HUMAN BLOOD PRESSURE AND PULSE AS AFFECTED BY ALTITUDE.

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THE pressure of the blood in the arteries of man has been made the subject of much speculation and study from early times; the force of our arterial blood current against our vessels both in health and disease offers an interesting and important symptom, and one that has been observed by the method of noting the pulse at the wrist for centuries. It is, however, only in recent years that careful and systemic study of the force of the blood in its circulation through the body has been undertaken. The finger on the radial artery at the wrist, while valuable, and in the hands of experienced men of much practical utility in determining diseased conditions or changes in blood pressure, is, after all, a crude and uncertain method, depending entirely upon the tactile sense of the observer, and while the number of beats per minute can be counted, and the volume of blood and the condition of the artery noted, it is a method only approximately exact; too much depends upon the factor of personal equation in the observer. Considerable advance was made when instruments were devised by which a needle was made to move by the impulse at each pulse beat of the artery, and a graphic record traced on a moving slip of paper. This method was also found to have its limitations, and in recording pressure of blood not always exact. A decided advance was made in the last few years in using several forms of apparatus depending upon the principle of mechanical constriction of limb, or finger, and using the pressure of the blood constricted in this manner to elevate some form of index, as a slender column of mercury in a graduated tube, or by a needle on a dial. In this manner the pressure can be taken in man without the errors of the older methods, and a standard established for a large number of human beings under different

conditions. With the use of these more recent instruments of precision it has been made possible for us to measure the force of the blood stream in certain diseases, and in health. Many peculiar effects are noted from the use of drugs, exercise, and mental disturbances on the delicate mechanism of the circulation.

It was, therefore, to take advantage of this comparatively new means of measuring the force of blood in the arteries, that some three years ago we decided to test the effect of the altitude in Colorado on the blood pressure in human beings. Some work had been done on this subject in Europe, but the reports differed in several essential points. In Mexico two observers also have made a report, but with only instruments of older date. As to the general impressions on this subject, it has been observed that as at a considerable height above the sea some individuals suffer from a feeling of fullness in the head, with hemorrhages from the nose, etc., the blood pressure at these elevations must be increased, and the serious symptoms occuring at altitude, such as rapid pulse, breathlessness, dizziness, and even fainting in otherwise healthy people, have been clearly shown a pronounced effect from altitude upon the circulatory apparatus in human beings. What effect this was on the actual tension of the blood was more or less a disputed point. This is, however, a point of some importance—to definitely determine the effect of altitude upon the heart and blood vessels, and it has seemed to us well worth the effort. There are in the United States at present a number of cities at a considerable elevation. We have a large and rapidly growing population in our Western States on both sides of the Rocky Mountain ranges that live under an air pressure on their bodies of 20% less than that air pressure would be at the sea level, or about 24 inches of mercury Bar. Pressure as compared to 30 at sea level. Such a difference represents about three pounds to each square inch of the human body. Although it is true that in mose cases the effect of this difference in surface pressure is met promptly and effectively by the wonderful adaptation of our nervous and circulatory mechanism, even when the change is made with some rapidity, so that the physiological disturbance is slight or absent, it is well known that there are cases that do not adapt themselves so readily, and some that never do, while in certain diseases affecting the heart, this diminished pressure is apt to prove a dangerous factor.

Exactly how such effects are produced from the altitude of

our elevated regions has not been satisfactorily explained. Any light on this obscure subject cannot fail to be of value, as it would tend in time to place the study of altitude effects upon a definite scientific foundation, and what is of more importance, enable the physician to deal with such effects during disease, in an intelligent manner.

It was therefore with this aim in view that we began a series of investigations in blood pressure in Colorado. We selected only healthy individuals to experiment with, as it was first necessary to establish a normal mean pressure for altitude, as has been done at sea level, and not pressure subject to the irregularities or fluctuations produced by diseased conditions, however slight. We were fortunate in having unusual opportunities for this series of investigations. We were in a city of 30,000 inhabitants, at an elevation of 6,000 feet above the sea. A well equipped scientific laboratory in the new science building of Colorado College was, by the kindness of President Slocum, placed at our disposal, while the Professor of Physics, John Cutler Shedd, Ph.D., and of Biology, Professor Edward C. Schnieder, Ph.D., gave us every aid in their power. Among the college students we could choose any number for experiment, and they kindly offered their services at any time. Five miles away by electric cars the Pike's Peak Railroad took us easily and without exercise to the summit of Pike's Peak, 14,000 feet altitude, while on the summit a stone building offered us all the advantages as a shelter from cold or wind, so necessary in conducting delicate scientific experiments. The technique was as follows:

The instruments used were two Riva Rocci with 5 c.c. cuffs, a new Janeway with a 12 c.c. cuff, and an instrument modified from the Janeway with a 12 c.c. cuff. The individual examined was at rest in a sitting position, cuff on left arm, all muscles relaxed and all disturbing factors eliminated. Measurements were made several times in each case and by four observers with three instruments, to obviate personal differences in technique. The average in these measurements was then taken as the result for that case, also each case was measured on several occasions, during several days. The time of day was noted to obviate diurnal variations. By this care we feel reasonably sure of our normal mean pressure in each case.

The pulse rate was taken with the same detail. We divided the work into groups.

Group No. 1.

Average pulse and blood pressure in men and women of all ages, resident at 6,000 feet altitude for over one year.

In averaging a large number of individuals we came to the conclusion that as a rule blood pressure was slightly lower than that given as the normal at sea level, while the pulse rate did not show the increased rapidity said to be present in altitude dwellers.

Group No. 2.

Average pulse and blood pressure in men who had lived at 6,000 feet altitude for over twenty-five years.

Fifty males were now measured who had lived at least 25 years at 6,000 feet altitude, and a number 30, in two cases 44 years. We found in these cases that, considering age, the blood pressure was certainly lower than that given for sea level (2) while the pulse was normal. Evidently prolonged residence at 6,000 feet altitude had not increased the blood pressure in these individuals; but caution should be used in taking too much, as proved from our work in this group of experiments. These individuals possibly represent a survival, not only from death of a certain number during the 25 or more years, but from the fact that at this altitude any disease of heart or arteries is very likely to cause the patient at once to seek a different and generally less elevated climate, leaving survivors who represent a special class, and our observations were on this special class.

Group No. 3.

Effect of muscular exertion upon college men.

We now turned our attention to Group No. 3. First determining the normal blood pressure, we then had our men exercise violently at football, running, etc., etc. The result differed very little from similar experiments conducted near sea level. Pressure was, as usual, increased by muscular work at first and at last returned to normal.

Group No. 4.

Effect upon blood pressure and pulse upon 22 men and women taken from 6,000 to 14,000 feet.

The individuals comprising this group were tested a number of times and their average pulse and blood pressure estimated

at 6,000 feet. They were then taken up to 14,000 feet on the Pike's Peak Railroad in a private car without any muscular exertion, were measured while in the car on the summit, and again after three and one-half hours at 14,000 feet. Some returned sooner to 6,000 feet, and all were again tested on their return to 6,000 feet to note any possible effects of the change in altitude. While work on this group was interesting and showed some peculiar phases of blood and blood pressure due to changes in altitude, we did not feel that our results were as accurate, or our averages as scientific as we had determined to have them. The personal element as a factor entered too largely into the calculations, while the marked differences in age, occupation and mental disturbances were not, in our opinion, sufficiently guarded against. We therefore for another year perfected ourselves in technique and tested a large number of people under different conditions, and in June, 1904, we felt we could venture on some reliable work.

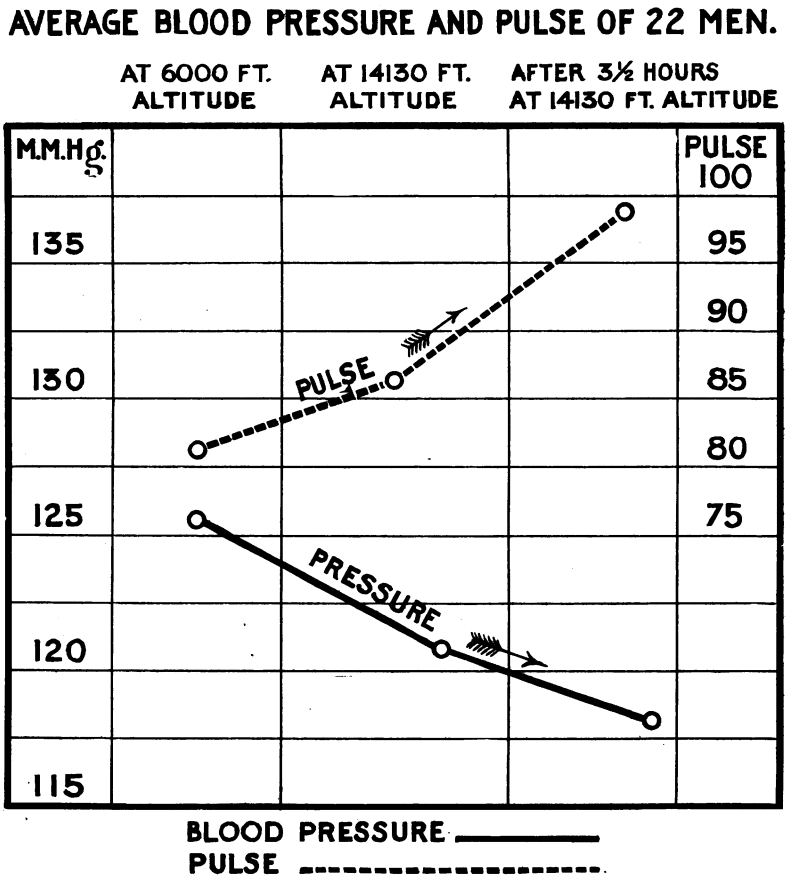
Group No. 5.

Effect upon pulse and blood pressure in 22 college men, taken from 6,000 to 14,000 feet, and the effect of three and one-half hours at 14,000 feet.

We selected 22 students from Colorado College of nearly the same age and occupation, and for some weeks in the Science Laboratory estimated their individual and average pulse and blood pressure. Our normal pressure obtained in this way we compared with the work of O. Z. Stephens, M.D., of Chicago, Ill., on 22 college men. We found that our group at 6,000 feet altitude had a lower blood pressure and a slower pulse rate, blood pressure average being 126 mm. at 6,000 feet, 130 mm. at sea level; pulse at 6,000 feet 80, at sea level 82. The men were now taken by special engine and private car to the summit of Pike's Peak, and on arrival were taken to a room in the hotel; all excitement and exertion were thus avoided. They were then tested, using same technique as employed in the laboratory at 6,000 feet. Results showed an average pulse of 86 and blood pressure of 121, a gain in pulse rate of 5 and a reduction of blood pressure of 5 mm.

After three and one-half hours at 14,000 feet, the men were again examined. The pulse rate had now gone up to 99 per minute, and the blood pressure fallen to 118 mm. Some exercise,

such as walking, had, however, been taken by all the individuals of this group during the three and one-half hours at 14,000 feet altitude and should be remembered in estimating results in this series. No doubt an equilibrium is established in time and the



pulse rate and blood pressure return more nearly to a normal standard. How long this takes probably varies in different individuals. From examination of some employes at the summit who had lived at 14,000 feet altitude for two months, we judge this equilibrium does not take more than a few days, but that the

tension after compensation has taken place is always lower than the tension of that individual would be at sea level or at a lower altitude, in almost all cases.

The men were examined during several days after their return from this trip and nothing unusual was noted.

The full significance of this fall in blood pressure due to altitude, in young, healthy adults, we cannot at present estimate. It is a complex subject and requires more detailed study from many points of observation. It is, however, interesting to note the difference between the position of the body as affecting blood pressure, and the effect of altitude. If the body is placed in the prone position, the heart beats more slowly, while the blood pressure is increased. In ascending to a high altitude, the heart beats faster and the blood pressure is lowered.

We found a rough ratio between pulse rate and blood pressure: the more rapid the pulse the lower the blood pressure. It was also noted that when a pulse rate was but little affected by an altitude of 14,000 feet, that the blood pressure was also more constant; that cases of mountain sickness were accompanied by a fall in blood pressure and a rapid pulse rate.

From this work upon the pulse and blood pressure we feel justified in offering the following suggestions: Although we found the average pressure of the blood was not lowered more than from 8 to 10 mm. of Hg. in a diminished atmospheric pressure of 8,000 feet altitude, and that this change in pressure in the blood is a small one in healthy young adults, it can easily be seen that such a change from the normal, continued for a considerable time, especially in many diseased conditions, would be a positive and possibly a serious interference with the mechanism of the human circulation, an interference that under given conditions might be a strong influence either for good or ill.

In cases where (due to changes in the heart muscle) the blood tension is abnormally lowered, a further reduction would be dangerous, and in such cases, taking the tension at sea level, one could possibly determine the danger of the effect of altitude in further lowering it; while in other cases, as in some forms of aneurisms, with high tension, and in some forms of valvular diseases of the heart, the effect of altitude would be decidedly beneficial, and such cases have, indeed, come under the observation of the writers. It must, however, be remembered that the effect of altitude upon the circulation of the blood in human beings is at

best a complex subject. We know that in healthy persons the arterial pressure in the main blood vessels is lowered in response to the diminished atmospheric pressure upon the body, as the elevation above the sea is increased, but we know very little as yet as to the effect of diminished atmospheric pressure upon the venous system. It is highly probable that the right side of the heart and venous system play a more important part in the phenomena of altitude effects than we are at present in a position to verify. The smaller, or capillary blood vessels, on the surface of the body, and on exposed mucous membranes, are enlarged when atmospheric pressure is diminished, and this is seen by examination of the blood, and by bleeding from mucous surfaces. As to a resulting lowering of pressure in the capillaries of internal organs due to the external hyperemia, we as yet know nothing positively, and it is by the further study of the pressure in the venous system that altitude effects upon human circulation will yield the mose valuable results in the future.

We want to acknowledge with many thanks the kindness of Professor Slocum for the use of the Science Building of Colorado College, and of Professor Snyder, Dr. Dennis, and Dr. Scully for valuable assistance, and of Mr. Sells of the P. P. R. R. for many courtesies extended, and of all who kindly submitted to being tested.

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DISCUSSION.

DR. SEWALL: This question has interested me for a long time, and I think it is of extraordinary importance. I do not think the question of the small amount of depression of arterial blood pressure makes the matter insignificant. The heart is affected very materially in its most serious aspects by very small events. And it is very easy for us to make grave errors in *a priori* reasoning from the arterial blood pressure if we forget that there are two kinds of blood pressure, there is an arterial blood pressure and a venous blood pressure. When the arterial pressure diminishes it is either by marked weakness or by opening of the capillary resistance; by raising the capillary resistance the venous pressure must be raised.

DR. JENNINGS: I would like to ask the doctor what effect the high altitude has upon aortic insufficiency, with fair or good compensation?

PRESIDENT PHILLIPS: I would like to ask Dr. Gardiner if he has examined the work by Oliver on Blood Pressure. I notice the results which Dr. Gardiner has obtained are diametrically opposed to those given by Oliver, who says that altitude increases the arterial blood pressure, and markedly so. Another case of further investigation.

DR. JACOBI: I simply wanted to ask a similar question put by Dr. Jennings on aortic stenosis, and what diseases can be benefited there.

DR. GARDINER: In regard to Oliver's work, I understand he uses a bag filled with fluid pressing upon an artery. This is very apt to give erroneous results, and is not trustworthy in altitude work.

I am not prepared to discuss effects of altitude upon heart disease, as so far we have simply observed and recorded effects of altitude upon healthy hearts. I do know that in two cases of advanced heart disease, with lost compensation and oedema, great benefit was obtained at an altitude of from 6,000 to 8,000 feet after sea level pressure had been tried for eight months, and the patient while at sea level had grown very much worse. But we do not know enough about the physics of the question yet, and it will take long and patient study to determine the exact truth.

DR. JACOBI: Do I understand Dr. Gardiner to say that only valvular disease will be benefited? We would like to know what cases to send there. Has the Doctor nothing to recommend?

DR. GARDINER: At present we cannot afford to be dogmatic; we have more to learn. Some cases are certainly benefited—why, we do not know. I would like to hear from Dr. Babcock, who has written more on this subject than any one else present so far as I know.

DR. BABCOCK: It seems to me that the difference in blood pressure is so slight, that on that fact alone I can hardly see any explanation of benefit or the reverse that might accrue. It seems to me we cannot lose sight of the increased depth and vigor of respiration in its effect on cases, so that there are certain problems connected with it that ought to be worked out. I should think, theoretically, a case of compensated aortic

regurgitation ought to be favorably affected, since any condition which would lessen peripheral resistance, as could be done by decreased arterial tension, ought to have a favorable effect. As pointed out by Dr. Sewall in the New York meeting, one of my patients with mitral stenosis that came to him did not seem to be benefited.

DR. SEWALL: At altitude it is the right side of the heart that we must consider, as it is here the strain of compensation occurs in lessened pressure. I consider it is in such work, reported by Dr. Gardiner, that the true scientific knowledge will come to light.

DR. GARDINER: I have nothing to add. We are simply pursuing our work, as in any scientific investigation, to see what results we can obtain. It is a most complex subject, and one that can be easily misunderstood; possibly it will be years before the exact relations between diseased conditions and blood pressure is known.