Blood-Pressure

AND

Tissue-Lymph Circulation

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With the author's compliments

A CONTRIBUTION TO PHYSIOLOGICAL MEDICINE

BEING

An address delivered before the British Balneological and Climatological Society on May 21st, 1903

AND

A Preliminary Communication on the measurement of tissue-lymph in man read before the Royal Society, June 11th, 1903, with additions and illustrations

BY

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An Address

ON

BLOOD-PRESSURE.

MR. PRESIDENT AND GENTLEMEN,—Two years ago it was intimated to me that this Society wished to do me the honour of calling me to its presidential chair. Inasmuch as circumstances prevented me from accepting that honour, I have since been haunted by a desire to indicate in some way my appreciation of your goodness to me; consequently, I have been casting about for some suitable avenue in which to express it. Therefore, I gladly embrace the present opportunity of addressing you—an opportunity for which I am indebted to you, Mr. President, and to the Council of the Society.

The physician practising at a health resort may be regarded as a specialist in chronic ailments; for by far the larger number of his patients have been out of health for periods of varying length. Now chronic ailments are generally the outcome of some long operating cause or causes—hereditary or individual—and the material which they furnish for his daily thought and work induces the physician to cultivate a trustful study of, and reliance on, physiology as the guiding star of his practice. He endeavours to make his knowledge of physiology a living power in his daily work; he therefore adopts as far as possible methods of physiological observation in gauging and treating pathological deviations from the normal. He is alert to turn to practical ends the results of laboratory work which are apt to remain sterile ; and thus he endeavours to enrich the practice of his art. In a word, his aim is to become a practical physiologist, and something more. But we all know how difficult it is to attain to such a high ideal as this ; for the exigencies of professional life tend rather to disintegrate the scientific spirit and to afford a somewhat insecure footing to the exact methods of science. As, however, medicine is moving forwards, she is happily adopting a closer walk with physiology ; and her votaries are growing keen to appropriate any bit of physiological lore that may first be tested as a working fact, and which, when proved to be a truth, will in due time be deftly fitted into the future edifice of physiological medicine. One of the far-reaching branches of physiology which has of late years been pressed into the service of medicine is the study of blood-pressure and of the distribution of the blood. I propose to glance at a few sections of this interesting chapter of physiological medicine which have more particularly engaged my attention during the past year or two, and which may be of interest to some of you as practitioners in balneology and climatology. But in submitting my jottings to your consideration, I must crave your indulgence in allowing me to draw exclusively on the data which I have myself collected ; and if I refer but sparingly to the work of others, it is not because I do not duly appreciate it. We are all fellow-workers in the good cause of endeavouring to advance our efficiency as practitioners of the healing art, and it is the duty of each one to contribute his mite to the common store.

Normal Blood-pressure.

The first requisite for the clinical study of blood-pressure is a knowledge of the normal blood-pressure ; for that is, of course, the standard to which clinical deviations should be referred. It is well recognised that in healthy subjects it is liable to very appreciable variations above and below a certain mean, and these extremes of normal fluctuation should be familiar to the practitioner. They are due to such physiological conditions as the ingestion of food, exercise and temperature. I have taken the opportunity afforded by the past winter's rest from clinical work, to study afresh these normal fluctuations of the circulation ; and I will now sketch an outline of the results. It may appear to you to be somewhat of a reversion now-a-days to re-examine some of the elementary facts in our studies of blood-pressure ; but I think you will agree with me that the best possible assurance we can have of our advancing securely in a somewhat untrodden field like this, is to retrace our steps occasionally and to re-test the safety and soundness of the track. In so doing we may verify or correct our position, and we may perchance pick up a few fragments of truth which before we passed by unheeded.

For the most part, the observations on the arterial pressure were made with the hæmodynamometer ; but Hill and Barnard's sphygmometer and Gärtner's tonometer were likewise occasionally used.

I have elsewhere* shown how delicate readings of the arterial pressure may be read for physiological purposes by the blood-pressure gauge. A small artery (like the superficialis volæ) is selected, and the pulsation of the indicator is gradually developed — by gently increasing the pressure on the water pad—to its maximum degree, when the reading should be made, it will then be found that beyond this point the motion at once diminishes. With a little practice differences of even 1 or 2 mm. Hg. may be reliably read. I have found it useful to use rubber covers,† which can be placed over the pad so that the motion of the radial pulsation can be limited to a similar minimum range. This arrangement makes the reading of the arterial pressure taken from the

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* See " Blood and Blood-pressure," 1901.

† Made by Mr. Hawksley, 357, Oxford Street, London, W.

radial artery more precise, and prevents a secondary rebound of the indicator, apt to be produced in some cases when a high pressure is applied to the pad, which may lead an observer to infer that the arterial pressure is higher than it is.

THE INFLUENCE OF DIGESTION ON THE CIRCULATION.

During the past winter I have been much interested in the effects which the ingestion of food produces on the circulation. I had previously worked on this subject, and the results of the observations then made, and published in 1901, were confirmed; but this more thorough and more critical inquiry has revealed an extension of these results. It has shown that the ingestion of food initiates a most interesting

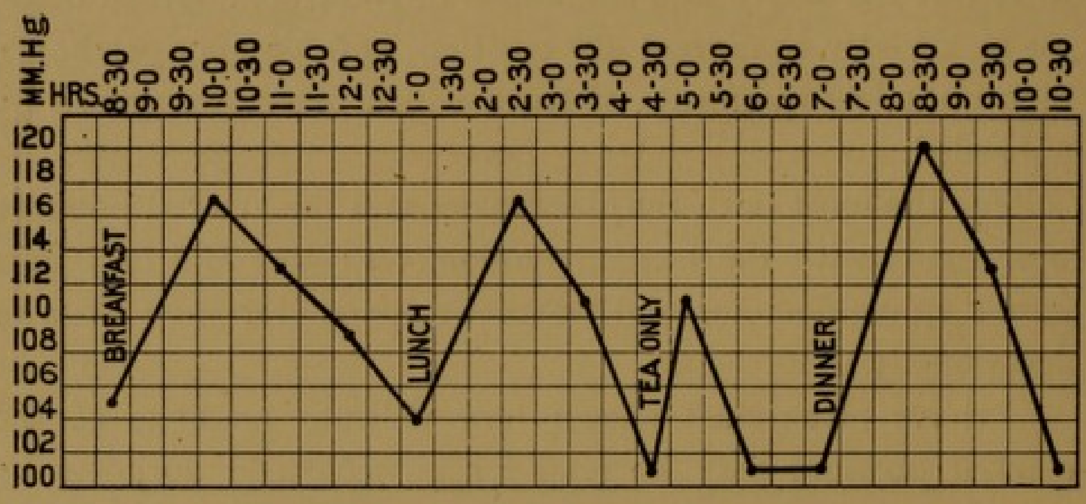

FIG. 1.—Hourly Observations of Mean Arterial Pressure.

series of circulatory events which recur with perfect regularity after every meal. The observations have proved that the influence exerted by the act of digestion on the circulation is not a mere transitory one, which may pass away, for example, within half an hour or so after a meal—it is a much more prolonged physiological disturbance, which can be traced for fully three or four hours.

I will first describe the effect of digestion on the arterial pressure, then on the capillary and venous pressures.

In fig. 1 are recorded hourly observations on the mean arterial pressure throughout the day from 8.30 a.m. to 10.30 p.m., in a subject leading an ordinary quiescent life with comparative rest of the muscles. You observe that the pressure follows a rhythmical course, that there is a marked rise immediately after each meal, which attains its maximum development in an hour, and then the pressure slowly subsides. This wave-like rise and fall of the arterial pressure produced by each meal lasts from two and a half to four hours. I have observed that the amplitude and length of the curve are, as a rule, proportionate to the size of the meal. The observations show that the average maximum rise of the mean arterial pressure attained in an hour after a meal amounts to 15 mm. Hg., though it may reach 20 mm. Hg.; for example, a typically normal blood-pressure wave should rise from 100 to 115, and then gradually return to 100 mm. Hg.

Now, you will naturally ask, why should we have a rise in the arterial pressure after meals, when dilatation of the splanchnic arterioles should make for a lowering of that pressure? Observation with the arteriometer shows that the arterial calibre is slightly lessened when the splanchnic diversion takes place. There is, therefore, apparently a compensatory reduction of the systemic area of the circulation; and the increased tonus of the arteries is one factor in raising the arterial blood-pressure, the other being cardiac —an increase in the output of the ventricle and stimulation of ventricular contraction.

These digestive waves are also present when the arterial pressure is above the normal range. In determining the arterial pressure in clinical work, a correction for the influence of digestion on the mean arterial pressure may be usefully made by applying the following rule: To deduct from a pressure observed in the first hour after a meal 15 mm. Hg., in the second hour 10 mm. Hg., and in the third hour 5 mm. Hg.

The best time to make a reliable observation of the mean arterial pressure is within an hour before a meal.

The study of the capillary and venous blood-pressures during the digestive circulatory wave has likewise afforded some interesting results. The venous blood-pressure is easily determined by a method of using the hæmodynamometer elsewhere described *; but so far no reliable method for gauging the capillary blood-pressure has been suggested. I have, however, employed a method which is simple and practical; but as I hope to improve it I will not describe it. This method has so far shown that the capillary blood-pressure is considerably raised at the acme of the digestive circulatory wave, and that it then gradually falls during the decline of the disturbance. The rise and fall of the capillary blood-pressure, therefore, coincide with those of the arterial blood-pressure. The venous blood-pressure, on the other hand, falls during the full development of the digestive circulatory wave; sometimes, however, it falls immediately after the meal (A, fig. 2), but more generally it rises a little at first, concurrently with the increase of the arterial and capillary pressures, and then it falls (B, fig. 2), or it merely remains stationary, failing to rise with the other pressures (C, fig. 2). But in all cases the venous pressure rises rather suddenly after the acme of the circulatory disturbance is attained, and then it reads much higher than before the meal, and again concurs with the capillary pressure. Fig. 2 illustrates the behaviour of the three blood-pressures after a meal. Now were the capillary pressure to subside with the venous pressure, we should infer that this concurrent fall of these blood-pressures was caused by contraction of the arterioles; and in clinical observation equally low readings of them, along with an increase of the arterial pressure, furnish good evidence of the predominance of arteriolar resistance. But the rise in the capillary pressure excludes this cause, and this rise together with the diminished venous pressure suggest an increase of resistance beyond the capillaries. We know that the venules and veins are endowed with muscular fibres, so that these vessels can offer a varying resistance to the onflow of blood from the capillaries. It is

* See *Journal of Physiology*, Cambridge and London, 1898, and "Blood and Blood-pressure," 1901.

true that these fibres are somewhat less abundant than in the arterioles and in the small arteries ; but inasmuch as the capillary pressure is normally low, it is not necessary that the venules should be provided with so large an amount of muscular tissue as the arterioles, which have to resist the arterial blood-pressure, and have thus to shield the capillaries from that high pressure. These muscular fibres of the

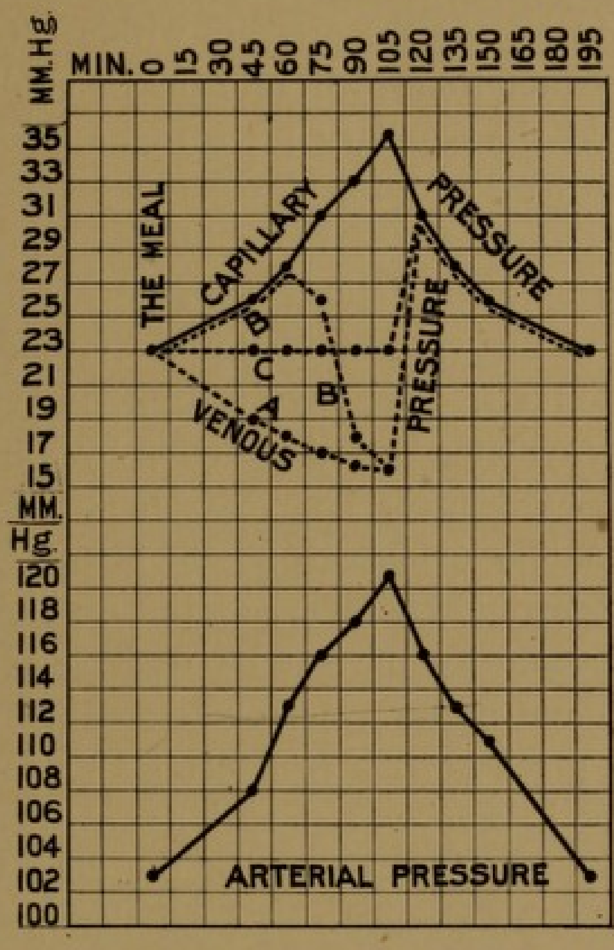

FIG. 2.—Diagram illustrating Concurrent Observations of the Mean Arterial Pressure, the Capillary and Venous Pressures every Fifteen Minutes after a Meal.

venules must surely serve some purpose in the economy of the circulation ; but regarding it physiology has hitherto remained silent. The foregoing observations, however, suggest that during the digestive disturbance of the circulation, the venules play an important part in regulating the capillary blood-pressure ; at one time, as at the acme of the disturbance, contracting and so increasing that pressure, and then relaxing and letting it down. I have, however, observed that contraction of the venules only comes into play when the body is at rest, for it is overcome during exercise, which raises both the venous and capillary pressures together, though it may reassert itself when the exercise ceases. I have just lately discovered that my friend Sir Lauder Brunton, so long ago as in 1879, when writing on the contractility of the veins, anticipated this function of the venules. "It is obvious that, if venous radicles contract, they may oppose a resistance to the flow of blood in the capillaries, and by thus increasing the pressure within them, may cause more fluid to exude from them into the tissues."*

Why should the capillary pressure be raised during the digestive disturbance of the circulation? As suggested by Sir Lauder Brunton, a rise in capillary blood-pressure may cause an increased exudation of tissue fluid. The experimental work of Ludwig and Noll,† of Starling,‡ of Lazarus Barlow,§ and others, undoubtedly supports this view; and following a new method of observation by which the tissue-lymph may be measured, I have been fortunate enough to obtain confirmatory evidence of it in man. May not these periodically recurring variations of the capillary blood-pressure which accompany the act of digestion be of supreme importance in nutrition? Moreover, do they not afford us a glimpse of a much broader fact than is signified by the mere act of digestion? For when food is taken there is, it would seem, not only the internal flow of the digestive secretions, but there is likewise a concurrent exudation into every tissue of nourishing fluid expressed from the blood into the interstitial spaces. Should further inquiry substantiate this view, the physiological significance of the prolonged rhythmical movement in the circulation produced by the ingestion of food will be apparent.

In reading quite lately Professor Paulow's lectures on the

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* "Collected Papers on the Circulation and Respiration,' by Sir Lauder Brunton, F.R.S., 1903, p. 537.

† *Zeitschrift f. rat. Med.*, 1850, Bd. ix., S. 52.

‡ *Journal of Physiology*, Cambridge and London, vol. xvii.

§ *Journal of Physiology*, Cambridge and London, vol. xvi work of the digestive glands,* I could not avoid observing the similarity of the form and duration of his curve of the secretion of gastric juice in the dog after a meal, with the curves of arterial blood pressure incited by digestion in man—as if both were concurrent events, which proceeded from the same physiological movement in the system; the maximum secretion, like the acme of the digestive wave, being attained in an hour; and then the gradual subsidence of both occupying some three or four hours. For the purpose of comparison I have reproduced one of Paulow's gastric juice curves in fig. 3.

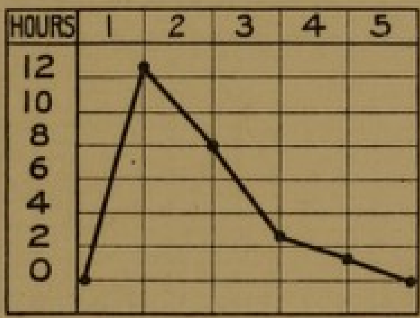

FIG. 3.—Curve of Secretion of Gastric Juice after a Meal of Flesh. After Paulow.

I have observed that the beverages, tea and coffee, produce a similar rhythmical disturbance of the circulation to that which follows the ordinary meals; it is, however, less pronounced and shorter (see fig. 1).

THE INFLUENCE OF EXERCISE ON BLOOD-PRESSURE.

It is now well known that the primary effect of exercise is to raise the arterial pressure, but I do not think it is as generally recognised as it should be, that this immediate rise of pressure is but temporary, and is soon succeeded by a marked fall, which fall persists during the further continuance of the exercise and for some time after the cessation of it. The peripheral tubing very soon widens, and the rise is thus converted into a fall. Fig. 4 illustrates how quickly and how effectually the mean arterial pressure may be lowered

* "The Work of the Digestive Glands." Lectures by Professor J. P. Paulow. Translated into English by W. H. Thompson, M.D. &c., 1902.

by merely throwing the muscles of the limbs and trunk into a state of contraction for short intervals. You observe two deep indentations in the curve of the digestive wave; they are the impressions made on the normal course of that curve, produced by throwing the muscles into a state of sustained tension for two minutes. In spite of these interruptions the digestive wave of blood-pressure continues its course, and ultimately subsides in a normal manner. The effect is therefore only temporary; but it is instructive in showing how

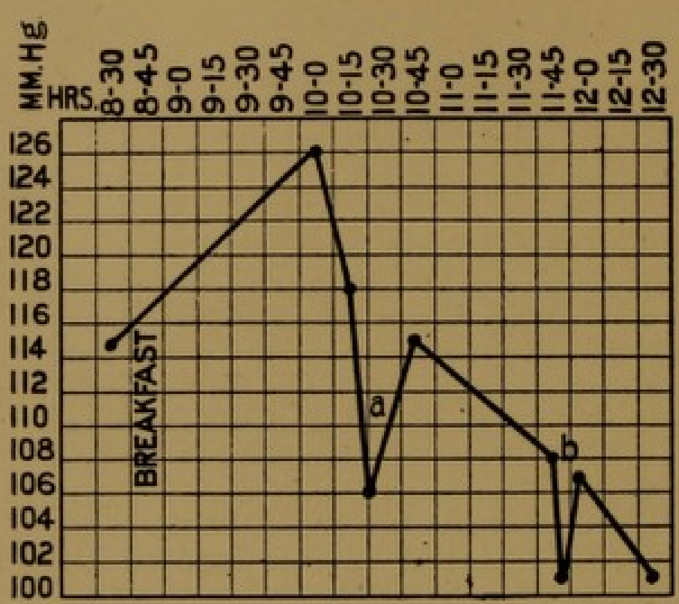

FIG. 4.—The effect of two minutes' Static Contraction of the Muscles (a and b) on the Digestive Curve of the Mean Arterial Pressure.

great is the power of muscular contraction in lowering the arterial blood-pressure. This is the fundamental fact in resistance exercises. But this fall in the arterial pressure is but a portion of the physiological fact we are now studying; it is simply the result of the widening of the arterioles produced by the muscular contraction—a fact which is proved by the rapid, though transitory, concurrent rise in the capillary and venous blood-pressures. It therefore follows that mere static muscular contraction lets down, as it were, a large volume of arterial blood into the capillaries, and in this way brings more oxygen within reach of the tissues, and thus raises the metabolic processes. But it may do more than this; for, by raising the capillary pressure, it may greatly accelerate and increase the flow of interstitial fluid filtered from the blood into the vacuoles of the tissues, and may thus flush these spaces and favour the clearing away of residua from them. From the clinical standpoint such effects as these produced by mere muscular contraction should prove useful in the treatment of diseases of the suboxidation type, in which the removal of waste products is imperfect, as in chronic goutiness. Static contraction of the muscles produces all the physiological effects of exercises on the periphery of the circulation, thereby easing the unloading of the ventricle, without increasing the work of the heart, as ordinary exercise does.

A large group of our cases at a health resort have as a prominent feature of their circulatory disturbances a hypertonic* state of their arteries and arterioles, and in a large majority of these cases the mean arterial pressure is considerably raised. In some such cases both the capillary and venous pressures are lowered together—showing the preponderance of arteriolar contraction; while in others the capillary pressure is raised along with the arterial, while the venous pressure is lessened—indicating the predominance of venular contraction. Now in such cases the pulse is generally *felt* to be small, and is often reported as feeble, and the hands and fingers are apt to be clammy and cold, and sometimes they may even afford a cold, fish-like impression to the touch. The unguarded physician is apt to regard these signs as indicating a feeble heart and a weak circulation, and when he places his hand over the apex and finds it displaced outwardly he is confirmed in that view. In many such cases the heart muscle remains unaffected; but in nearly all, the second aortic sound is markedly accentuated. In nine out of ten such cases the trouble originates in the periphery of the circulation. The physiological tonus of the arteries, arterioles and venules have passed the normal bounds and

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* The appropriate term "arterial hypertonus" was first employed by Dr. Wm. Russell (*Lancet*, June 1, 1901, p. 1519).

become pathological. There is, in fact, a persistent hypertonic condition which often threatens to overmaster the ventricle. The embarrassment is peripheral, and the bravely acting heart muscle is apt in time to yield, and, indeed, does very frequently yield, and then there is established a new centre from which a fresh series of pathological deviations emanate. In a large majority of such cases the physiological measures applied at a well-equipped balneological resort will rectify the disordered peripheral mechanism, and then the blood-pressures (arterial, capillary and venous) either approximate to their normal relationship to one another, or they become normal. After the course of treatment, it is a matter of some importance to suggest such simple methods of preventive management as may be easily followed up at home, so that the benefit acquired from the visit may be maintained. Among other measures designed to this end, I have found static or tension exercises of considerable value. At first the duration of the sustained tension of the muscles should be brief—so as not to be irksome—and as time goes on it should be lengthened. The exercises should be practised perseveringly at all odd times and seasons, but especially during the hour before every meal—this being the time when Nature herself produces a normal fall in the arterial blood-pressure. It is interesting to find how such exercises will frequently warm the extremities. One patient (a doctor) volunteered the remark that in his case the effect resembled that of a dose of nitro-glycerine ; and that reminds me that Brunton and Tunnicliffe suggested in a recent article that muscular contraction may produce some product which possesses the property of dilating blood-vessels.*

It is apparent that the ultimate physiological effect of muscular contraction on the circulation is much the same as that induced by warmth, namely, a widening of the peripheral channels and a consequent easing of the work of the heart and a proportionate lowering of the arterial pres-

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* See *British Med. Journal*, October 16, 1897.

sure. But beyond this result, common to both, there is a difference between the therapeutic effect of warmth and that of exercise; for heat merely relaxes muscular fibre, while exercise—even though tiring at the time—is followed by improved tone and vigour. It seems to me that physiology has a promising suggestion to offer to account for this difference; for Ranke showed that whenever muscles contract they absorb water from the blood: now, that water is proteid-containing water, which, after serving the immediate needs demanded by the contraction, may provide for repair and construction. So that we may say that exercise, like heat, expands the contracted peripheral mechanism, and thus reduces the consequent increased arterial blood-pressure, but does more than heat in providing for repair.

It is an easy matter for you to test this lowering effect of muscular tension on the blood-pressure during the course of your examination of a case. I have frequently done so. Of course you must see that the patient preserves quiet and regular breathing when he throws the muscles into static contraction. You will not uncommonly observe, when the arterial pressure is raised, while the venous pressure is lowered, that after a minute's, or even after half a minute's, muscular tension the former will fall 20 or even 30 mm. Hg., and the latter will be doubled.

The Influence of Temperature on Blood-Pressure.

We now come to the third leading cause of variation in the blood-pressure, namely, temperature. We are all familiar with the contracting influence of a fall of temperature on the walls of the blood-vessels with rise in blood-pressure, and the relaxing effect of warmth with lowering of that pressure; but few of us, I think, quite realise how powerful is the influence of changing temperature, not only on the systemic blood-pressure, but on all the physiological processes governed by that pressure. With the view of obtaining some evidence bearing on this point, I registered daily at 8.30 every morning for over three months during last winter, the mean arterial pressure, and some other physiological data, as well as the temperature as recorded in Stevenson's screen and in the room. Though these observations on the circulation were made in the house and before experiencing the influence of the outside air, the record obtained was certainly instructive ; for it showed that the circulatory mechanism is very sensitive to thermic variations in the weather. The record is, of course, too long to quote in detail. Suffice it to say, that the average reading of the mean arterial pressure was 120 mm. Hg. for all the screen temperatures below 36° F., and 107 mm. Hg. for all those above that temperature.

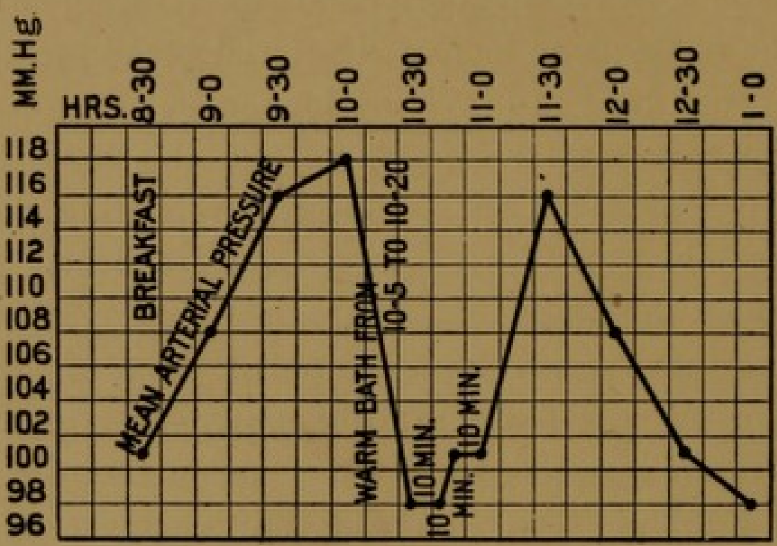

FIG. 5.—The Effect of a Warm Bath on the Digestive Curve of Mean Arterial Pressure.

Such striking effects being traceable in a normal subject, we gain some notion of the disturbing influence of thermic changes of the weather on many of our sensitive patients. Thus it may be that "cold snaps" (as they are popularly called) may throw as much additional strain on a yielding ventricle—even though the patient be quiescent—as might result from an uphill walk. Surely our patients suffering from arterial hypertonus need quite as much the protecting influence of an equable winter and spring as do our bronchitic invalids.

Fig. 5 shows the effect of a warm bath (temp. 100° F.) on the mean arterial pressure taken a little over an hour after a meal. You observe how deeply it indents the normal course of the digestive wave of blood-pressure. The influence of warmth quickly passes off, as in this example. It is, nevertheless, a great power when judiciously directed in balneological practice. It acquires its force as a curative agent by repetition, as in a course of baths. My physiological observations have suggested that in certain cases the beneficial influence of warm immersion bathing may be enhanced by directing the patient to throw the muscles into a state of tension for short intervals during the immersion. In this way the dilating effect on the periphery of the circulation is increased, and the warm bathing becomes less relaxing. I have also found it useful to direct those patients who suffer unduly from the exhausting effects of warm immersion baths to contract the abdominal muscles frequently, so as to reduce the abdominal stasis which warmth encourages. Massage, and especially abdominal massage, is also a valuable addition to the warm immersion bath.

To return from this slight digression. Cold may raise the line of the digestive curve on the blood-pressure scale so that the commencement and the finish may read from 5 to 10 mm. higher than the strict normal (100), and warmth may lower these points 2 or 3 mm. These figures furnish somewhat of a guide to the clinical correction for the effects of temperature on the arterial pressure.

It will be recognised from this sketch of the respective parts taken by these three leading causes of variation in the arterial pressure—digestion, exercise, and temperature—that the influence of digestion is paramount and constant; for the long curves of rise and fall produced by the meals recur with perfect regularity, and persist beyond the temporary variations of the blood-pressure produced by muscular action and by temperature, which, therefore, modify the line of these curves in a mere transitory way.

The Influence of Altitude on the Blood-pressure.

In the winter of 1899-1900 I made some observations at Arosa (5,900 ft.) in Switzerland on the mean arterial pressure with the view of ascertaining the effect of altitude upon it. These observations led me to conclude that in the winter months the blood-pressure is raised in high altitudes. Inasmuch as intensely cold weather prevailed during the visit, I could not on that account regard my observations as altogether conclusive; especially, too, as other observers were led to believe that altitude lowered the blood-pressure. Summer is undoubtedly a more suitable period of the year for observations of this kind than winter; for then there is less liability to encounter the disturbing influence of a low temperature. Unfortunately for myself, I can only make any such observations in the winter: still, even then they may prove instructive; for, if it be a fact that altitude does lower the blood pressure, and if that lowering influence is apparent in the cold months, it should on this account be all the more readily accepted.

Having, last January and February, five or six weeks at my disposal, I spent them in Switzerland, where I made a large number of observations at different altitudes, and at some (Châteaux d'Oex, St. Moritz, Zurich, Klosters, and Süs) the blood-pressure was taken at different times. At Château d'Oex (3,498 ft.) and at St. Moritz (6,100 ft.) serial observations were made at 8.30 every morning in a warm room, and a number of digestive waves were recorded, and the effects of exercise on the blood-pressures at these altitudes were also determined. Having previous to the visit made a large number of observations of the blood-pressure under the same conditions at home, I had the advantage of having a well-worked-out standard for comparison. Besides these observations on myself I made others on another subject, on many visitors, and on some residents.

Now what is the teaching afforded by the three groups of the observations, namely (1) those made apart from the influence of digestion and exercise; (2) those afforded by the digestive waves and (3) those furnished by exercise?

In fig. 6 are plotted out the mean arterial pressures determined at 8.30 a.m. or an hour before a meal, in a state of rest in London, and at fourteen different altitudes, advancing progressively from 1,128 to 7,835 ft. You will observe that at about 1,000 ft. there is no appreciable change; that a marked fall is apparent when a little over 2,000 ft. is reached; that at 3,500 ft. (Château d'Oex) the blood-pressure, though somewhat higher than at the lowest point reached, is much lower than at home; and that above that altitude (3,500 ft.) there is a rise progressive with the altitude until we reach the highest point, the Fluela Pass (7,835 ft.).

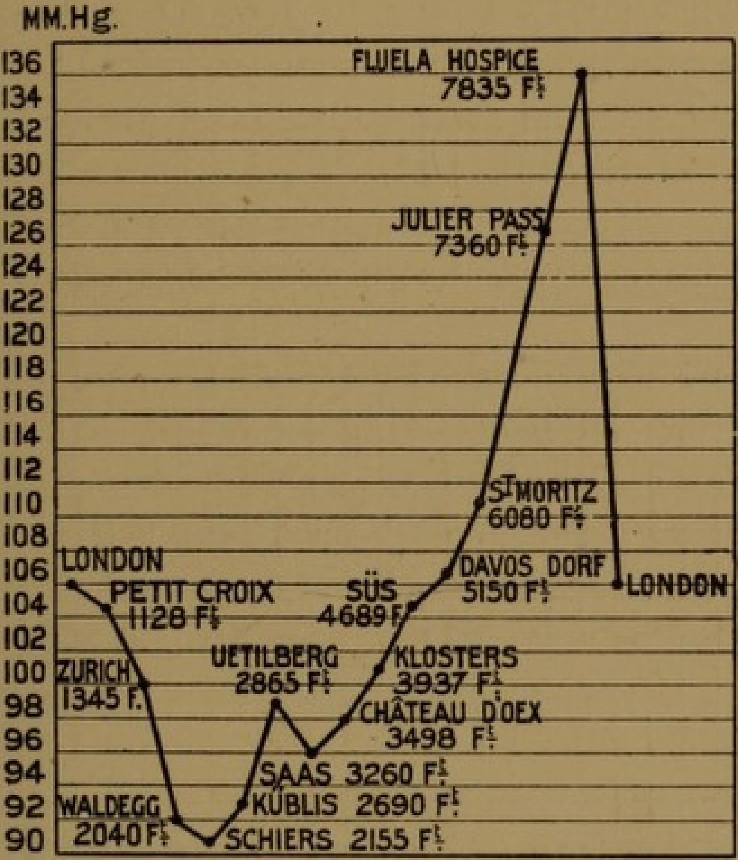

FIG. 6.—Mean arterial pressure taken at 8.30 a.m., or an hour before a meal, at various altitudes in Switzerland in January and February, 1903.

In fig. 7 are recorded the consecutive morning observations at Château d'Oex and St. Moritz (8.30). You observe the relative position of the two records on the scale: the spurts of pressure above the lowest readings were due to falls of temperature, as shown in the lower curves. Guided by my previous observations on the effects of variations in the temperature on the blood-pressure at home, I am quite sure that such decided falls in the thermometer as occurred at

Château d'Oex and at St. Moritz would in our own climate have produced much greater impressions on the blood-pressure than are here recorded.

In fig. 8 are shown two digestive waves of blood-pressure (both after lunch without alcohol), one (*a*) taken at Château

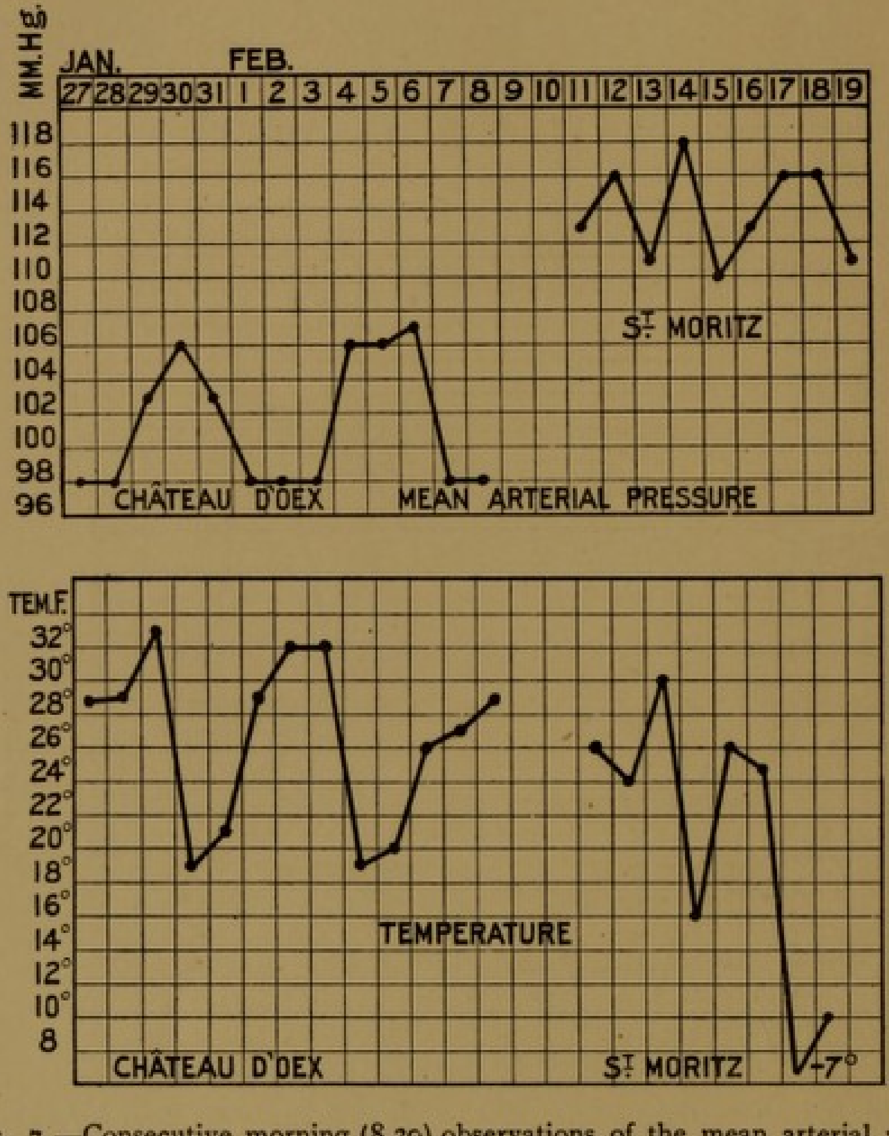

FIG. 7.—Consecutive morning (8.30) observations of the mean arterial pressure and temperature at Château d'Oex and St. Moritz.

d'Oex and the other (*b*) at St. Moritz. These waves are typical of others. You observe that the wave at Château d'Oex begins at and falls to a lower point on the blood-pressure scale, namely, 98 instead of 110 mm. Hg., as at St. Moritz.

The effects of exercise on the arterial pressure also show that the pressure is lower at Château d'Oex than at home or at St. Moritz, and that it is higher at St. Moritz than at home. At home the usual effect of active exercise is to cause a fall of my arterial pressure to 97 mm. Hg. (observed just after the exercise is over); at Château d'Oex a similar amount of exercise reduced the pressure to 92; but at St. Moritz I could not diminish it below 105.

After completing the foregoing observations I made some interesting readings of the arterial pressure at Zurich, where there is a railway which ascends from 1,345 ft. (Zurich) to 2,865 ft. (Uetliberg), with a midway halt, 2,040 ft. (Waldegg).

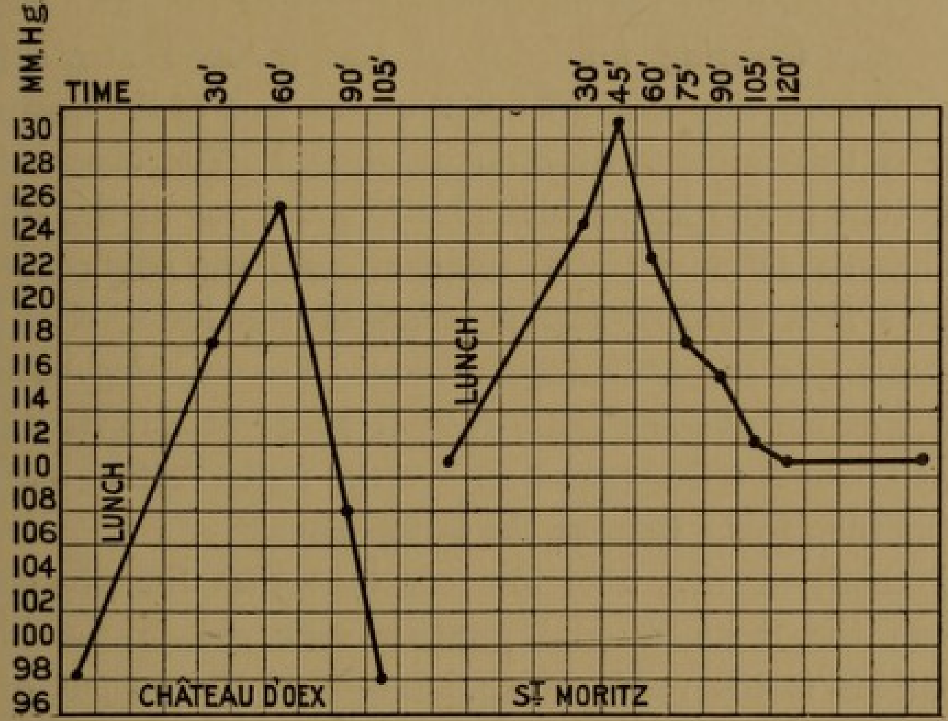

FIG. 8.—Digestive waves of arterial pressure at Château d'Oex and St. Moritz.

The uniform temperature and rest of the railway carriage afforded the most favourable conditions for comparable observations of the blood-pressure. The results furnished by the up and down journeys, which corroborate each other, appear in fig. 6, and confirm in a general way the previous observations made at similar altitudes.

The concurrent testimony of all these observations made in winter, points, I think, to the conclusion that altitude does lower the blood-pressure within certain limits—and especially so between 2,000 and 3,500 ft.—above which the pressure rises.

When one thinks of it, it is surely improbable that altitude should either lower or raise the blood-pressure progressively throughout all gradations; for in either case life would soon be threatened or would cease. We know that Nature when dealing with organic life does not, as a rule, work in straight lines; it is but the limitations of our view that give us that impression. She is ever deviating by her corrections to her beneficent ends. We should not, therefore, be surprised at this contrary effect of altitude on the blood-pressure, as it is apparently but an example of this universal law; for the observations suggest that at a certain point the lowering influence of the reduced atmospheric pressure is met by an adjustment on the part of the organism. How is this adjustment brought about? The observations show that in the higher altitudes (6,000 ft. as at St. Moritz) the heart's action is more frequent, and the calibre of the arteries is somewhat smaller than in the lower elevations (3,000 ft., or so at Chateau d'Oex). The morning observations give an average pulse rate of 76 at St. Moritz and of 71 at Château d'Oex; and an average radial calibre 0·4 mm. less at the former than at the latter place.

I think we may therefore conclude that the progressive rise in the mean arterial pressure observed in the higher elevations is the result of an increase of the output of the heart and of the normal tonus of the arteries.

Observations at St. Moritz on several visitors—even on those who had been sojourning there for two and three months—and on one whom I had observed at Chateau d'Oex, were exactly similar to those on myself; but those made on a few natives showed that the mean arterial pressure in them was lower—in fact, it was much the same as in England. From this it may be inferred that acclimatisation in a high altitude is not a question of a few months only.

I am sorry I could not prolong my visit so as to extend these observations to other altitudes and to verify or to correct those already made by repetition; and I regret this the more because at the highest point reached—namely, on the Fluela

Pass, 7,835 ft.—it seemed to me as if a second compensation, having for its object a reduction of the blood-pressure, were coming into play—namely, a vagus effect. I hesitate to mention this single observation, as there may be nothing in it. I was, however, struck with the fall of ten beats per minute below the average pulse-rate which I had observed at St. Moritz, as a slow pulse at the highest altitude reached seemed to be somewhat noteworthy. Should a vagus effect develop in still higher elevations it would, of course, counteract the rise of blood-pressure maintained by a further increase of the arterial tonus, and might afford a suggestion as to the cause of that mysterious ailment "mountain sickness."

I merely give you my limited observations, which without further extension you should regard as but tentative, though they were made with care so as to exclude fallacies as much as possible. I trust that other observers may be induced to take up this work and report their results. Climatology is sorely in need of exact physiological data; and we cannot have too many good observers. I think it is highly probable that in the warm months the lowering influence of altitude on the blood-pressure may extend to a much higher limit than my observations made in winter indicate, for warmth reduces the arterial tonus. But so far as these observations go I am inclined to think they have a suggestive bearing on practical climatology. I am not aware of a climatic condition that will lower the mean arterial pressure to the same extent as the medium altitudes. Why should we not think of this when deciding where to send some of our patients with *plus* arterial pressure in the winter months? Then, again, our colleagues at Aix-les-Bains, and other foreign bathing resorts for the gouty, wisely advise their patients after the "course" to resort to a moderate altitude for their "after cure"; now, according to these observations this advice means that the effect of the baths in lowering the arterial pressure will be maintained, even though the course of treatment has terminated. Can we not utilise some of our own moderate altitudes in a similar way after a course at one of our bathing resorts? Perhaps, however, I am looking too far ahead, as the question of accommodation on our mountain sides is doubtful. Then there is a thought that will occur to you in connection with the raised blood-pressure maintained in the winter by the higher altitudes. These should be well adapted to the climatic treatment of cases which require construction and repair, such, for example, as the phthisical; and should be contra-indicated in cases in which the removal of waste products should be the keynote of treatment, such as in gout and chronic Bright's disease; and should be further contra-indicated when we cannot be sure that the heart muscle will safely bear the additional strain of a high altitude.

The Balance between the Visceral Blood Supply and the Systemic Blood Supply.

There is another branch of our subject which, having an important bearing on practical medicine, I will briefly refer to. For many years I have been studying the evidence bearing on the relation which exists in health, and which is so often perverted in disease, between the quantum of blood in the abdominal area and that in the systemic area. This is a large subject which cannot be adequately handled, were a lengthened address devoted to it—much less in the few minutes that remain to me; I will, however, endeavour to outline it sufficiently, I hope, to enable you to see some of its possibilities and bearings on practice.

In the earlier observations of ten years ago, I inferred that the volume of the blood in the abdomen was increased when the radial calibre (determined by the arteriometer) became considerably enlarged on the patient assuming the recumbent posture—a reduction of the calibre in that position being the normal variation in persons of good vaso-motor tone. The explanation of this reversed reading that suggested itself was, that the diminution or loss of gravitation control in the splanchnic area led to a loading of the capacious abdominal veins in the erect position of the body, and that when the circulation was freed from the influence of gravity in the horizontal position, the surplus blood was liberated, and merged itself into the general circulation, and thus the systemic arteries became fuller and larger in that position. Though this was but an indirect way of clinically testing whether the gravity control of the splanchnic was impaired or lost, I found it to be a most useful clinical guide, and one on which I placed—and still place—much reliance. But during the past few years I have been fortunate enough to find a supplementary method, which provides direct corroboration of the inference drawn from the reversed postural variation of the radial calibre; it is based on the displacement of the surplus abdominal blood by means of a weight, and on the measurement of the effect which this displacement produces on the systemic blood-pressure. The patient having assumed the recumbent position, the mean arterial pressure is taken from the radial or ulnar artery—the arm being extended in a line with the body; then a bag holding 14 lb. of shot is placed on the abdomen, and the arterial pressure is again read. The result of observation has shown that in persons of healthy tone, the arterial pressure is not altered, or is not very appreciably altered by the weight—except for a short time after a meal, when it is raised about 10 mm. Hg. In the course of clinical work, however, a large number of cases are met with which afford a marked rise (of from 10 to 20 or even 30 or 35 mm. Hg.) at all times. It is this fact which is a matter of interest, because it is abnormal; and this interest is increased when it is found that, after suitable treatment, in a large proportion of these cases the weight will fail to produce a rise in the blood-pressures, when it is presumed the abdominal stasis has passed away.

This clinical sign (for such I take it to be) characterises a large group of cases. What does it signify? The only satisfactory explanation of it which I can discover, consistent with all the observations made, is, that in the cases referred to, the weight displaces at all times some considerable volume of blood from the abdomen, just as it does in health shortly after a meal only, and for the same reason : namely, because the volume of the splanchnic blood is increased. There is, therefore, a continuous increase of the splanchnic area instead of an intermittent and transitory one as in health. The condition may be described as one of splanchnic stasis. How is it brought about ? Broadly, there appear to me to be four types of cases presenting this clinical sign.

Firstly, there is the group of cases due to cardiac failure, in which a certain volume of the blood falls away from the control of the circulatory forces, and passively collects in the deep abdominal veins.

Secondly, blood often collects unduly in these veins, when the muscles of the abdominal wall become flabby and toneless, as after pregnancy, the removal of abdominal tumours, &c., Nature's abdominal belt having become weakened.

Thirdly, there is a group of cases which may be termed auto-toxæmic, in which the arteries are hypertonic (the contraction being shown by the arteriometer), a condition which may result from the irritating presence in the blood of auto-generated products and residua, as in chronic goutiness and in various abdominal disorders. In such cases it would seem as if a certain portion of the blood is simply drifted, as it were, into the abdominal area from contraction of the systemic area.

Fourthly, there is a very large group of cases depending on diminished tone of the splanchnic arterioles, so that at all times in the erect postures a considerable volume of blood simply drains, uncontrolled by these vessels, into the capacious abdominal veins. This class of case includes patients suffering from all forms and degrees of exhaustion and lowering of tone, however produced ; but the most prominent members are neurasthenics. In every case of neurasthenia I have so far met with—and I have seen not a few—the shot bag test has invariably afforded decisive evidence of pronounced splanchnic stasis. I need scarcely point out the usefulness of an objective sign, which the observer can himself fully appreciate, in an ailment like neurasthenia, with its interminable catalogue of subjective symptoms.

In all these classes of cases the shot bag and the blood-pressure gauge indicate that there is a considerable volume of blood constantly present in excess in the wrong place—in the abdomen. The blood thus withdrawn from circulation (for such it is) will doubtless limit and cripple the nutrition of the whole organism, and especially that of the master centres.

Now, though splanchnic stasis is always caused by something—such as cardiac weakness, auto-toxæmia, exhaustion of nerve centre—it is itself a cause of endless derangements of function, so long as it remains uncorrected. It is, indeed, the centre of an ever-widening vicious circle. To follow its effects in all their clinical ramifications would lead me too far afield. Suffice it to say that beyond the incapacitating influence which it produces on the brain and the muscles—in limiting the power of thought and exercise—splanchnic stasis favours the production of various abdominal ailments and derangements of the cerebral circulation. In the abdomen it predisposes to catarrhal inflammations of the various hollow viscera, to gastrectasis, enterectasis, and their sequelæ, fermentation and the generation of toxins, to hepatic derangements, to menorrhagia, &c. I have also frequently found splanchnic stasis associated with marked and persistent forms of vertigo, and also with insomnia.

Draining of blood into the splanchnic veins frequently produces a pale quasi-anæmic appearance, especially in young subjects. The pallor in some such cases may, of course, be due in part to actual anæmia; it is not so, however, as a rule, but is entirely caused by the reduced volume of blood in the vessels of the skin, lips, conjunctivæ, &c.* In a word, it suggests hæmorrhage; and in the sense of blood diverted from circulation, there is virtual hæmorrhage, only

* Unless the blood is examined it is not easy to determine whether the anæmic appearance is due to actual anæmia or to splanchnic drain.

the blood withdrawn is temporarily resting, as it were, in the splanchnic veins. In most cases there is a slight loss of colour and a faded look, which appeal to the practised eye as suggestive of splanchnic stasis. In fact there is a lowered capillary pressure in the systemic area.

There is, I think, some ground for suspecting that splanchnic stasis may be occasionally set up for the purpose of relieving the heart and the circulation; the volume of the blood in some cases being, perhaps, in excess, or if normal, it may nevertheless be too much for a failing ventricle, and so a portion of the blood drops out of circulation and gathers in the capacious splanchnic veins, which form a convenient over-flow chamber. This view probably affords one explanation of the discomfort produced in certain cases by the application of the shot bag to the abdomen, the breathing becoming hurried and oppressed and the heart's action becoming disturbed. I have sometimes observed that when the ventricle is yielding under increased peripheral resistance and the apex is felt well out to the left in the sitting position, on the patient assuming the recumbent posture the arterial pressure will fall and the apex will come distinctly within the nipple line; then the application of the shot bag will cause the apex to move outwards again, and the arterial pressure will rise as in the sitting posture. In such cases of diminished tone in the ventricular wall, it is not desirable to attempt to bring the excess of splanchnic blood into circulation, for by doing so we add to the load, which is already too much for the ventricle. Our aim should be first of all to tone the ventricle. In fact, splanchnic stasis of this type is frequently rectified by a course of cardiac tonics alone.

In those cases in which the abdominal muscles are soft and atrophied, and especially when the abdomen is pendulous, the practitioner is often tempted to order abdominal belts; but, inasmuch as mechanical supports of this kind rest the muscles, and in this way perpetuate the atonic condition of the abdominal wall, though they may afford temporary relief and comfort, they should, if possible, be avoided. Persistent attempts should be made by electrical treatment and by specially devised exercises to strengthen the muscles of the abdominal wall.

In all cases in which splanchnic strain is the result of asthenia the treatment should be concentrated on the cause of the stasis, namely, on the toneless state of the splanchnic arterioles. General tonic treatment alone will sometimes suffice to tone up these vessels; but it is always aided by the adoption of suitable measures addressed to the splanchnic area itself. Your knowledge of physiology will now afford valuable clinical guidance. I have referred to the fact that in healthy subjects the shot bag may afford a rise in the arterial pressure for a short time after a meal. Should the splanchnic arterioles be more open than they usually are, they will be specially so during the first hour of digestion, when the erect position of the body will aggravate the splanchnic stasis. Hence the importance of absolute recumbency for an hour after the meals, and especially after lunch and dinner. Then before the patient rises it is desirable if possible to incite some contraction of the arterioles; and for this purpose I have found it useful to advise him to apply a shot bag (weighing from 7 to 11 lb.) to the abdomen for ten minutes, through which he may massage the abdomen. Deep and thorough massage of the abdomen should also be systematically practised for ten minutes some time during the hour before each meal; and for this purpose the shot bag has been found valuable, as through it, as thorough an effect can be obtained by the patient himself as by the hand of a masseur. Direct abdominal douching is also of considerable value in the treatment of splanchnic inadequacy; and occasionally I have seen the D'Arsonval current useful.

In neurasthenia the existence of splanchnic stasis provides the *rationale* of the rest cure, now regarded as an important factor in the successful treatment of this ailment. In the less severe cases the recourse to absolute rest and isolation, however, becomes less necessary when sufficient prominence is given to the measures which favour the restoration of tone to the splanchnic arterioles, and when such measures are perseveringly followed up.

Conclusion.

Though our knowledge of the physics of the circulation is now considerably advanced, there remains much yet to be learnt, especially in regard to the peripheral part of the circulation—that part which is so intimately associated with nutrition and its derangements, and with various pathological conditions, such as chronic gout ; and it is to be hoped that the further study of this portion of the circulatory mechanism will throw some light on what may be termed the physics of metabolism. We practitioners in balneology attach much importance to the powerful influence which the measures at our command exert on the distal parts of the circulation ; for the outlying area of the circulatory tubing, actuated as it is by delicately balanced forces, is specially prone to get out of gear, and observation teaches us that the physiological methods of treatment we employ are more potent than drugs in clearing away and rectifying peripheral obstructions and embarrassments.

The Circulation of Tissue Fluid in Man.

(*PRELIMINARY COMMUNICATION.*)

In the course of some observations made with the view of eliminating tissue fluid as a cause of variability in the samples of blood obtained for examination, I found that the rolling of a tight rubber ring over the finger from the tip to beyond the interphalangeal joints will, as a rule, considerably raise the percentages of the blood corpuscles and of the hæmoglobin. I could not arrive at any other conclusion than that the ring not merely empties the vessels, but likewise clears away any tissue fluid present in the skin and subcutaneous tissues.* The needle in puncturing the capillaries liberates a certain portion of lymph from the areolar tissue which surrounds them, and this dilutes the blood. When, however, both fluids have been dispersed as much as possible by the compression of the firm rubber ring, a puncture made just before removing the ring yields blood *per se;* for the blood instantly returns to the vessels, whereas an appreciable interval must elapse before the lymph reappears, or is exuded afresh (see p. 37). I am aware that some may regard it as an open question as to whether or not lymph can be dislodged from the skin and the tissues covering the phalangeal bones; consequently I have exercised myself as to how all the facts observed can be otherwise accounted for. Having, however, failed to conceive of any other satisfactory explanation of them than this, and my friends, physiological and medical, being unable to suggest another view consistent with all the data observed, I cannot avoid

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* It may be that the lymph is dislodged from the skin only. Blood derived from punctures of varying depth has, however, afforded the same results.

the inference that the reading of the difference in the percentage of the corpuscles or of the hæmoglobin before and after the use of the ring provides a measure of the tissue lymph, and makes the study of the circulation of it in man possible. We know that slight œdema can be completely transferred by compression from one part of the cellular tissue to another, and that the tissue fluid present in the intercommunicating lacunæ of that tissue is akin to it.* The finger is anatomically well adapted to this mode of observation, for the phalangeal bones provide a firm and fairly uniform base on which the soft tissues may be effectually compressed.

This simple method having furnished somewhat unexpected results, I naturally accepted them at first with reserve, and for some time the data were allowed to accumulate, until at last it was quite apparent that they invariably fell into the same order. Inasmuch as the method did not provide results which were exceptional or erratic or contradictory and unaccountable, reliability on it became gradually established by the mere repetition of the observations.

A number of observations have been made on normal subjects leading a quiescent life with comparative rest of the muscles, and on persons subjected to varying degrees of exercise and to different temperatures. In this communication I limit myself, however, to a statement of results obtained in the former class of subjects only.†

The numerous observations which this inquiry necessi-

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* The connection between tissue lymph and œdema has not yet been worked out. It will, however, be shown that the exudation and absorption of tissue lymph are controlled by the capillary blood pressure; whereas it would seem that œdema is tissue lymph which has fallen away from that control, and, being amenable only to the force of gravity, may therefore be regarded as the pathological analogue of hypostatic congestion as compared with the normal capillary circulation.

† Among other additions to this "Preliminary Note" now reprinted are one or two results of clinical observation on the tissue lymph circulation, which illustrate the bearing of the physiological data on practical medicine.

tated on the corpuscles and on the hæmoglobin were made by the hæmocytometer tubes and the hæmoglobinometer, which were described by me before the Physiological Society some few years ago,* and the specific gravity of the blood was determined by Roy's method. The blood-pressures (arterial, capillary and venous) were read by the hæmodynamometer.† Hill and Barnard's sphygmometer and Professor Gärtner's tonometer were also occasionally used in determining the arterial pressure.

The Mode of Observation.—A sample of blood is taken from the first easily flowing drop derived from near the root of the nail, the object being to obtain the actual proportion of lymph present in the tissues around the puncture. No difference, however, has been observed in the reading of the corpuscles when the first drop was wiped away and the pipette was filled from the second drop. Three stout rubber rings are rolled in succession slowly from the tip of the finger to beyond the interphalangeal joints, and these are then removed by placing over the finger a rigid tube on to which the rings are rolled; in this way compression of the tissues in one direction only is secured, namely from the tip. The original puncture will generally suffice for supplying the second sample. The finger is held upwards until the blood is made to flow; for observation shows that compression does not now alter the proportion of the corpuscles. The hæmocytometer tubes are then read in the usual way,‡ and the difference between the readings indicates the percentage of tissue-lymph.

The sample of blood obtained after the compression is invariably darker and more venous looking than that yielded before the use of the rings. This difference is not due to a higher concentration of the blood, for it is apparent when the samples read alike, but is probably a result of the suspended oxidation of the tissues.

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* See *Journal of Physiology*, Cambridge and London, vol. xix.

† See *Journal of Physiology*, vols. xxii., xxiii.

‡ See "Blood and Blood-pressure," 1901.

The samples are then washed into the hæmocytometer tubes by which the corpuscles are enumerated in the manner elsewhere described.* Two graduated tubes and two measuring pipettes are required—one for the sample of blood taken before, and the other for that obtained after the use of the rubber rings. The difference afforded by the readings of the tubes (before and after compression) will be referred to as "the lymph difference." Should the two samples of blood furnish the same readings, there is no "lymph difference," and it is then inferred that no measurable lymph is present at the time of observation. This fact is referred to as "the zero point" of lymph.

General Conclusions.

Some of the general conclusions afforded by the observations may be thus epitomised :—

(1) *The Amount of Tissue Lymph varies* at different times in the course of the day, and each variation is of short duration.

(2) *The Ingestion of Food produces a rapid flow of Lymph into the Tissue Spaces,* which in an hour after meals acquires its maximum development, and then slowly subsides, and only ceases to be apparent after the lapse of from three to four hours (fig. 11, A A A A).

(3) *The Digestive Curve of Variation always follows the same General Type,* the rise being rapid, the acme short and the subsidence somewhat gradual. The curve of variation is therefore rhythmical, recurring after each meal with perfect regularity (fig. 11).

The following are two examples :—

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* For a description of this method of enumeration the reader is referred to "Blood and Blood-pressure," H. K. Lewis, 1901.

Example I.

	Corpuscles. Per cent.	Corpuscles. Per c.mm.	Difference.	Percentage of Lymph.
Before the meal (breakfast) ..	99* .. 103 ..	4,950,000 5,150,000	200,000	4
One hour after ..	91 .. 106 ..	4,550,000 5,300,000	750,000	15
Two hours after ..	94 .. 105 ..	4,700,000 5,250,000	550,000	11
Three hours after ..	96 .. 104 ..	4,800,000 5,200,000	400,000	8
Four hours after ..	98 .. 101 ..	4,900,000 5,050,000	150,000	3

Example II.

	Corpuscles. Per cent.	Corpuscles. Per c.mm.	Difference.	Percentage of Lymph.
Before the meal (dinner)	99* .. 99 ..	4,950,000 4,950,000	None	0
One hour after ..	91 .. 108 ..	4,550,000 5,400,000	850,000	17
Two hours after ..	94 .. 106 ..	4,700,000 5,300,000	600,000	12
Three hours after ..	104 .. 104 ..	5,200,000 5,200,000	None	0

(4) *As the Digestive Lymph Wave develops there is a rise in the percentages of the Corpuscles, of the Hæmoglobin and of the Specific Gravity of the Blood.*—The differential readings of the hæmocytometer tubes, of the hæmoglobinometer, and of the specific gravity of the blood demonstrate the same fact, namely, that the blood becomes more and more concentrated as the effusion of lymph into the tissues progresses, and is most concentrated when the acme of the lymph wave is attained. The average rise of the corpuscles and of the hæmoglobin is 15 per cent., and of the specific gravity is $7\frac{1}{2}°$ (fig. 10).

(5) *As the Digestive Wave declines there is a fall in the percentages of the Corpuscles, of the Hæmoglobin and of the Specific*

* The figure on the first line represents the percentage of corpuscles before, and the figure on the second line that after compression of the finger by the rubber rings.

Gravity of the Blood.—In proportion as the water effused into the tissues is restored to the blood the percentages of the corpuscles and of the hæmoglobin and the specific gravity of the blood fall.

(6) *The interchange of Fluid between the Blood and the Tissues may be measured.*—The observations have shown that 15 per cent. of the volume of the plasma flows into the areolar spaces during the maximum development of each lymph wave. Now if we assume that the blood forms one-thirteenth of the body weight, a man weighing 11 st. should exude 850 cc. (or 28 oz.) of lymph into the interstitial spaces of his tissues after each meal, during the short period occupied by the acme of the wave. This large interchange of fluid between the blood and the somatic tissues exceeds other fluid-transfers from the blood, consequently when the maximum exudation takes place the volume of the blood will shrink considerably; during absorption it will increase, and when absorption is completed it will acquire its fullest expansion. Therefore after each meal there is a rhythmical diminution and increase in the volume of the blood, in keeping with the periods of transfer of fluid to and from the tissues.

(7) *The Exudation of Tissue Lymph.*—Physiologists are divided as to whether tissue lymph is a pressure product (Ludwig, Starling and others) or a secretion (Heidenhain). Inasmuch as the amount of lymph in normal subjects is always proportionate to the rise in the blood-pressure (arterial and capillary), my observations seem to me to support Ludwig's theory. It therefore follows that the prolonged rhythmical curves of rise in blood pressure elsewhere described (see p. 6) following the meals are identical with the curves of the digestive lymph waves. In fact, the agreement between the blood-pressure and the exudation of lymph is so complete, that the "lymph differences" provided by the hæmocytometer tubes and the readings of the mean arterial pressure by the hæmodynamometer furnish interchangeable scales,

one point of lymph being equivalent to 1 mm. Hg. pressure; so that from the blood-pressure it is possible in normal subjects to predicate the amount of lymph, and from the "lymph differences" may be inferred the degree of pressure which produces it. Moreover, in cases of splanchnic drain the limited exudation of lymph into the somatic tissues, which is in keeping with a feeble rise in the systemic capillary pressure, is markedly increased if that pressure be raised by mechanically dislodging the extra load of blood in the splanchnic veins (see p. 47). Furthermore, a supernormal or a subnormal blood-pressure determines a corresponding variation in the tissue-lymph circulation (see p. 42). The following example illustrates the agreement between the blood-pressures and the amount of lymph.

	Percentage of Lymph.	Blood-pressure in mm. Hg. Mean arterial	Capillary.
Before the meal ..	None ..	100 ..	20–22
Half hour after ..	10 ..	110 ..	27–30
One hour after ..	16 ..	116 ..	30–35
One hour and a half after	8 ..	108 ..	27–30
Two hours after ..	5 ..	105 ..	25–27
Three hours after ..	None ..	100 ..	20–22

(8) *The rate of the effusion of Lymph.*—Fig. 9 gives some data which illustrate the rate of the exudation of lymph.

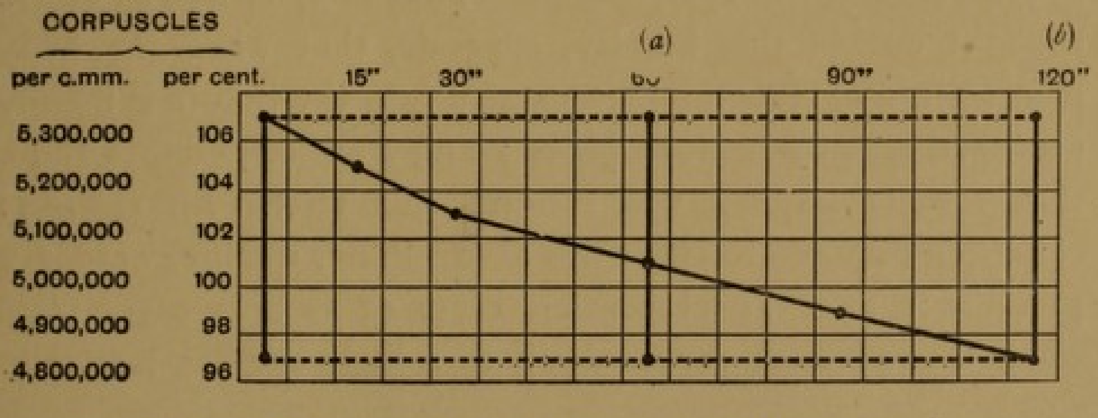

FIG. 9.—Illustrating the rate of the exudation of tissue lymph.

The "lymph difference" was found to be 10. A series of observations were made at short intervals, allowing successively after each, 15, 30, 60, 90 and 120 seconds to elapse before the blood was drawn after compression—the finger the while being held up to prevent gravitation of lymph. The aim of this observation was to ascertain how soon the "lymph difference" of 10 becomes reduced (showing how quickly a fresh exudation takes place) and the time required to replace the whole of that difference. The initial reading of 10 points was confirmed at (*a*) and (*b*); so that the tissue-lymph was thus proved to be uniform in amount throughout the observations. The mean arterial pressure was also taken before each observation, and was found to remain at the same reading. In 15 seconds some fresh lymph was formed already; in 30, 60 and 90 seconds the new exudation progressively increased, and in 120 seconds the whole of the original amount was effused. That the exudation of lymph is rapid is also shown by the fact that in splanchnic stasis a low percentage of lymph (*e.g.*, 6) may be considerably raised (*e.g.*, to 15) in five minutes by applying a shot bag (14 lbs.) to the abdomen (see p. 47).

(9) *The Absorption or Disposal of Tissue-lymph.*—In the normal condition of the circulation, each exudation or lymph wave completely disappears before its successor is thrown out. Lymph can only be disposed of in two ways, namely, by (*a*) absorption into the capillaries and (*b*) by transmission along the lymphatics. Experimentation on animals has shown that muscular action of some kind is necessary to ensure a flow of lymph along the lymphatics.* That fact, as well as others brought out in this inquiry, suggests, that when the body is in a state of rest, the fluid exuded into the tissues is mainly absorbed directly into the blood; and I am disposed to think that further inquiry will confirm this view. An essential condition required to effect this absorption is a falling capillary pressure;† and the absorption becomes as a rule complete when that pressure settles down to a little over 20 mm. Hg.

* "Text-Book of Physiology." E. A. Schäfer. Vol. i., pp. 291 and 301.

† Starling regards the osmotic attraction of the proteids of the plasma as the force which determines the absorption of lymph from the interstitial spaces of the tissues, this force, which he estimates as equivalent to 30 mm. Hg., coming into play when the capillary blood-pressure falls.

Should the blood-pressure when higher than this cease to fall, absorption likewise ceases to go on, and at whatever point it halts in its descent, at that point the lymph flow from the tissues is arrested. Hence the continuous charge of lymph in the tissues of those in whom the blood-pressure is supernormal (see p. 42).

(10) *The Intermediary Circulation.*—The to and fro transfers of fluid from the capillary to the tissue spaces constitute a circulation which appears to suffice for all the requirements of metabolism while the body is in a state of rest. This circulation, interposed as it is between the capillaries and the lymphatic vessels, may be appropriately termed the "intermediary circulation." It is merely an extra-vascular extension of the capillary circulation controlled by the forces which actuate that circulation.

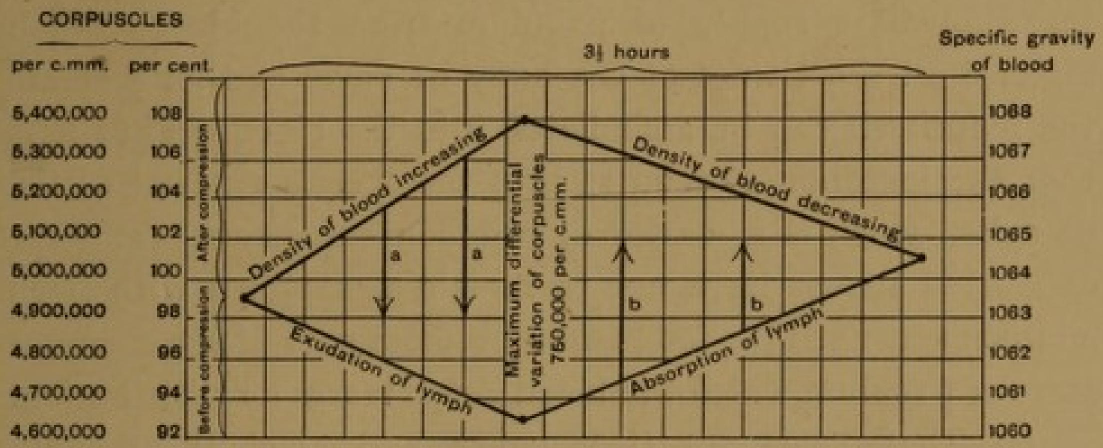

FIG. 10.—Diagram showing the average variation in the enumeration of the corpuscles and in the specific gravity of the blood before and after the compression of the finger during the flow and ebb of the lymph (digestive lymph wave); (a, a), exudation of lymph conveying proteids and salts to the tissues; (b, b), absorption of tissue fluid containing soluble waste and salts.

(11) *The Physiological ends served by the Lymph Waves.*—Inasmuch as proteids are diffused through membranes in proportion to the pressure which exudes them, it may be inferred that the physiological end served by the rise in the capillary blood-pressure which produces the digestive exudations of lymph is to supply pabulum to the tissues. Proteids are therefore probably distributed to them in the exudation current which flows from the blood (fig. 10, a). Inasmuch as

absorption does not commence until the blood-pressure begins to fall, the current from the tissue spaces to the capillaries will not set in until after the acme of the wave has been reached. This return stream (fig. 10, b) probably consists of a solution of salts and waste products only; and any surplus of proteids not used up in construction and repair of the tissues may be restored to the blood by transmission along the lymphatics, rather than by direct retransfer through the capillary wall—for there is a difficulty in explaining how proteids can be absorbed from the tissues by this direct route.

If these views on the physiological purport of the lymph waves be correct, it may be inferred :—

(*a*) That the intermediary circulation provides the mechanism, as it were, for the supply of pabulum to the tissues and for the removal of soluble waste products from them.

(*b*) That the lymph wave which follows a meal ensures the immediate supply of pabulum from the blood, which restores all the tissues of the body at once, and long before the food itself can be assimilated into the blood. Thus it is that the ingestion of food secures the speedy renewal of the energies, which is a matter of common experience; and the exhausted tissues have not to remain unsupplied with fresh nourishment until the food taken becomes part of the common store of pabulum which the blood keeps ready for distribution.

(*c*) That beverages (tea, coffee and alcohol) probably invigorate the body by inciting a flow of lymph into the tissues (fig. 11). Beverages, however, viewed from this standpoint, differ from food-stuffs, in that they fail to restore to the blood the outflow of pabulum which they create. They are therefore but temporary expedients of nutrition.

(12) *The Zero Point of Tissue-lymph.*—It was a surprise to me to find that at certain times of the day in normal subjects, the differential readings of the hæmocytometer tubes indicate the apparent withdrawal of tissue fluid; for though nothing hitherto has been ascertained as to variations in the volume of that fluid, the presence of a certain portion of it at all times seemed to be more probable than the temporary

absence of it. It is not improbable of course that when the tubes afford a negative reading, some minimum quantity of tissue-lymph is actually present, though too small to be measurable by that mode of observation. But whether this be so or not, it is a well-assured fact (the observations, made with exceptional care, being now so numerous as to exclude doubt) that in normal subjects the tissue-lymph is at certain times apparently absent—the two hæmocytometer tubes then reading exactly alike. This zero point is invariably met with after the lapse of three or four hours following a meal and as a rule, just before the next meal—when in fact the lymph wave has ceased ; and is not found at any other time during the day.

In adults it is as a rule apparent when the mean arterial pressure is 100 mm. Hg. and the capillary and venous pressures are 20 or 22 mm. Hg. From the few observations which have been made so far on growing subjects it would seem as if the blood-pressure must fall still lower in them before the zero point of tissue-lymph is reached. Inasmuch as in young subjects tissue-lymph is exuded under a lower capillary pressure than in adults it is probable that in them the capillary wall is more permeable. Exceptional cases have been met with in adults in which the arterial pressure follows a subnormal range (*e.g.*, from 90 to 105 mm. Hg.). But in such cases the capillary blood-pressure was relatively higher and the lymph wave was found to be normal.

(13) *Types of Digestive Lymph Waves.*—The agreement between the readings of the tissue-lymph and of the blood-pressure is also well illustrated by the effect produced on the lymph waves by a blood-pressure above or below the normal. In fig. 11 are represented a day's series of three typical forms of digestive lymph waves. The continuous line (A) shows the curves which are observed in subjects in whom the blood-pressure follows a normal course ; and the interrupted lines (B and C) indicate variations of the normal waves produced by a rise in the blood-pressure (B) and by a fall of that pressure (C).

The typical physiological wave is that which rises out of an apparently lymph-free condition of the tissues and completely subsides to the same zero point. When such is the case, in the majority of adults the arterial blood-pressure rises from 100 mm. Hg. before to 115 or 120 mm. Hg. after a meal, and then falls to 100 mm. Hg. before the following meal; and the capillary blood-pressure rises from 20 to 35 mm. Hg. and again subsides to 20 mm. Hg. (see pp. 7, 8 and 9). But when the blood-pressure follows a higher course than normal, there is invariably a large percentage of lymph in the tissues before every meal; then the lymph wave rises out of and subsides into a certain quantum of lymph permanently present (fig. 11,

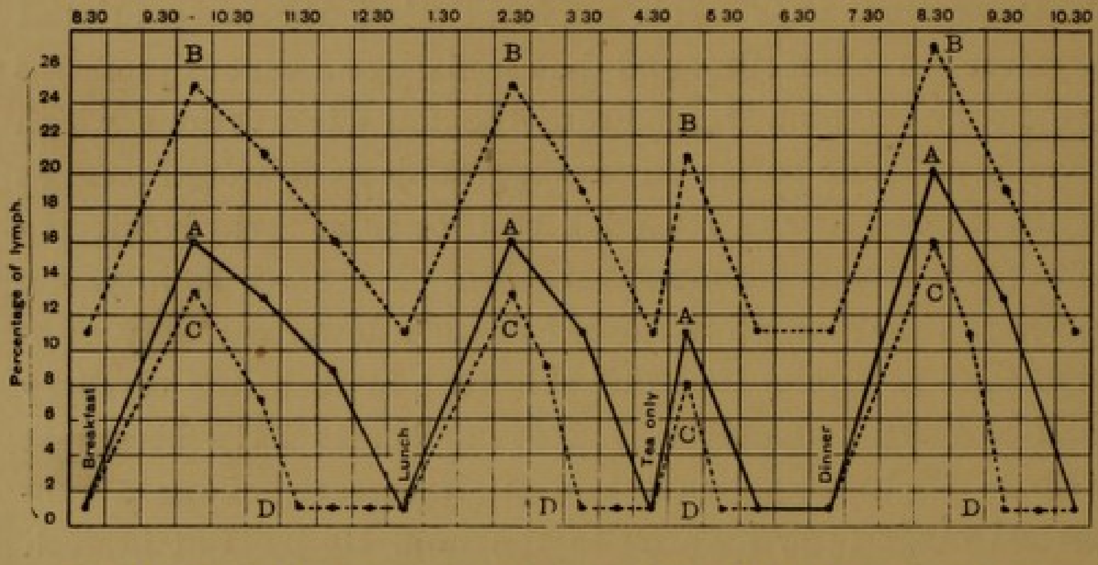

FIG. 11.—Typical digestive waves of tissue-lymph. (A) Blood-pressure normal; (B), blood-pressure super-normal; (C), blood-pressure sub-normal; (D), zero points of lymph.

B B B). This form of the wave was observed in high altitudes where the hæmodynamometer indicated a rise in the blood-pressure (see p. 19); this rise was therefore demonstrated by two totally different modes of observation, namely, directly from the arteries and indirectly from the differential readings of the blood.

When the arterial blood-pressure is subnormal, the lymph waves become somewhat reduced in amplitude and duration, and the lymph-free intervals before the meals are consequently lengthened (fig. 11, C D). This type of lymph wave was observed in the medium altitudes (from 1,000 to 4,000 ft.) which lower the blood-pressure (see p. 19).

(14) *The density of the Blood in Circulation is largely controlled by the Capillary Blood-pressure.*—According to my observation the specific gravity of normal blood is in close agreement with the number of the blood corpuscles per cmm. of blood; one degree in specific gravity being nearly equivalent to 100,000 corpuscles, or to 2 per cent. on the scale of the hæmocytometer tube. I will therefore refer to the density of the blood as expressive of the percentage of the corpuscles as well as of the specific gravity. This inquiry has shown that the density of the blood in circulation cannot be accurately ascertained from a sample yielded by the finger in the ordinary way; it can only be learnt after the tissues have been compressed as by the rubber rings. This procedure has demonstrated that the density of the blood increases *pari passu* with the rise in the capillary blood-pressure and in the consequent exudation of lymph, and decreases with the fall in that pressure and the gradual withdrawal of lymph from the tissues. Furthermore it has likewise shown that when the blood-pressure becomes supernormal, as in high altitudes, in chronic goutiness (see p. 45) and in kindred ailments, the density of the blood rises in proportion to the increased and persistent exudation of tissue-lymph; and when the pressure falls below the normal range (see p. 47), the fluid exchange between the blood and the tissues diminishes and the density of the blood tends to be low.

(15) *The bearing of Lymph Observation on the Clinical Determination of Blood-pressure.*—It has been conclusively shown by my clinical work, that the hæmocytometer tubes afford useful information, not only in regard to the intermediary circulation in various ailments, but in definitely settling the question of blood-pressure—whether it be normal, supernormal, or subnormal. I have found this mode

of observing the blood-pressure through the blood a most reliable one. As a clinical method, it possesses one great advantage over the ordinary modes of directly determining the blood-pressure. The data it furnishes are not affected by a temporary nervous perturbation of the patient.

As previously stated (see p. 36), the scales of the hæmocytometer tubes and of the hæmodynamometer are interchangeable within the normal range of variation (from 100 to 115 mm. Hg.) but for arterial pressures above 115 or 120 mm., the percentage of lymph rises in a decreasing ratio; for example, there may be no more than 25 per cent. or so, though the arterial pressure may be 135 or 140 mm. Within the normal range of variation of the blood-pressure, there appears to be a fairly constant relation between the rise and fall of the arterial and capillary blood-pressure; but beyond that range the rise of the capillary pressure may be modified by arteriolar contraction, or if it is not so modified, the filtering capacity of the capillary wall may be relatively lessened for the higher capillary pressures.*

(16) *Clinical Observation of the Intermediary Circulation.*—The types of digestive waves just described (fig. 11 B and C)

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* It has been shown by experiments on filtration through animal membranes that "the quantity of filtrate rises with the pressure, but in lower ratio" ("Schäfer's Text-book of Physiology," vol. i., p. 281). Increasing viscosity of the blood, produced by increasing capillary blood-pressure, may likewise retard filtration. Experiments have also demonstrated that a period of rest between two filtration experiments increases the permeability of the membrane (*op. cit.*). This fact may suggest that the rhythmical falls of the capillary blood-pressure, observed during the ebb of the lymph waves, and when digestion is at an end, will restore the capillary wall as a filtering membrane; and that the alternating rise and fall of the capillary blood-pressure is the best possible arrangement for affecting filtration and for the recovery of the filter.

Observation has shown that a comparatively limited rise of the blood-pressure, if persistent (*e.g.*, 5 or 10 mm. Hg.), is of clinical importance in profoundly modifying the fluid exchange between the blood and the tissues.

are frequently met with in the clinical field. The waves which rise out of, and which subside into, a varying quantity of lymph are met with when the blood-pressure (arterial and capillary) is supernormal, as in chronic goutiness, &c. In this class of case the prominent features of the peripheral circulation are (*a*) a low venous pressure and (*b*) a raised capillary pressure. A persistent increase of resistance in the venules would account for these alterations in the circulation in chronic gout; and this increased resistance may arise either from contraction of the muscular fibres of the venous radicles (see p. 8), or from obstruction to the flow of blood through them in consequence of an increase in tissue tension (tissue-lymph pressure.)*

The volume of the lymph before a meal (a time when no lymph should be apparent), may be as large as it is at the acme of a normal lymph wave, or it may be even larger. The following typical example illustrates this fact and also shows the effect of treatment in restoring the zero point of lymph :—

	1st. obs.	2nd. obs. (6 days).	3rd. obs. (12 days).	4th. obs. (18 days).
Arterial press, mm. Hg.	145	112	104	100
Capillary press, mm. Hg.	35	30–35	25	20–22
Venous press, mm. Hg.	15	30	25	20
Percentage of lymph	†27	12	4	0

All the observations in this case were of course made at a time of the day when in a normal state of the circulation the reading of lymph is *nil*.

In all the cases of undoubted gout so far submitted to observation this obstructed form of the intermediary circulation has been found, but whether it will be invariably present in gout cannot at present be affirmed. It is conceivable that

* Starling has found that "a rise of tissue tension above the pressure of the veins causes collapse of these veins, a rise of capillary pressure, and a diminished flow of blood through the part." (Schäfer's "Text-book of Physiology," vol. i., p. 307.)

† The percentage of lymph was in this case exceptionally high, but in chronic goutiness readings of from 15 to 22 per cent. at the normal lymph-free periods of the day are not uncommon.

cases of gout may be met with in which tissue residua may lodge in the tissue-vacuoles in consequence of an imperfect interchange of fluid between them and the capillaries—the capillary blood-pressure being too low for the development of the normal lymph waves.

All the remedial measures which counteract chronic goutiness liberate the embarrassed peripheral circulation by reducing the increased venular resistance, and thus they secure a rise in the venous pressure, a fall in the capillary pressure, and a reduction in the exudation of tissue-lymph.

When the obstructed intermediary circulation in gouty subjects is thus relieved and the normal flow and ebb of tissue-lymph is restored the general health is improved and the local manifestations of the gouty state as a rule either disappear or are lessened.

In acute gout the condition of the blood, of the circulation and of the tissue-lymph circulation, has appeared to me to differ from that in chronic goutiness. For some years I have recognised, that when gout becomes acute, the blood-pressure falls and the density of the blood diminishes; and this change in the blood-pressure and in the blood takes place rapidly. Since employing the method of measuring the tissue fluid, which enables one to ascertain with accuracy the density of blood in circulation, I have obtained some confirmation of this position—though my opportunities for observing this transition have so far been few. It would seem as if, when gout becomes acute, the embarrassment of the peripheral circulation, which characterises the chronic form of the disease, suddenly vanishes, and the fall of the capillary blood-pressure which ensues, suffices to secure complete absorption of the pent-up tissue fluid; and then once more the normal flow and ebb of the lymph tides are established. If this be so it follows that whatever quickly lowers the capillary blood-pressure may precipitate an attack of gout; and that, in consequence of the normal fluid exchange between the blood and the tissues being thus restored, the patient becomes less gouty—at any rate for a time.

A reduction in the systemic capillary pressure and a corresponding lessening in the volume and duration of the lymph waves is well illustrated, as a rule, in those cases in which there is drainage of blood into the splanchnic veins from loss of tone in the splanchnic arterioles (see p. 26). It has been observed that when this failure of lymph exudation is apparent that the application of pressure to the abdomen, either by means of a shot bag or by tightening an abdominal belt, will not only raise the arterial and capillary pressure, but will in five minutes create an ample flow of lymph. The following is an example of the temporary restoration of the normal lymph wave by applying a shot bag (14 lbs.) to the abdomen.

PERCENTAGE OF TISSUE-LYMPH AND MEAN ARTERIAL AND CAPILLARY BLOOD-PRESSURE ONE HOUR AFTER A MEAL.

	Before application of shot bag.	Five min. after application of shot bag.
Percentage of lymph ..	6	15
Mean arterial pressure mm. Hg.	106	115
Capillary pressure mm. Hg. ..	25	35

When in this case the splanchnic inadequacy was corrected, the digestive exudation of lymph into the systemic area was restored.

ONE HOUR AFTER A MEAL.

Percentage of lymph ..	15
Mean arterial pressure mm. Hg. ..	115
Capillary pressure mm. Hg.	35

Then the application of the shot bag no longer altered the blood-pressure, and improved systemic nutrition was indicated by a rise in weight and a gain in strength and well-being.

(17) *The bearing of the foregoing data on our views upon Gout and kindred ailments.*—This inquiry has afforded me a convincing demonstration of the correctness of the generally entertained opinion, that goutiness primarily depends on the retention of some waste product or products—whether the *materies morbi* be specified as uric acid, or whether it be regarded as a group of residua. There may be differences of opinion as to how gout originates—though light is dawning on this obscure point—but as to how it is main-

tained when established my observations leave no doubt in my mind. They have shown that it is essentially dependent on a derangement of the intermediary circulation, and that, therefore, the tissues themselves form the arena in which gouty disturbances manifest themselves. Residua may accumulate and be deposited in the interstitial spaces of the tissues, because their removal is thwarted, either by an excessive capillary blood-pressure limiting the absorption of fluid from these spaces, or by a diminution of that pressure reducing the fluid exchange between the blood and the tissues. Hence the two leading types of gout which are well recognised. According to my observation, the continuous presence of a large quantity of tissue-lymph provides an important condition for the development of the local manifestations of gout, which were present in by far the majority of the cases observed, and those few cases, in which local signs of gout had not so far declared themselves, might fairly said to be gouty—in the sense of potential gout.

This inquiry is still in progress; and the results it has already yielded afford some assurance that further experience of the method of observation on which it is founded will extend still more our knowledge of the intermediary circulation. Over one thousand observations in various cases have not only confirmed the conclusions formed during the experimental stage of the inquiry, but have considerably enlarged these conclusions.