....
38	M	16	Normal.....	" 25, 1900	60 "	4,704,000	.....	.....	.....	736,000
39	M	32	Tuberculous. No Bacilli. ...	" 31, 1900	41 "	5,764,000	.....	1056	264,000	.....
40	F	35	Normal.....	Sept. 1, 1900	41 "	5,284,000	.....	.....	284,000	.....

Since many of the persons patronizing this resort are either health seekers or have recovered from lung troubles, the condition of the health has been given as a guide to an understanding of the results. That the cases were not normal as a rule, is to be regretted; but as most of them enjoyed apparent good health, this may not seriously affect the results. Further, there is as yet no evidence that tubercular cases should form any exception to the rule of increased blood counts in high altitudes. A point in favor of the cases selected is the considerable periods of time spent in the mountains. It must be added, however, that none of them came from a low altitude, but that they resided at Albuquerque with an altitude of 5,000 feet; thus the change in reality gave them only 2,000 feet increase over their former residence.

An examination of the counts of red cells shows the remarkable fact that they fall near normal or below. Further, cases No. 27, 34 and 35, which seemed to enjoy perfect health, are decidedly below normal. To eliminate any likelihood of accidental error in technique, re-examinations were made of Nos. 27 and 34 with substantially the same results as before. Case No. 35 slept in the open air. Nos. 27 and 34 slept in open tents and took considerable physical exercise. Case No. 27 is a strong advocate of fresh air and sunlight, and practiced exposing his chest for an hour or more daily to sunlight. At the time of the examination his chest was burned brown. The writer had confidently expected, notwithstanding the previous results, that these three cases would show a very high blood count. Imagine the surprise afforded by these counts which are as much below as they should be above normal! If we accept the altitude hypothesis without qualification, we are left without an explanation for these figures. Are they merely exceptions, or must we seek another explanation?

A review of the results embodied in Table IV. does not indicate that high altitude produces high blood counts. On the other hand, they would seem to indicate that for persons who have been at a given altitude for some time, the counts are substantially normal, or agree very well with those obtained at sea-level.

It was at this juncture that serious doubts arose in the writer's mind as to the correctness of the statement that altitude increases the number of red corpuscles per volume, unless that statement is materially qualified.

The question now arose: Does altitude ever increase the blood counts? A number of cases previously followed seemed to indicate at least a temporary increase. The following bear directly upon this problem:

TABLE V.—Presenting Blood Counts of Persons Coming to High Altitude.

	Date.	Number of Red Cells per Cu. mm.	Number of White Cells per Cu. mm.	Remarks.
Case No. 2.				
1st examination	April 26, 1899	5,120,000	.....	At Albuquerque 2 yrs, 5 mos.
2nd "	Sept. 9, 1899	5,120,000	.....	At Albuquerque 5 days since 3 months stay in Indiana.
3rd "	" 12, 1899	6,711,000	.....	8 days since return.
4th "	" 14, 1899	6,424,000	.....	10 " " "
5th "	" 18, 1899	5,730,000	48,500	14 " " "
6th "	" 25, 1899	6,216,000	39,900	21 " " "
7th "	Oct. 3, 1899	6,080,000	.....	29 " " "
8th "	" 10, 1899	6,320,000	35,200	36 days since return. Taken with pleurisy.
Case No. 5.				
1st examination	Sept. 15, 1899	5,520,000	.....	Returned from Ohio—2 days.
2nd "	" 27, 1899	5,728,000	.....	At Albuquerque 14 days.
3rd "	Oct. 13, 1899	6,320,000	.....	" " 30 "
4th "	Aug. 24, 1900	5,760,000	.....	10 months later.
Case No. 8.				
1st examination	Oct. 17, 1899	5,280,000	.....	From Iowa—several days.
2nd "	" 24, 1899	5,440,000	.....	Since first examination 7 days
3rd "	Nov. 2, 1899	5,520,000	.....	" " " 16 "
4th "	" 10, 1899	5,736,000	.....	Since first exam. 24 days. Took pneumonia and died.
Case No. 9.				
1st examination	Oct. 31, 1899	6,520,000	.....	At Albuquerque about 2 weeks
2nd "	Nov. 7, 1899	6,560,000	.....	" " " 3 "
Case No. 11.				
1st examination	Nov. 8, 1899	6,400,000	.....	One wk after arrival in Albuquerque from Minnesota.
Case No. 20.				
1st examination	June 18, 1900	4,773,000	23,000	.....
2nd "	July 19, 1900	4,822,000	32,100	....
3rd "	Aug. 23, 1900	4,853,000	24,700	....
Case No. 24.				
1st examination	July 20, 1900	5,404,000	17,900	.....
2nd "	Aug. 23, 1900	5,489,000	15,000	.....
Case No 41.				
1st examination	Nov. 19, 1900	5,502,000	.....	In Albuquerque 2½ months from Washington, D. C.
Case No. 50.				
1st examination	Dec. 19, 1900	6,462,000	.....	In New Mexico 5 days from Indiana.

Case No. 2.—Male; age 26; consumptive with both lungs involved and left lung almost completely consolidated; tubercle bacilli present and abundant; progress of disease apparently arrested; lived in New Mexico two and a half years; slight improvement during residence. First blood examination April 26, 1899. Patient returned home to Indiana where the months of June, July and August were spent; returned to Albuquerque September 4, 1899, apparently as well as before leaving for home.

The first count after two and a half years residence at 5,000 feet of altitude, is below normal. On returning from home the count was the same. Eight days after return, the number increased enormously (1,591,000), nearly reaching the highest point. The number of red corpuscles then oscillated about the 6,000,000 point for five weeks, when the patient was taken with pleurisy, accompanied by effusions, which terminated in death.

Case No. 5.—Male; adult; weak lungs but no tubercle bacilli have been found in sputum; enjoys good health. The first examination was made two days after return from a five months stay in Ohio. In this case the increase in red cells was gradual. The fourth examination made eleven months after arrival from East, shows a return of the count towards normal, but still the count is somewhat above the first. It is to be noted that the first examination was practically normal.

Case No. 8.—Male; adult; married; consumptive from Iowa; in Albuquerque about one week. Four blood counts were made at intervals of one week, and these show a slow but gradual increase to slightly above normal. Patient took pnuemonia and died.

Case No. 9.—Male; adult; single; slight "lung trouble" but tubercle bacilli not present; no cough; general condition excellent. Came from Iowa about two weeks before first examination. Only two counts were made, both of which were very high.

Case No. 11.—Female; age 44; married; came from Minnesota one week before examination; normal subject; only one count was obtained which was very high.

Case No. 20.—Female; adult; married; has had "lung

trouble" for 15 years, but bacilli not now present. Two examinations were made at Albuquerque, when patient left for Colorado (Colorado Springs, 6,400 feet,) on a three weeks visit. The important point involved here, is whether the blood would show an increase in red cells upon return from the higher elevation of Colorano Springs. A slight but immaterial rise was observed.

Case No. 24.—Male; age 15; normal subject enjoying excellent health. Case accompanied No. 20 on Colorado Springs trip, making conditions parallel. Again a slight but immaterial rise occured.

Case No. 41.—Male; age 20; normal; subject come from Washington, D. C. September 1, 1900. After two and one half months the count is normal.

Case No. 50.—Male; age 28; normal subject; football player enjoying good health; came from Indiana five days previous to examination. The count is decidedly above normal.

In summing up the results of these nine cases, we find that six (Nos. 2, 5, 8, 9, 11, and 50) show a considerable increase, all reaching above normal, and four exceeding 6,000,000 corpuscles. Cases No. 20, 24 and 41 do not properly belong with the others, but are of interest here. Case No. 41 is given to show that if an increase did occur, the blood has again returned to normal; this within the comparatively short period of two and one-half months. Cases No. 20 and 24 show only slight increments which are discussed later.

The closest watch was kept on case No. 2, but this was complicated with pleurisy, which perhaps veiled the true effect of altitude in the later examinations. Case No. 5 shows a return to practically the normal condition. Unfortunately, it furnishes no data regarding the length of time required for the return, nor do any of the remaining cases assist us in deciding this point. However, all (excepting perhaps No. 41) would appear to indicate an increase in red cells due to altitude. That the entire increase is due to altitude, may perhaps be doubtful. In seven of the cases cited above, all made long railroad journeys of 1500 miles or more; it is possible that part of the increase

is due to recuperation from fatigue. In cases numbered 8, 9 and 11, there was relief from former duties accompanied by complete rest from labors. To what extent these factors enter cannot be determined. It is not believed that they can account for the entire rise, for a rise from recuperation should, theoretically at least, reach the normal, or at most slightly above.

In cases No. 20 and 24 it is possible that a greater increase than is shown by the examinations, actually took place; but this may have been counteracted by the fatigue of the return journey to Albuquerque. However, the writer is more inclined to the view that persons living at a relatively high altitude are less sensative to altitude changes thereafter. This view is supported by the Camp Whitcomb cases, all of which fall in the same category with the above two.

Animal Experiments.

It was hoped that some light might be cast upon this question by animal experiments. Through the kindness of Capt. H. G. Whitcomb, it was possible to carry out a series of experiments to this end.

For the first experiment four common white rabbits were selected from the laboratory lot kept in the basement of the Hadley Climatological Laboratory. These rabbits had been fed on wheat and alfalfa. The room they occupied was large (25 x 30 ft.), sunny, well ventilated, and as dry as an eastern barn. Two of the rabbits, Nos. 2 and 3, appeared in excellent condition. Their coats were smooth and sleek and free from the yellow tipped hairs of poorly nourished animals. The other two animals, Nos. 1 and 4, were taken from a lot recently purchased, but which were badly sun-scalded. They were purposely selected, since altitude should effect them the same as the healthy specimens, if the increase in corpuscles is a physical phenomenon, i. e., due to concentration of the blood. On July 7, the four animals were taken to Camp Whitcomb (altitude 7,000 feet) where they were kept in a well lighted box in the open air, but in the partial shade of a tree. They were fed largely on vegetables, but also received some alfalfa and grain. The animals were examined before being taken to the higher altitude, twice at the camp, and again when returned to the Laboratory on August 22. The whole period of time was 46 days. The results are tabulated as follows:

TABLE VI.—Blood Counts of Rabbits Taken to Higher Altitude.

Rabbit No, 1.—Male; small; about 10 weeks old; injured by excessive heat.

	Place.	Altitude.	Date.	Weight in Pounds.	Time in Mountains.	Specific Gravity.	Number of Red Cells per Cu. mm.	Number of White Cells per Cu. mm.
1st examination..	Albuquerque.....	5,000 feet	July 5, 1900	1½	.....	1055	5,084,000	63,000
2nd " ..	Camp Whitcomb.....	7,000 "	July 28, 1900	.....	21 days	1052	5,882,000	15,400
3rd " ..	" "	7,000 "	Aug. 5, 1900	1½	29 "	1045	3,740,000	....
4th " ..	Albuquerque.....	5,000 "	Aug 23. 1900 Brought in Aug. 22, 1900	1¾	46 "	1045	4,191,000	.....

Rabbit No. 2.—Male; age about 14 weeks; healthy.

1st examination..	Albuquerque.....	5,000 feet	July 5, 1900	4	.....	1060	5,037,000	14,800
2nd " ..	Camp Whitcomb.....	7,000 "	July 26, 1900	.....	19 days	1052	7,220,000	14,810
3rd " ..	" "	7,000 "	Aug. 4, 1900	4	28 "	1050	6,651,000	9,200
4th " ..	Albuquerque.....	5,000 "	Aug. 22, 1900 Brought in same day.	4	46 "	1052	5,215,000	.....
5th " ..	Albuquerque	5,000 "	Aug. 25, 1900	.....	Home 3 days	1055	5,805,000	.....

Rabbit No, 3.—Female; age about 14 weeks; healthy.

1st examination..	Albuquerque.....	5,000 feet	July 5, 1900	3½	.....	1050	4 831,000	9 200
2nd " ..	Camp Whitcomb.....	7,000 "	" 27, 1900	.....	20 days	1050	5,649,000	10,500
3rd " ..	" "	7,000 "	Aug. 5, 1900	3½	29 "	1047	5,987.000	....
4th " ..	Albuquerque..... Brought in same day.	5,000 "	" 22, 1900	3½	46 "	1047	5,707,000	.....
5th " ..	Albuquerque.....	5,000 "	" 25, 1900	.....	Home 3 days	1047	5,311,000	.....

Rabbit No. 4.—Female; age (?); mother of No. 1; injured by heat.

1st examination..	Albuquerque.....	5,000 feet	July 6, 1900	4	.....	1050	3,960,000	15,400
2nd examination	Camp Whitcomb.....	7,000 feet	Aug. 4, 1900	4	28 days	1047.5	5,387,000	3,700
3rd "	Albuquerque..... Brought in Aug. 22, 1900.	5,000 "	" 23, 1900	4	46 "	1052	5.618.000	... .

Rabbit No. 5.—Male; 3 or more years old; in excellent condition.

1st examination..	Albuquerque...	5,000 feet	Aug. 20, 1900	5½	.....	1055	5,702,000	.....
2nd " ..	Camp Whitcomb.....	7,000 "	" 21, 1900	.....	10 days	1055	6,622,000	.....
3rd " ..	Albuquerque..... ..... Home 2 days.	5,000 "	Sept. 26, 1900	5¾	34 "	1055	7,069,000	..... .

Rabbit No. 6.—Male; 20 weeks old; in excellent condition.

1st examination..	Albuquerque.....	5,000 feet	Aug. 20, 1900	4½	.....	1055	6,702,000	.....
2nd " ..	Albuquerque..... Home 1 day.	5,000 "	Sept. 25, 1900	4¾	34 days	1055	7,650,000	.....

Rabbit No. 7—Male; 10 weeks old; in excellent condition.

1st examination..	Albuquerque.....	5,000 feet	Aug. 20, 1900	3	.....	1055	7,124,000	.....
2nd " ..	Camp Whitcomb.....	7,000 "	" 31, 1900	.....	10 days	1055	6,675,000	.....
3rd " ..	Albuquerque..... Home 2 days.	5,000 "	Sept. 26, 1900	3½	34 "	1055	7,306,000	.....

An examination of the counts of the red cells of rabbits (1 to 4) shows that a material increase took place in all cases and that this was greatest in rabbit No.2, amounting to 2,183,000. This enormous increase occured within 19 days after being taken to the mountains. It is especially important to notice that in three cases a fall in the number of corpuscles occured after the increase. In other words, there was a return toward the normal.

The highest corpuscle count obtained in No. 1 was reached in 21 days; No. 2 in 19 days; No. 3 in 29 days; and No. 4 in 46 days, no decrease having taken place in the latter. The decrease is most noticeable in Nos. 1 and 2, amounting to about 2,000,000 cells. No. 2 shows the greatest regularity in its changes, and may perhaps stand as a somewhat ideal example.

Largely for other reasons, a second lot of rabbits were sent to the mountains, blood examinations being made as before. They were all males and in excellent condition. The only variation introduced into the experiment was in feed, these receiving only wheat and alfalfa, their former rations.

The data regarding the above, Nos. 5, 6 and 7 have been included in Table VI. previously given. The blood counts agree very well with those of the former series, all showing an increase in red cells. No. 7 does not show the same regularity as the others; but perhaps the animal was too young for the experiment, being still in an actively growing condition.

It may be added that blood counts were made of three turtles, but the animals were accidently lost after the second examination. The results were uncertain, in that two showed a slight decrease while the third gave an increase. They appeared to be unfavorable subjects.

The White Blood Corpucles or Leucocytes.

Turning our attention to the white cells of the blood, we find that no satisfactory law can be deduced from the number of counts recorded in the above tables. It might have been expected that these cells would, in a general way, vary with the red cells; but this is not apparent from the counts made. It is probably more often the case that the

white cells vary inversely with the red, or a high count of red cells accompanies a low white cell count, the subject being normal. The white cell counts of the rabbits especially support this view, since in no instance was there any marked tendency for the white cells to follow the increase in the red. In the writer's experience, unfavorable conditions seem to increase the white cells of the blood, while any factor tending to restore the normal, tends to lower the count. Viewed in this light, the relative fall in white cells in case of the rabbits would indicate that the accompanying increase in red cells is to be interpreted favorably, rather than as a possible pathological condition.

Specific Gravity Determinations.

The experiments with the rabbits were undertaken mostly for the purpose of studying the specific gravity of the blood. Specific gravity determinations * were made at each examination. It was hoped that these might aid in solving the question as to why the number of corpuscles increase with an increase in altitude. It has been suggested that the increase in red corpuscles was due to concentration of the blood or loss of plasma, caused by the dryness of high altitudes. If this were true, then the specific gravity of the blood should vary with the count, or a higher count should be accompanied by a higher specific gravity.

An examinatiou of Table VI., rabbits 1 to 4, shows that exactly the reverse took place. In other words, the increase in red corpuscles was accompanied by a decrease in specific gravity. In Nos. 1 and 2 the decrease was continuous, while in the other two an increase appeared again toward the end of the experiment.

In view of the above fact it would seem that the blood concentration hypothesis is inadequate as an explanation for the increase in red cells. It must be added that the fall in specific gravity was undoubtedly due to a change in feed; the rabbits receiving many vegetables from the camp kitchen. In order to make certain of this point, a second

* The specific gravity tests were made by means of a series of glycerin solutions representing a scale, the solutions varying by two and three points. These solutions were frequently restandardized. The blood was taken with a white diluting pipette.

lot of rabbits was sent to the camp; but care was exercised that they were fed exclusively on wheat and alfalfa, the same food as they had received previously. In the second experiment the blood counts agree essentially with those of the first, as we have noted; but the most interesting fact revealed is that no change took place in the specific gravity of the blood. The two experiments supplement each other and tend to prove that altitude has no effect upon the specific gravity of the blood, and incidentally that the increase in corpuscles is not due to concentration.

Referring again to the experiment with the turtles, which was planned mostly with respect to the specific gravity problem, we find a fall in all the cases, being 2.5, 5 and 10 points respectively on a scale of 1000. This fall was due perhaps to either of two causes. First, the animals were kept wet continuously which is not the case in nature. Secondly, they may not have taken any food. For these reasons no positive inference can be drawn from the experiment. All that can be said is that altitude did not concentrate the blood under the conditions of the experiment, and that this fact is not contrary to the other results in this line.

A few specific gravity determinations were also made upon human cases at Camp Whitcomb (see Table IV). If we assume as normal 1051 to 1055 for woman, and 1056 to 1059 for man*, then there is no material deviation from the normal in these cases. Case No. 26 was recuperating from excessive hemorrhages which account for the fall below normal. Although the tests are so few, it is worthy of note that they do not indicate blood concentration.

Summary of Results.

We may now with advantage summarize the results that appear to have been established in the foregoing. These results are as follows:

1. An increase in the number of red corpuscles takes place on going from a lower to a higher altitude; but this increase is temporary, lasting for a few weeks only, when a gradual decrease sets in.

* Landois-Sterling.—Human physiology. 3rd Ed.

2. The increase is apt to be sudden and the entire rise may occur within a week or two, although this is not invariably the case.

3. The return to normal is more gradual than the rise, and may take a number of weeks.

4. Persons residing at a high altitude for a considerable period of time, show practically a normal blood count; this is true at least for the moderately high altitude of 5,000 feet.

5. The blood is probably less sensative to altitude changes after a considerable residence in high altitudes, say a year or more.

6. The temporary rise in the number of red corpuscles is not due to blood concentration or loss of plasma.

7. There is no change in the number of white corpuscles corresponding to that of the red ones.

It may be noted that the above conclusions, especially with respect to the normal number of red corpuscles found at high altitudes, and also with respect to the decrease after a temporary increase, are at variance with the results usually given by investigators in this line. The writer would feel some hesitancy in publishing results which are contrary to generally accepted statements, were it not that a co-laborer in this field, Dr. S. E. Solly of Colorado Springs, has, if correctly reported, obtained results which agree with the above, in at least one important point; that is the number of red cells does not vary materially from normal in persons living permanently at high altitudes. *

The writer is of the opinion that in most instances there has been a failure on the part of investigators to trace the blood changes for a sufficiently long period of time. Had Egger, Koeppe and others, carried on their observations for a longer period, especially upon permanent residents, it is believed that they would have arrived at a conclusion in harmony with ours †.

* Paper read before American Climatological Association, May 3, 1900; reported in Medical Record, June 2, 1900.

† Since writing this paper there has come to my notice the work of Turban who found that the increase in the number of red cells, due to altitude, is gradual, and is in turn followed by a gradual decline. Hence, my results are confirmatory of Turban's in this respect. (Munch. Med. Wochenschr. 1899. p. 792

Theoretical Considerations.

As yet it cannot be said that we have anything approaching a scientific explanation of the effects produced upon the human body by altitude. And if we take the specific problem of the effect produced upon the blood, much the same condition prevails. Although considerable pioneer work has been done, we believe that a most important factor has been overlooked entirely. This factor is presented in this paper. If high altitude does not produce a permanent increase in red corpuscles, then all explanations of altitnde based upon this false conclusion of a permanent increase, must necessarily fall.

It may be well to consider the various hypotheses advanced to account for the increase in red cells, though of course these could not at the same time acccount for the subsequent fall we have noted. The several hypotheses are as follows:

1. *Decreased oxygen supply results in decreased oxygen absorption by the red cells, and hence a greater number of red cells is needed to furnish the oxygen required by the body.* Or, more accurately stated, if the partial-pressure of oxygen is diminished, then the absorption of oxygen by the blood will also be diminished. More red corpuscles are required to make good the difference.

This hypothesis assumes that the laws of absorption of gases hold true for the blood, which, according to recent investigations, seem not to be the case. It has been shown that the plasma of the blood absorbs only a minimum amount of oxygen, and does not exceed that absorbed by distilled water at the same temperature *. Further, almost the total quantity of oxygen in the blood is united chemically to the haemaglobin and hence not subject to the law of absorption of gases. This is proved by the fact that blood does not give up its chemically united oxygen copiously until the oxygen pressure is lowered to 20 mm. of mercury, equivalent to about 1-6 atmospheric pressure †. Conversely, the blood takes up only a little

* Lothar Meyer, cited by Landois-Sterling. Human Physiology.
† Worm-Muller, cited by Landois-Sterling. Human Physiology.

more oxygen when the pressure is increased to six atmospheres (*). Again, animals caused to breath pure oxygen, or what amounts to the same thing, air under increased pressure, use no more oxygen than when breathing ordinary air. Further, if the pressure is diminished, provided the oxygen pressure does not fall below 25 mm. of mercury, all the oxygen is absorbed that is required by the body. In other words, the oxygen absorbed appears to be dependent upon the amount used up by the tissues of the body, and not upon varying atmospheric pressures †.

It is believed that the inconveniences experienced by mountain climbers are due to circulatory disturbances resulting from diminished pressure, but not from the lack of oxygen.

While laboratory experiments appear to be against an acceptance of this nypothesis, it must be admitted that certain phenomenon seem to be in harmony with it. How else can we explain the increased lung capacity which we have treated in another paper ‡?

The writer is more inclined to the view, however, that on taking up a residence at higher altitudes, increased oxidation occurs in the tissues; but as the corpuscles are capable of carrying only a definite amount of oxygen (the union between oxygen and haemaglobin being a chemical one) more cells are required to meet the demand. When this demand becomes normal, the number of cells again falls to normal. That increased oxidation does occur is indicated by exhilaration, increased heart action, increased respiration, etc.

Another hypothesis is that of—

2. *Blood concentration caused by loss of moisture from the body, due to dryness of the mountain climates.* Although this would seem to afford a most natural explanation, it must be admitted that no facts have been adduced in support of it. It has been pointed out by Czernys § that increased blood density is usually accompanied by loss of

* Paul Bert, cited by Landois-Sterling. Human Physiology.
† Martin—The human Body. 7th rev. ed.
‡ See Bul. No. III. Hadley Clim. Lab. Observations on Lung Capacity, etc.
§ Archiv. f. exp. Pathologic u. Pharmak..Bd. 34.

body weight, since the blood takes up water from the tissues to establish an equilibrium; but, on the contrary, persons seeking high altitudes almost invariably gain in weight.

So far as our experiments bear upon this hypothesis, we do not find any marked tendency to blood concentration. It will be recalled that the specific gravities of human blood are substantially normal; that in the second lot of rabbits there was no alteration in specific gravity when the feed was not changed; and that in the first lot the specific gravities fell while the blood cells increased, the fall being due to a less concentrated diet. In view of these facts, it would seem that little doubt can remain as to the inadequacy of the concentration hypothesis.

3. *The cells may be longer lived.*—This has been suggested by Fick †. There is as yet no evidence to support this suggestion.

4. *Reduction in the size of the blood cells, their total weight remaining constant.*—This view has been advanced by Koeppe ‡ who claims that the total volume of all the corpuscles does not change, although the number of cells is increased. The volume of the cells was determined by the haematokrit.

In our experiments, the specific gravity determinations may have a bearing upon this point. The second lot of rabbits (Nos. 5, 6 and 7) showed no change of specific gravity, although there occured a considerable increase in red corpuscles. It will be recalled that the food was not changed when the animals were taken to a higher altitude.

The specific gravity of red corpuscles is given as 1105 (C. Schmidt) while that of plasma is 1027 (Hammersten). It is evident that an increase in red cells should give increased specific gravity, unless there were at the same time a corresponding decrease (or dilution) of the plasma. But it would also appear that increased dilution would result in a lower cell count. In other words, these two factors should neutralize each other. Manifestly, the two conditions do not accompany each other, and at the same time produce an increased cell count.

† Pflugers Archiv. Bd. 60. p. 589.
‡ Munchen. Med. Wochenschrift. 1890. No. 41.

If, however, we should assume that the red cells were diminished in size, it is evident that we might have an increased blood count while the specific gravity remained constant or even fell. Plainly, this may explain the increase in the cell count, but it cannot explain the subsequent decrease to normal, unless it should be found that the size of the cell again returns to normal.

In this connection we may note the curious fact that rabbits and most other rapid breathing animals have relatively small corpuscles, while slow breathers, as the turtles, show very large cells, man standing between the two. It has also been observed that increased altitude produces temporary increase in the respiration rate. It is barely possible that a connection may exist between this increased respiration and the size of the cells. It is suggested that smaller corpuscles would circulate more rapidly through the capillaries and hence complete their circuit in shorter time. In this way they would reach the capillaries of the lungs more often and a given number of small cells would furnish more oxygen to the system than a like number of larger ones. Should the demand for oxygen again decrease, due to decreased tissue change, then the number of cells might again fall off and return to normal.

It may be noted that this explanation is not antagonistic to the view already expressed, viz., that altitude probably results in increased oxidation of the tissues, for a time, and to furnish the necessary oxygen, both factors may take part.

The above has been put forward as a suggestion only. There are as yet too many unknown factors to permit its acceptance as an explanation for the phenomena observed. It need only be added that experiments are still in progress, which it is hoped will afford some light in solving this most intricate problem.

Unavoidable delays in the publication of this Volume have made it desirable to issue the articles separately as they may be printed.

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