THE BLOOD AND BLOOD-PRESSURE

A CONTRIBUTION

TO THE STUDY OF THE

BLOOD AND BLOOD-PRESSURE

FOUNDED ON PORTIONS OF THE CROONIAN LECTURES DELIVERED BEFORE THE ROYAL COLLEGE OF PHYSICIANS, LONDON, 1896, WITH CONSIDERABLE EXTENSIONS

BY

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PREFACE.

THE leisure afforded by the winters of the past ten years has enabled me to study, in an experimental way, several physiological questions having a bearing on clinical medicine; and my professional life during the summer months has furnished opportunities of testing the physiological positions suggested by these enquiries, and the practical efficiency of the instrumental methods of observation employed. The following pages, containing the results of a large portion of this experimental work, present firstly, an outline of observations on the physiology of the red blood-corpuscle and of blood-pressure; and secondly, some clinical applications of the instruments used in this enquiry.

Some portions of the material now published have already appeared in the Croonian Lectures delivered before the Royal College of Physicians of London in 1896, and in a series of Articles in the *Edinburgh Medical Journal*, 1898. Inasmuch as the enquiry during the past four years has considerably amplified and extended the results previously recorded, I am led to hope that their appearance in this collected form may be acceptable as a small contribution to physiological medicine.

In publishing these observations (physiological and clinical) I am conscious of many shortcomings, and of the inadequate handling, and need of further experiment in several portions of the enquiry. The clinical matter in Chapters III. and VI. is merely adduced to illustrate the application of some of the physiological conclusions, and to show the usefulness and adequacy of the instruments when employed in the course of medical practice.

I have not attempted to handle the clinical aspects of blood-pressure in a systematic way. There is scope for the observation of many workers in this department of clinical work; for example, on the bearings of hæmodynamometry on diagnosis, prognosis and life assurance.

The enquiry has not embraced a study of the effects of drugs on the blood-pressure. The observations, however, which I have made on the treatment of high blood-pressure have shown, that the action of drugs is, as a rule, but transitory and inefficient as compared with the more enduring and effective influence of the physiological methods referred to in these pages; these methods exerting a beneficial influence when followed for lengthened periods, without being accompanied by the deleterious collateral effects so apt to arise from the prolonged use of drugs. This conclusion, which may be said to have gained general support, must substantiate the important position which physiological medicine is gaining in the treatment of many chronic ailments.

Perhaps I should add one word respecting the value to be attached to the clinical employment of the instrumental methods here described; especially, as a large portion of my professional life having been spent without the aid of those instruments, I am in a position to compare the results afforded by them with those observed before they were devised. I am led to the conclusion that they contribute so much to the precision and efficiency of observation, that now I could not discontinue their use without experiencing the loss of an acquired power. Moreover, I have not found them to be tedious or difficult to apply, or time consuming.

I must express my indebtedness to my friend, Dr. Edgecombe of Harrogate, for his valuable help in correcting the proofs and in making the index. My thanks are also due to the editor of *The Lancet* for the use of several blocks, which were used to illustrate the Croonian Lectures published in that Journal.

January, 1901.

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ERRATUM.

Page 25, 14th line from bottom, *for* "Zeiss-Ptoma," *read* "Thoma-Zeiss."

ON THE

BLOOD AND BLOOD-PRESSURE.

CHAPTER I.

THE BLOOD; APPARATUS FOR DETERMINING THE HÆMOGLOBIN AND THE CORPUSCLES.*

I. THE HÆMOGLOBINOMETER.

BEFORE describing the apparatus I will first of all explain the principle that underlies the arrangement adopted, and then point out some of the difficulties that have been met with and indicate the steps that have lead to the present form of the instrument.† A review of all these preliminary matters is essential to a clear conception of the reasons that have determined the adoption of the several details of construction.

* These hæmometric methods were described at the meeting of the Physiological Society held at University College, London, March, 1896. See "Proceedings Phys. Soc.," *Jour. of Physiology*, 1896.

† I am indebted to Dr. Edgecombe of Harrogate for much valued aid in the working out and settlement of important details.

The Principle followed.

The method of observation is founded on the colorimetric principle, according to which depth of colour indicates quantity, but the application of that principle, as hitherto adopted, has been modified in the following ways:—

1. By using light doubly transmitted (or reflected) instead of singly transmitted.

2. By selecting a pure white background on which the solution of the blood and the standard colours rest.

3. By presenting the standard split up into a series of definite gradations.

4. By comparing the depth of colour of the blood solution with that of the standard in camera.

1. **Reflected (or doubly transmitted) light preferred.**—It seems to me that certain advantages are secured by comparing the sample of blood and the standard by means of reflected rather than by transmitted light. These advantages may not at first sight be very obvious, but in this particular mode of observation they nevertheless exist.

In the first place, the depth of colour when observed by double transmission of light is nearly twice as much as it is when viewed by single transmission, for the blood solution is seen through a medium of the same colour induced by the incident rays, and consequently the colour of the reflected rays is proportionately increased. Hence a much smaller measure of blood is required under reflected light to produce the degree of colour made apparent by transmitted light ; and it is obvious that in clinical work such a reduction may sometimes prove a distinct advantage, as when 5 c.mm. of blood amply suffice in place of 10 or 20 c.mm. Then again, light reflected lends itself much more satisfactorily than light only once transmitted to the attainment of the uniform physical condition of a flat surface in the strata of the blood solution, and of the standards ; and in consequence of the exactly equal adjustments which thus become possible the finest differences in depth of colour become recognisable, and the readings can be made with an exactitude which cannot otherwise be obtained. This improved definition has tended to greatly reduce that unavoidable variable element in all observation—the equation of the observer.

2. **The uniform white background.**—The use of reflected light introduces a difficulty in regard to the reflecting background, for this must be uniform not only in the same instrument, but in other instruments that may be made. The slightest variation in shade or tone of colour must produce discordant readings. In the earlier observations opal glass was selected for this purpose ; it was, however, soon discovered that different samples of it were far from invariable in colour. It therefore became necessary to select some

white substance that could be relied on for uniformity and purity of colour; and dry finely powdered precipitated lime sulphate was chosen. This substance forms a most delicate and uniform reflecting surface immediately under the blood solution and the standard colours, and contributes considerably to the exactitude of the readings.*

3. **The standard.**—It is a matter of great practical importance in constructing a hæmoglobinometer to determine how the standard should be presented, so as to obtain the most definite readings. In von Fleischl's hæmometer the whole scale is formed by a wedge of coloured glass—the depth of colour gradually merging off to the lowest reading; and as the field of view always embraces no less than 20 degrees (*i.e.*, 20 degrees heavier on the right than it is on the left) it is easy to understand—even when the colour of the glass should happen to match that of the blood solution—that very often considerable uncertainty is apt to exist before an estimation can be made. This mode of presenting and using the standard is obviously faulty. I have found, however, that all doubt as to the position of any particular sample of blood on the scale is entirely obviated when the latter is split up into a number of definite gradations of ten degrees, and this mode of disposing the standard has therefore been adopted. Each grade becomes a subordinate standard definitely recognisable from its neighbours, and by

* Calcium sulphate is likewise used in the reflector of von Fleischl's hæmometer.

means of a simple method to be subsequently explained, the intervening units are read. Moreover, there exists another reason why each stage ought to be separately standardized, and why a mere gradation of the same colour is not only indefinite but is misleading, and that is the specific colour-curve of the blood elsewhere described (pp. 6, 7, 11 and 12).

On setting up the standard.—To anyone who has not made an attempt of this kind it may seem an easy matter to prepare an imitation of the exact colour of a given percentage of normal blood in water, and thus to accomplish the first step towards the setting up of a hæmoglobin standard. But a few trials will dispel such an impression, and will demonstrate the existence of a number of unforeseen difficulties which are inseparable from the task. The standardizing involves two steps, namely, (*a*) the adjustment of colour, and (*b*) the determination of the scale.

(*a*). *The adjustment of colour.*—In the first instance, following others in the same line of work, experiments were made with carmine or carmine and picro-carmine in a glycero-gelatine basis. After much observation it was provisionally settled that the closest approximation to the colour of the blood solution was obtained by a combination of carmine, picro-carmine and hæmatoxylin; the blood and the standard solutions being observed by candle-light in cells having a background of opal glass. The gradations, of course, necessitated that the cells should be quite uniform in depth. After the lapse of some few weeks it was, however, obvious that the colour of the standard was undergoing a change, especially in the lower grades which were becoming darker and brownish. That led to some experiments on the effect of light on the constituent pigments; and it was found that all of them were unstable when exposed to daylight, and especially to direct sunlight. Of the three constituents having found that hæmatoxylin was the most fugitive it was excluded. Still the carmines became slowly affected by the exposure incidental to work.

Furthermore, at an early stage of the observations another difficulty was encountered, the explanation of which was not at that time forthcoming. The gradations of the standard were made by diluting the carmine solution of the highest grade to the required degrees. When, however, the blood solution which exactly matched the topmost gradation of the scale was diluted in exactly the same manner, marked discrepancies were apparent between these dilutions and the standard gradations, and especially was this the case in the lower half of the scale. They should have agreed; but they did not. Since then a satisfactory explanation of this discrepancy has been afforded by Mr. Lovibond, whose valuable and practical work on colour measurement will presently be referred to. This observer has shown that every coloured substance when progressively varied in concentration or in strata thickness furnishes a colour-curve peculiar to itself, a curve of colour composition which he designates "the absorption colour-curve" or "specific colour-curve."* According to this explanation the specific colour-curves of the solutions of carmine and of hæmoglobin, though coinciding at a certain degree of concentration, diverged below that point, and thus the disparities between them became more and more apparent as the dilution increased. This view of specific colour-curves derives some support from the spectroscope; for it is known that the position and the amount of absorption correspond with the percentage solution of the coloured substance under examination. It therefore follows that no one substance or combination of substances can correctly furnish a percentage series of gradations of hæmoglobin. The uniform tone of colour of the glass wedge of von Fleischl's hæmometer, for example, cannot properly represent the colour of the blood solution throughout the scale. In corroboration of this conclusion we have the observations of Osler, Neubert, and Letzius as quoted by Busch and Kerr. "Osler says that the error in the Fleischl instrument may not be more than two per cent. in blood which is nearly normal, but he cites Neubert and Letzius as having shown that in a much impoverished blood the error may be as high as twenty per cent.†"

* "Colorimetric Analysis or colour as a means of quantitive estimation," by J. W. Lovibond, *Journal of Society of Chemical Industry*, 1894; and "The Absorptive Method of Colour Analysis," by J. W. Lovibond, *Journal of Society of Dyers and Colourists*, 1894-5.

† "The Relation of the Specific Gravity of the Blood and its Hæmoglobin Percentage," by F. C. Busch and A. L. Kerr, *Philadelphia Medical News*, Dec. 21, 1895.

In order to avoid the difficulties presented by the instability of pigments when exposed to light and moisture, and by the specific colour-curve of the blood, it may occur to some, why not standardize with oxy-hæmoglobin itself? Unfortunately, here again gradual change of colour arises as a bar to its adoption; even though the solution of it is sealed up, it becomes reduced and no longer retains the colour of freshly drawn blood.

Fortunately, however, all the difficulties which have been encountered in attempting to standardize the colour of the blood have now been resolved, and there no longer exists a necessity to continue the search after a standard which is permanent, and which is in accord with the specific colour-curve of the blood; for Mr. Lovibond's practical and accurate system of colour measurement supplies this desideratum.

In as few words as possible, I will endeavour to convey an outline—the merest outline—of Mr. Lovibond's mode of determining colour; and for the necessary details I must refer you to his work on the subject,* and to the various contributions he has made to the Societies on the applications of his method. This observer has devoted at least twenty-five years to the practical study of light and colour, and the outcome of his work is the construction of a system of measuring colour which is now being adopted in various trades in which colour is a leading indicator of the

* "Measurement of Light and Colour Sensations," by Joseph W. Lovibond, F.R.M.S. The Colour Laboratories, Salisbury.

quality of produce or material, and also in some forms of analytical work, such as in the estimation of lead in potable water,* of carbon in steel, &c., and in the testing of colour-blindness.†

The matching and the measurement of colour is effected in a camera apparatus (the tintometer) by the aid of three sets of definitely graded glasses—one for each of the dominant colours, red, yellow, and blue. The graduations are of equivalent value in all the sets; the test of equivalency being the destruction of all colour and the production of grades of neutral tint by combining the equivalent glass of each set—the observation being made with white light. When the equivalent glasses of two of the dominant colours (red, yellow, and blue) are combined, the three subordinate colours are produced, namely green, orange, and violet. All other shades and degrees of colour are obtained by combining the glasses of the dominant colours in non-equivalent proportions; so that any colour can be accurately matched by them.

The colour scales are made up of units and decimal parts of a unit down to 0·01—which is the lowest fraction of a unit that can be differentiated by the vision. The fixing of the unit has necessarily been

* It is claimed that so minute a quantity of lead as one millionth of a per cent. may be detected by Mr. Lovibond's method.

† When I set up my standards with Mr. Lovibond's standard glasses I was not aware that Dr. Copeman had used, with much satisfaction, Mr. Lovibond's tintometer in hæmometric work. My hæmoglobinometer is apt to be called a tintometer, from which it differs, however, among other details in having a fixed and invariable scale of colour grades instead of adjustable glasses.

arbitrary; as has indeed been that of any standard measure, such as the mass of distilled water which has been chosen to represent a gramme, &c. Inasmuch as the unit chosen complies with the requisites of a standard—being uniform, recoverable, and arbitrary—it should be accepted as such; the actual dimensions of it, so long as they serve the practical ends in view, are of no importance. Of course the correct grading of the glasses from the original standards is essential to the success of the method, and this is, I believe, effectually attained by an elaborate system of cross-checking by a series of trained matchers. These graded glasses of determined value provide a numerical quantitative measure of any colour to be gauged, and they enable the measurements made by them to be recorded, so that the colour thus measured may be reproduced at will or may be preserved indefinitely.

With the view of fixing the blood standards I had the advantage of working in the Colour Laboratories at Salisbury and of obtaining the valuable assistance of Mr. Lovibond and of his well-trained staff.

Samples of blood, taken at different times of the day, were diluted with distilled water, and standardized by my carmine standard of the highest grade. The colour of the different percentage dilutions placed in the blood-cell was then carefully matched and determined by the graded glasses, finely powdered precipitated lime sulphate forming the background of the cell and of the glasses; and the estimations were made by the aid of the camera tube (p. 15).

The standard gradations of the apparatus were thus settled, and they form the two specific colour-curves of the blood—one determined by uniform candle-light and the other by white daylight. The difference between the two sets of standards is so remarkable that it is obvious that hæmoglobin cannot be estimated by the same standard used indifferently in the two kinds of light. The colour-curves (figs. 1 and 2) are made by entering the colour units on the side of the diagram

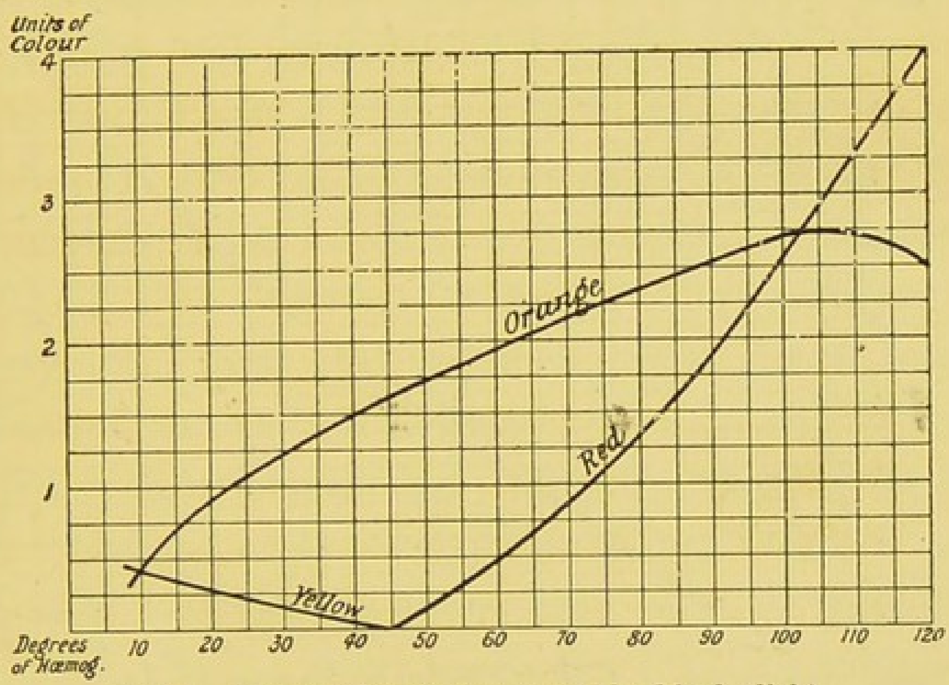


FIG. 1. The specific colour-curve of blood in daylight.

to form abscissæ with the standard gradations which appear at the foot.

In daylight (fig. 1) it will be observed that the specific colour curves of the blood are made up of varying proportions of red, orange and yellow. In the lower percentages (10, 20, 30 and 40) red as a separate colour does not exist; it is only present in combination with yellow as orange, which is made up of equivalent proportions of each. In these lower gradations the place of red is taken by yellow. Between gradations 40 and 50 yellow dies out, and then red appears and progressively increases until at the highest grade it is the dominant colour. In these daylight gradations the curve of orange is the predominant one, though it begins to die out in the higher part of the scale.

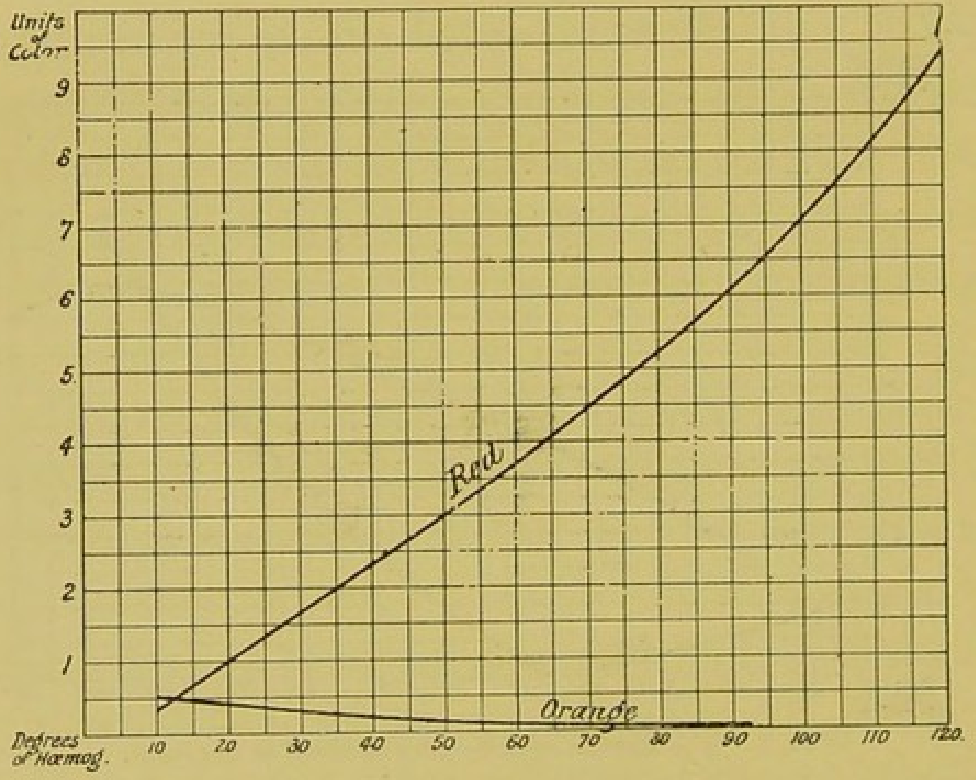


FIG. 2. The specific colour-curve of blood in candle light.

In candle-light (fig. 2) the colour curves are quite different and are less complicated. Red is predominant throughout, except at the lowest grade where it is subordinated to orange. From this point upwards orange gradually diminishes and vanishes entirely at 90, and then pure red distinguishes the highest grades.

The remarkable difference between the colour curves furnished by the two kinds of light is doubtless due to the preponderance of yellow emitted by the candle-flame.

The standard colours and gradations having been duly measured and determined, there still remains a further adjustment to be made. It is found that the solution of blood possesses in a remarkable degree the quality of colour-purity or brilliancy, a quality which is distinct from colour depth and colour composition, for it remains after these have been duly matched.* Inasmuch as this property of the blood may prove a distracting element with some observers, and may possibly lead to errors in observation, it is important that it should be eliminated from the view, especially as Mr. Lovibond's system of graded glasses supplies the remedy. It is met by using one of the lower grades of the blue glasses as a cover glass to the blood cell; and it has been found that this adjustment does not disturb the correct reading of the hæmoglobin.

(b) The determination of the scale.—The hæmoglobinometers hitherto used merely furnish estimations of hæmoglobin which are relative to a certain quantity believed to represent the proportion present in the blood of man in health—a quantity which is, moreover, undetermined and therefore unknown. Inasmuch as the blood of healthy subjects is not quite so invariable as it is usually believed to be (see Chaps. ii. and iii.)

* Mr. Lovibond tells me that this fact is occasionally observed in matching the colour of other substances, notably that of some of the aniline dyes.

it would seem to be more satisfactory to be able to quantitatively determine the amount of oxy-hæmoglobin present in each sample of blood tested than to rely entirely on an indefinite arbitrary standard.

The quantitative equivalence of the scale in oxy-hæmoglobin has therefore been determined. The blood of the dog was preferred to that of man for this purpose, because the process of separation is comparatively easy, while in the latter it is in many respects unsatisfactory. Great difficulty was, however, encountered in obtaining a pure product, which retained the exact colour of freshly drawn blood, so that accurate estimations of it could be made. Ultimately this result was attained by determining certain percentages of the moist crystals and afterwards correcting for the water.* It was found that each degree of the scale is equivalent to 0·155 per cent. oxy-hæmoglobin in the sample of blood under examination. Therefore 100 degrees represent 15·5 per cent; and determinations above or below that point will require the addition or subtraction of 0·155 per cent. for each degree. It may be mentioned that Preyer *(Die Blutkrystalle)* gives the average percentage of hæmoglobin for women as nearly 13, and for men 14. Dr. Augustus Waller *(An Introduction to Human Physiology*, 1893, p. 35) has found 17 per cent. in the blood of the dog. Observation has

* In carrying out this part of the work I must express my indebtedness to Prof. Moore (then Assistant Professor of Physiology, University College, London, and now Lecturer on Physiology, Charing Cross Hospital Medical School) for his valuable aid.

shown that the mean percentage of hæmoglobin present in the blood of man in health containing 5,000,000 corpuscles per cm. (or 100 per cent. of corpuscles) is represented by 100 degrees.

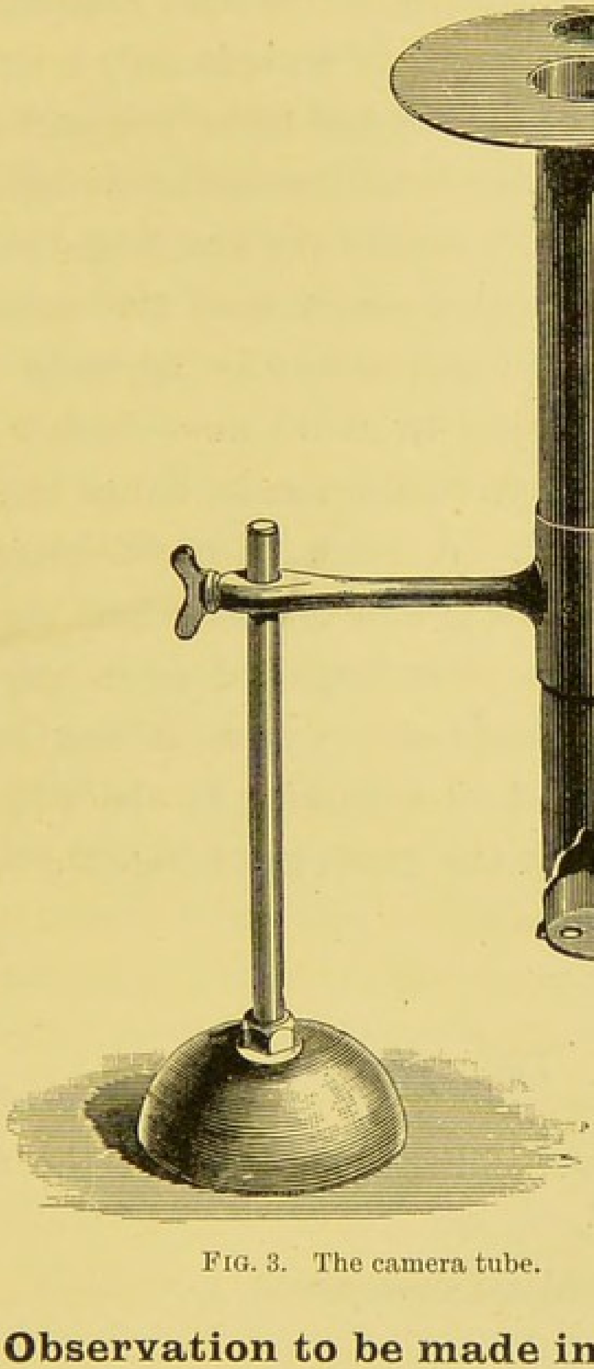


FIG. 3. The camera tube.

(4) **Observation to be made in camera.** From the first it was found that a reliable judgment between the colour of the blood solution and that of the standard, when closely approximated, could not be formed

unless the colours were observed through a tube so arranged as to shut off all side lights and other causes of distraction. The best results were obtained by use-ing a long tube, resembling a microscope tube, blackened inside, and presenting below two circular holes of 5 mm. in diameter, so as to include only a small but equal area of each of the colours to be compared; and encircled above by a diaphragm or collar which shields the eyes from the direct rays of the candle-flame. The tube is held in a vertical position over the colours by means of a side-stand; and it may be adjusted to the required height so as just to avoid any shadow which may be cast by the rays of the candle-flame impinging on the lower end of it. A piece of green glass is let into the collar; for it was found, that when the sense of colour appreciation was impaired from any cause, such as long and frequent observation, it was restored or was even intensified after looking at the candle for a few seconds through the green glass (fig. 3).

The Apparatus.

The different parts of the apparatus are the following:—

1. An automatic blood measurer.
2. A mixing pipette.
3. The blood cell and cover glass.
4. The sets of standard gradations.
5. The riders and slip of colourless glass.

6. The camera tube.
7. The candle and candle holder.
8. A bottle of antiseptic fluid.
9. The pricker, and
10. Threaded needle.

1. **The automatic blood measurer** (fig. 4, *c.*) has a capacity of 4·7 c.mm. and fills readily by capillary attraction. It differs from the fragile capillary measurer hitherto used, in being made of stout glass and therefore serviceable; in being larger and more manipulable; and in having the end which is presented to the blood well polished, so that all traces of blood adhering to the outside can be entirely removed from it by the finger. The bore is dried out before an observation, by passing a needle threaded with darning cotton through it. The handle is useful for stirring together the blood and water in the blood cell.

2. **The mixing pipette** (fig. 4, *d.*) is provided with a rubber nozzle which fits over the polished end of the blood measurer and ensures the complete rinsing of the blood with the first few drops of water.

3. **The blood cell** (fig. 4, *c.*) is of more than sufficient capacity to ensure the liberation of the hæmoglobin. When filled level with the rim it yields a blood solution of rather less than one per cent. It is itself the measure of the amount of water to be added; and it is quite easy to fill it accurately.

4. **The standard gradations** (fig. 4, *a.*) are arranged as circular discs in two slabs, six in each; and

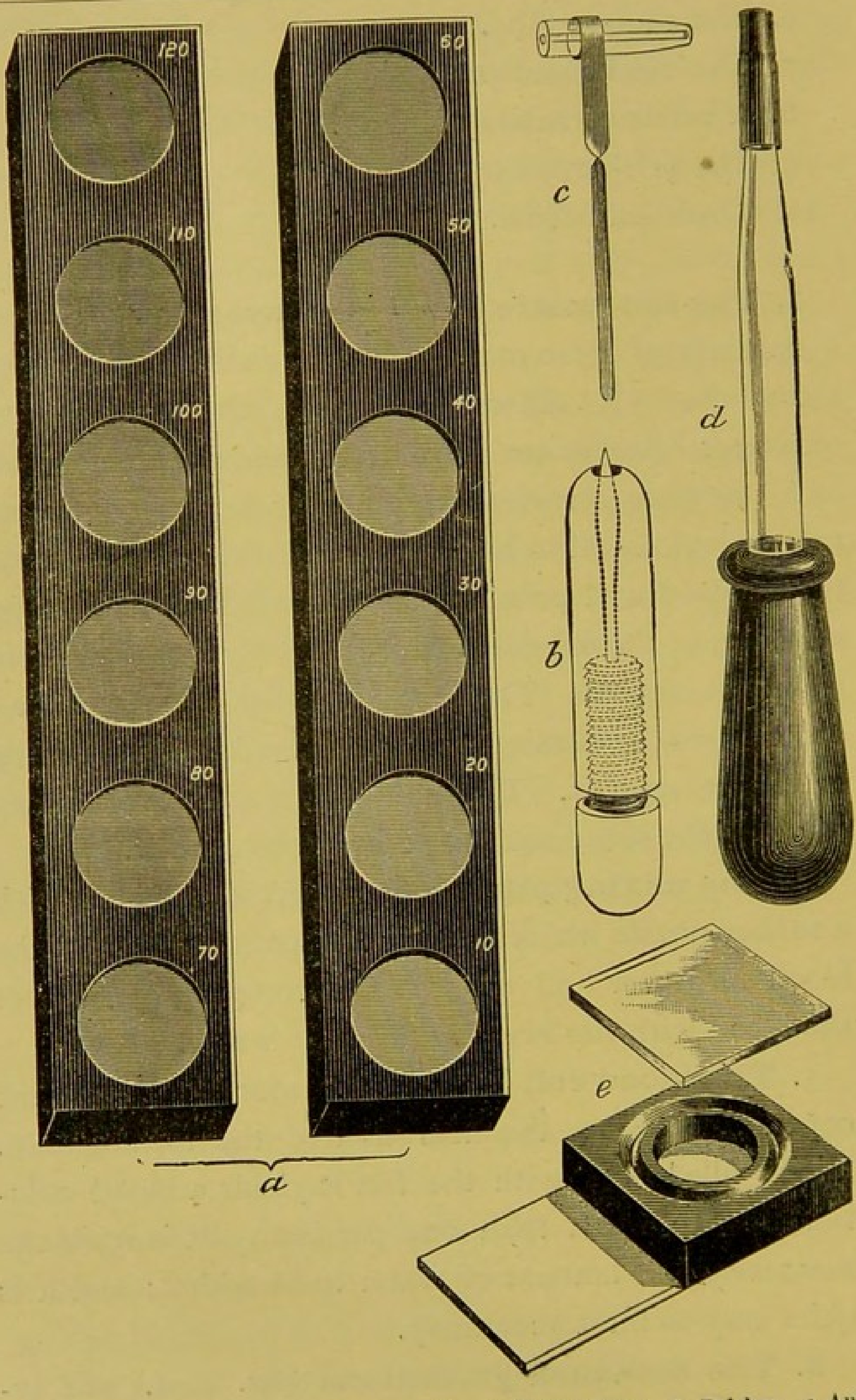


FIG. 4. The hæmoglobinometer. *a*. Standard gradations. *b*. Pricker. *c*. Automatic blood measurer. *d*. Mixing pipette. *e*. Blood cell and cover.

they represent the divisions of 10 degrees of the scale from 10 to 120 inclusive.

5. **The riders** are small squares of tinted glass provided for the reading of the degrees intervening between each of the standard gradations. When they are used, a slip of colourless glass is placed over the cover of the blood cell, so as to balance the effect of the mere layer of glass of the rider which is laid over the standard.

Two sets of riders have been arranged. One suitable for physiological observation, to ensure the finer readings, *e.g.*, of one degree; and the other sufficient for ordinary clinical observation, to enable the observer to determine differences of two and a half degrees. For the reading of the units nine riders are required which are grouped into three slides. It should be premised, that the value of the riders is neither the same in the two standards required for candle-light and daylight, nor in the upper and lower halves of either standard. This want of uniformity arises from the differences of the specific colour-curves in the two standards, and in the two portions of each. In the six lower grades of both standards the value of each rider is double that in the upper six gradations. In the transition grades—the lowermost of the upper half and the uppermost of the lower half—this rule does not quite accurately apply, but inasmuch as the departure which the riders necessitate is constant in all observations, and is, moreover, slight, it may be disregarded for the sake of simplicity.

The daylight standard is less adapted to the finer readings than the candle-light one, because the value of each rider when used with it is doubled, *i.e.*, number one rider becoming equal to two degrees in the upper half of the scale and four degrees in the lower half.

Therefore, the candle-light standard is preferable for such readings; and when it is used each rider has an equivalent value in the six stronger grades, 1 = 1 degree, and a double value in the six weaker grades, 1 = 2 degrees.

For ordinary clinical use one rider only may be used, namely that which is equivalent to five degrees in each slab of the standards. When in using it the blood solution is deeper in colour than any particular standard gradation, but is overstepped by the rider, the mean between the two may be taken as the reading; and the same rule will apply, when the colour of the blood is higher than the rider, but is not so high as that of the next standard grade above. Hence this single rider may be made to provide readings of 2·5, 5 and 7·5 degrees.

6. **The camera tube.**—It has already been pointed out that observation should only be made through a camera tube, and the one which has been employed throughout this enquiry has been described. It is, however, perhaps somewhat elaborate for the ordinary course of clinical observation, therefore one of simpler construction is provided which may serve this purpose, and, being collapsable, packs into a small compass with the other parts of the apparatus.

7. **The light.**—For observation by artificial light in a darkened room it has been found that the small sized wax candles known as Christmas candles are the most satisfactory in affording the most suitable intensity of light, and one, moreover, which is sufficiently uniform.

The position of the candle is important; it should be such as to shed an equal light on the blood cell and the standard, and also such as to furnish a high light—so that the flame should be three or four inches above the cells. The distance must be regulated by the observer, who will soon learn how to adjust it to the the best advantage, so that he may match the colours with thc greatest certainty and accuracy. The actual distance does not affect the reading, but when the candle is placed too near the points of observation the illumination becomes too strong and is somewhat distracting—especially when the lower grades are under observation, which require less degrees of light than the higher.

In daylight all colorimetric modes of estimating hæmoglobin are less or more unsatisfactory, for they require a uniform degree and kind of light, which cannot always be obtained when daylight is resorted to. The colour of the blood solution varies in a marked degree according as the light is blue or white, or is feeble or waning, or is strong. Therefore the candle-light standards are to be preferred—as being always available with a uniform light.*

* Dr. Solly of Harrogate has devised a very compact and ingeniously arranged camera box which combines the advantages of a dark room with those of the camera tube.

8. **The antiseptic fluid and pricker.**—Before every observation the pricker should be dipped into an antiseptic solution that will not corrode the metal, and a little of the solution should be smeared over the part to be pricked. I prefer a mixture of equal parts of carbolic acid and spirits of wine.

How to make an observation.

The bore of the blood measurer is first of all dried out by passing through it the needle threaded with darning cotton, and then the polished point is presented to the drop of blood which flows on applying gentle pressure to the pad of the finger, after pricking near the root of the nail. Care must be taken to see that the pipette is really quite filled, and, if it has been necessary to re-apply it to the drop, it should be observed whether there is a break in the column of blood. Any blood adhering to either end must be carefully wiped away with the finger. The rubber nozzle of the mixing pipette, charged with water, is adjusted over the polished end of the pipette, and the blood is washed into the blood cell by pressing through the water drop by drop. The handle of the pipette is then used as a stirrer, and the further additions of water are made to impinge on it—for it serves to graduate the size of the drops required to accurately fill the cell. It is in this way quite easy to do this when the observer catches the reflection of the light on the surface of the fluid. A final thorough mixing with the handle will be required and perhaps another slight addition of water may be necessary to secure a perfectly level filling. The cover-glass is then adjusted, when a small bubble is sure to form—a sign that the cell has not been overfilled. The blood cell is then placed by the side of the standard gradations, and the eye quickly recog-

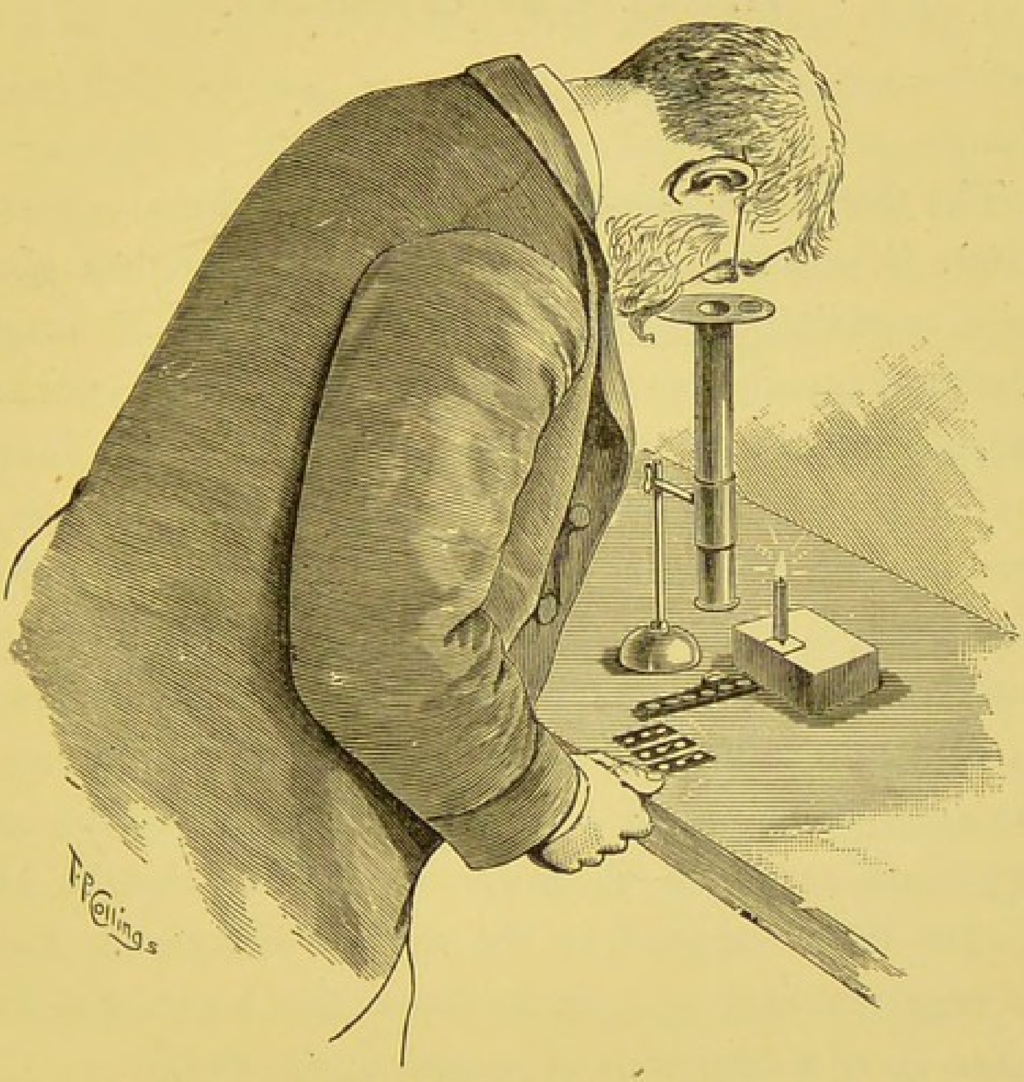


FIG. 5. Mode of estimating the hæmoglobin by the camera tube.

nizes its approximate position on the scale. Then the camera tube will more accurately define it (fig. 5). If it is found that the blood solution is matched in depth of colour by one of the standard grades, the observation is of course at an end; but if it is observed to be higher than one gradation but lower than that above it the blood cell is placed opposite to the former and the riders are added to complete the estimation.

II. The Hæmocytometer.

The Principle followed.

The method is based on the following facts:—

(*a*). When a candle-flame is viewed through a glass tube containing water, a transverse line of bright illumination is seen, consisting of closely packed minute images of the flame produced by the longitudinal fibrillation of the glass. In the process of drawing out, the tube becomes minutely corrugated or fibrillated in the direction of its axis. The corrugations are extremely small, but they are easily observed when a tube is held before a flame and the structure of the glass is examined by a pocket lens, when the corrugations are seen to produce alternate bright and shaded lines disposed in the vertical direction. Each corrugation acts as a lens, hence the horizontal line made up of a congeries of images of the flame.

(*b*). When some fixing fluid (such as Hayem's or a solution of potassium ferrocyanide, sodium chloride, &c.) is added to blood, the mixture presents a certain degree of opacity according to the amount of blood, or of the fixing fluid.

(*c*). The opacity thus produced completely shuts out of view the illuminated line, until, on diluting further, a definite point is reached, when it can just be detected as a fine thread of light across the tube—the dawn, as it were, of the bright minute images of the flame seen when the opacity is absent or is further reduced. Repeated observation has shown, that the development of this delicate horizontal line by dilution with the fixing fluid selected is a very sensitive indicator of the percentage of the blood corpuscles. This was shown in various ways, for example, by the measure of the fixing fluid required to bring the line into view being always in proportion to the different quantities of the same blood experimented with—and therefore in proportion to the number of the blood corpuscles present at each observation.

The determination of the scale was made by the enumeration method extended to 256 Zeiss-Ptoma squares applied to the blood of normal man. 100 degrees represent the generally accepted standard of five millions of corpuscles per c.mm.; therefore 80 degrees are equivalent to four millions, and each degree to 50,000.

The method viewed from the physiological standpoint.—The white corpuscles in a state of health do not affect the readings. The proportion of one white to 500 red, or one-fifth per cent., is equivalent only to one-tenth of one of the smallest divisions on the scale, and this is unreadable. So that were the white corpuscles to increase to one in 250 such a rise would not appreciably affect the reading of the chromocytes. The normal variation of the white corpuscles therefore may be safely neglected.

The method viewed from the clinical standpoint.—I have employed this method in clinical observation, and found it not merely simple and time saving, but useful. Apart from the leucocythæmic condition the white corpuscle is not a source of interference.

A distinction should, however, be made between the method of enumeration and a volumetric method like this or like that of centrifugal separation; for the aim of the former is to determine the individual corpuscle irrespective of size, whereas, that of the latter is to refer the collective volume of the corpuscles to that of the normal standard. Pathologically it is important to ascertain the size of the red discs; and therefore, the microscopical inspection of the fluid is a useful addendum to the observation. So long as the average or normal size of the corpuscles is unaltered the method is comparable with that of enumeration, on which it is founded. But inasmuch as that in certain cases may vary (*e.g.*, the microcytes of chlorosis* and the macrocytes of pernicious anæmia) the method should strictly speaking be regarded as a volumetric one like that of centrifugal separation. It is highly probable that it is clinically advantageous to be able to estimate the corpuscles in any case by comparing

* So far the only discrepancy which been met with between this method and that of enumeration has been observed in chlorosis, in which when many microcytes exist the readings of the tube may be somewhat reduced. Still even in such cases the method is practical and useful.

them with the normal percentage volume employed as a standard. Such an estimation will probably afford a true gauge of the aggregate corpuscular value of the blood; for it is the collective capacity of all the corpuscles, whatever their size, that is measured by the physiological standard.

The Apparatus.

The principle just described has been made available for determining the percentage of the cellular elements of the blood by mixing a definite measure of the blood with Hayem's solution in a graduated flattened tube.

The apparatus (fig. 6) consists of:—

1. A graduated flattened tube.
2. An automatic blood measurer.
3. A mixing pipette.
4. A candle.
5. A bottle of Hayem's solution, and
6. Threaded needle.

1. **A flattened tube** (fig. 6 *c*) has been adopted because it was found that a round tube of such a diameter as to furnish the required degree of opacity will only provide a sufficiently wide scale when a much larger quantity of blood is taken than is generally used for observation of the blood; whereas, when the observation is made through the long diameter of a flattened tube, it is not necessary to use more than 10 c.mm. and the scale is lengthened in proportion to the reduction of the lateral area. A tube of 15 mm. in the long

diameter, and 5 mm. in the short diameter, provides a good workable scale of 12 centimetres for the deter-

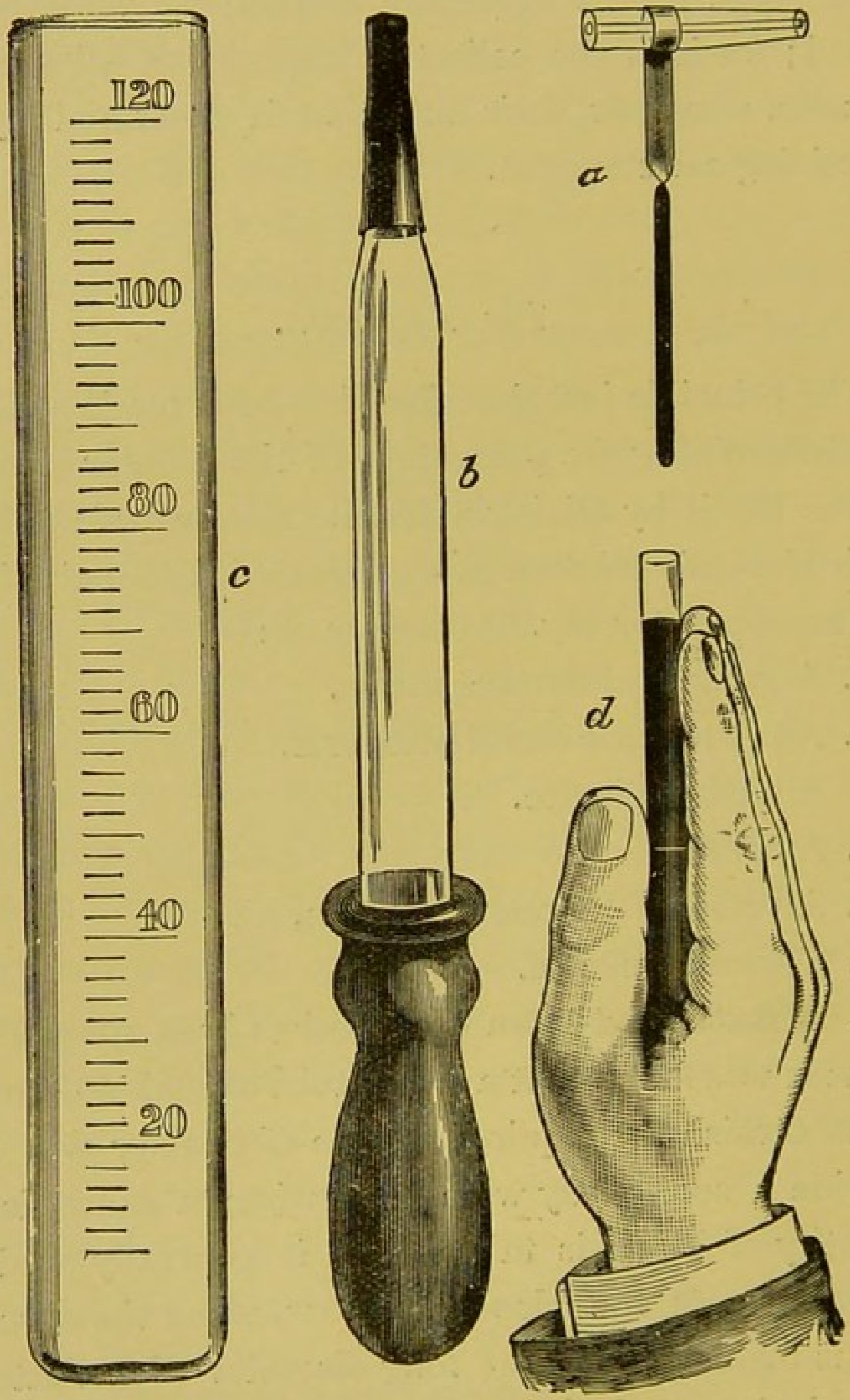


FIG. 6. The Hæmocytometer. *a.* Blood measurer. *b.* Mixing pipette. *c.* Flattened tube. *d.* Mode of holding the tube for observation.

mination of 125 degrees of corpuscles. The divisions of the scale represent two degrees, and they are sufficiently apart to allow the eye to read one degree, or even less.

2. **The automatic blood measurer** (fig. 6 *a*) is the same in construction to that used in the estimation of hæmoglobin, only its capacity is greater.

3. **The mixing pipette** (fig. 6 *b*) is provided with a rubber nozzle which fits over the polished end of the blood measurer.

4. **The candle** should give a small flame, for that furnishes a more defined line than is obtained from a large flame. The small sized wax candles known as Christmas candles are the best. A reduced gas flame also answers perfectly well.

5. **Hayem's solution.**—It was found that each kind of fixing fluid furnishes its own scale. Hayem's* was selected as the most satisfactory. The chief advantages of it are, that it is cleanly to use, that the corpuscles are less affected by it than by other fixing fluids, and may be examined under the microscope

* The formula is as follows :—

Hydrarg. perchlor. grammes 0·5
Sodii chlorid. grammes 1·0
Sodii sulph. grammes 5·0
Aq. destill. c.c. 200.

Strict accuracy as to the quantities of the constituents and absolute purity of the chemicals are necessary, otherwise the solution will afford incorrect readings. Moreover, inasmuch as inexplicable differences are apt to be met with in Hayem's solution prepared by different chemists, Mr. Lovibond (the Colour Laboratories, Salisbury) has been induced to provide a preparation proved to be correct by direct observation.

after the observation has been made without fear of material changes, and that the reading undergoes no variation after the lapse of many hours (*e.g.*, twelve), so that the blood may be washed into a tube and the observation may be made later on, if more convenient. It may be suspected, however, that the proteids of the plasma may be precipitated by the mercuric chloride present in Hayem's solution, and thus a variable addition may be made to the opacity caused by the corpuscles. This point has been carefully tested, with the result that it does not present a source of fallacy. 50 c.mm. of the plasma separated from a blood containing 100 per cent. of corpuscles were washed into the tube with Hayem's solution, but only as far as the 20 per cent. mark, so that the solution contained 25 times as much of the proteids as would be contained in 10 c.mm. of the blood diluted to the 100 per cent. mark, and there was apparent the merest haze, so small indeed that it could not possibly be determined. It is therefore obvious that the proteids of the plasma do not increase the opacity induced by the fixing of the corpuscles by means of Hayem's solution.

The Mode of Observation.

The pipette, previously dried out by passing through it a needle threaded with darning cotton, having been accurately filled, the slightest traces of blood on the outside of the glass either at the ends or on the side are very carefully wiped away with the finger. The rubber nozzle of the mixer filled with Hayem's solution is then applied over the bevelled end of the pipette, and the blood is thoroughly washed into the flattened tube (fig. 7). The amount of the fixing fluid to be used in the first instance will be roughly suggested by the

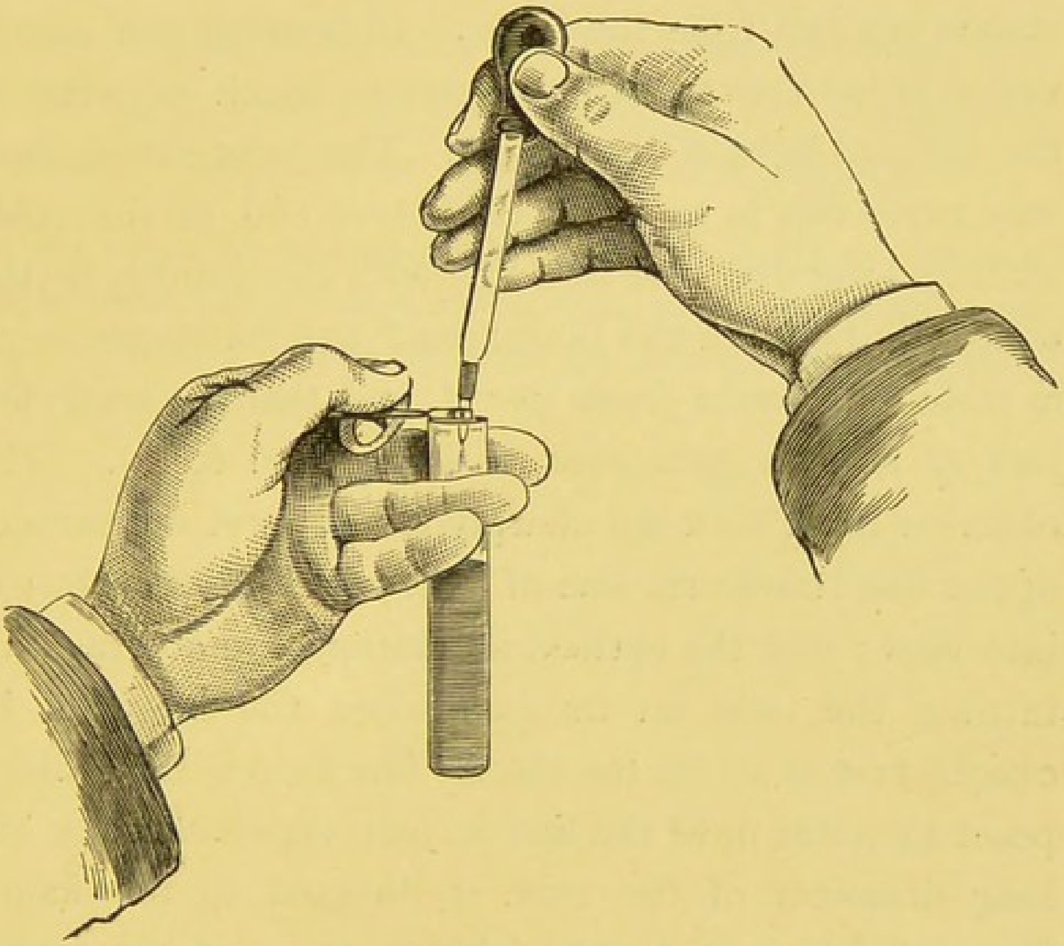


FIG. 7. Mode of washing the blood into the graduated flattened tube.

previously made hæmoglobin estimation; if this, for example, afforded from 90 to 100 per cent. or more the dilution may at once proceed to the 90 per cent. mark, but if it yielded a lower figure the preliminary dilution should be proportionately smaller. The contents of the tube are then uniformly mixed by inverting the tube a few times with the thumb over its mouth, care being taken on removing the thumb to draw it over the lip of the tube so as to restore as much as possible of the fluid adhering to it. This procedure should of course be repeated after every addition of the diluting fluid. The observation is made in a dark room, or in a darkened room free from cross lights. The observer stands ten feet from the flame. In making the observation it is important to shut out as much as possible the diffused light of the candle. The most satisfactory way to do this is to place the lower end of the tube, with its long diameter in a line with the candle, in the concavity between the thumb and the forefinger, *so as to make as it were a frame for it*, and then *to bring this part of the tube quite close to the eye* (fig. 6, *d.*). The observer must look out sharply for the first appearance of the fine transverse line of light which dilution brings into view; and the earliest indications are obtained by turning the tube on its axis when the line will be caught first of all on the side. The fluid is then added point by point until the line is just apparent when the long diameter of the tube is directed to the flame. This indication is a very delicate one, and requires a little pains at first in order to clearly recognise it without overstepping the necessary dilution, which of course brings it more definitely into view. The first difficulty is the only one, for when the earliest appearance of the line has been once observed it cannot fail to be afterwards recognised.

There is, as a rule, a rather rapid transition between the total absence of the line quite across the tube and the presence of it. Most observers will find no difficulty in defining their readings by stages of half a division, *i.e.*, one degree. It is not necessary to hurry over each observation after adding more fluid and mixing up; for the opacity remains uniform for several minutes.*

The hæmoglobinometer and hæmocytometer as well Dr. Solly's camera are supplied by the Tintometer Company, The Colour Laboratories, Salisbury.

* The corpuscles themselves and the uniform distribution of them may be observed as separate particles when, on turning the short diameter of the tube towards the flame, the contents are examined by means of a pocket lens.

CHAPTER II.

The Blood: Normal Variations in the Hæmoglobin and the Corpuscles.

The Physiology of the Red Corpuscle.

Notwithstanding recent advances in our knowledge of the chemical, histological, physiological and pathological aspects of the blood, there still remains much to be learnt in regard to the definite influence of the leading physiological conditions and processes upon the life-history of the red corpuscle. It is true we are led by recent investigation to entertain certain views as to its birth-place and as to how it terminates its little cycle of life; and we know well enough the all-important rôle it plays in the organism which it serves; but our present knowledge of the physiology of the corpuscle fails to furnish definite answers to such questions respecting it as the following:—What is the influence of the different physiological conditions that obtain from hour to hour, and indeed from day to day and from week to week, on the relationship which subsists between the corpuscle and the plasma on the one hand, and between it and the hæmoglobin on the other? Do the variations in the physiological state of the organism, be it that of rest or exercise or the ingestion of food or water or the like, induce corresponding variations in the corpuscle in its twofold aspect? and if so, what are the ordinary limits of the fluctuations thus induced in the blood in health and furthermore in disease?

The solution of such questions as these is highly desirable from a purely physiological standpoint; and it is moreover, an absolutely necessary preliminary to any satisfactory clinical hæmometric observation.*

New Apparatus Necessary.

In order to prosecute successfully this enquiry into the physiology of the red corpuscle, it was soon discovered, that it was necessary to devise new instruments of observation, which ensured much narrower limits of possible error in the observer than were afforded by the apparatus hitherto in use.

The Collection of Data.

With the view of determining the variations in the hæmoglobin and the chromocytes it was of course

* Much has already been achieved in this field by the labours of a number of workers, such as Hayem and his pupils Dupérie and Cadet, Grawitz, Schiff, Tietze, Egger, Schüller, Hedin, Cohnstein, Miescher, Zuntz, Sterlin, Chéron and Lloyd Jones among others too numerous to name individually.

necessary to make a large number of observations under different physiological conditions.

The blood of many healthy subjects was observed in order to ascertain the influence of age and sex; and two long series of observations were made on the blood of subjects A and B, the former 27 and the latter 54 years of age. In both these subjects the corpuscles and hæmoglobin were determined night and morning for seven months. Besides this long series of consecutive observations, innumerable others were made in order to determine the effects of exercise, of digestion, and of other causes of physiological variation in the the proportion of the corpuscles and hæmoglobin. The collection of these physiological data was the conjoint work of Dr. Edgecombe of Harrogate and myself. The subjects were placed under the same physiological conditions, and the results were not recorded until cross-checked by each of us. There was, however, rarely any discrepancy between us as to the readings, and when any did arise it was trifling, and was adjusted to our mutual satisfaction. This fact shows two things; first the advantage of two observers working together in making such observations as these, and secondly the smallness of the personal equation to be attached to the methods employed. Besides the special experiments referred to, a series of consecutive hourly observations was made during several weeks in which the ingestion of food and liquid and the output of urine were noted.

I observed the effects of altitude on the red corpuscle in various subjects during two visits to Switzerland—to Davos Platz in 1896 and to Arosa in 1899; and likewise the effects (1) of variation in the humidity of the atmosphere at Florence in 1899, and (2) of the low humidity of Egypt in 1900.

Observations were also made by me on animals. In the first instance dogs were used, but it was found that the thick hide renders these animals much less suitable for this kind of observation than man. Some satisfactory and reliable observations were, however, made on the blood derived from the veins on the outer surface of the rabbit's ear, showing the range of daily variation.

The rapid hæmometric methods described in Chapter I. have also been applied during the past four years to the general run of cases in order to determine the value of such extended observation of the blood in clinical work.

I estimate that not fewer than 40,000 observations have been made with the view of determining the physiological and clinical variations in the chromocytes and hæmoglobin.

The numerous data thus collected have thrown some light on the influence of gravity, exercise, work, rest and sleep, digestion, altitude and atmospheric humidity in varying the proportions of the hæmoglobin and of the chromocytes.

The Blood derived at the same time from different parts of the body.

The blood furnished by different regions of the body does not always afford the same proportions of corpuscles and hæmoglobin. A large number of observations were made on subject A, with the invariable result that the blood furnished by the toes was much poorer than that afforded by the fingers. Sometimes the difference was enormous (fig. 8).* This disparity

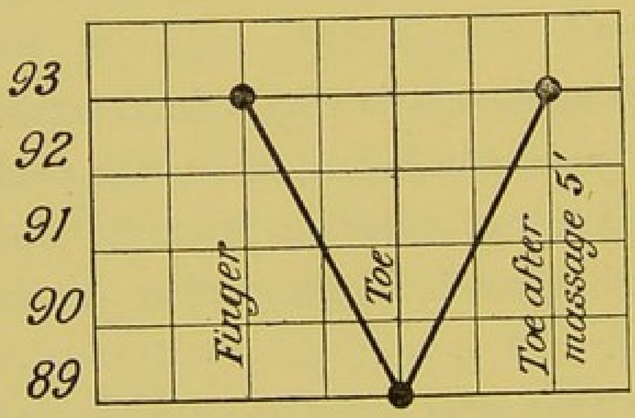


FIG. 8. Percentage of corpuscles in finger and in toe before and after massage of toe.

does not seem to be the same in all individuals; for in subject B, who possesses a higher arterial pressure, it was less apparent. It does not, however, follow that the blood present in the vessels of the part in question is actually different in quality; for it has been repeatedly found, that when the toe, which yielded a

* For the sake of clearness and brevity, the variations in hæmoglobin are omitted from all the figures.

sample of very inferior quality was well rubbed, it furnished another quite comparable with that derived from the finger (fig. 8). Probably, therefore, the cause of the difference is not in the blood itself, but is to be found outside the vessels. It is not unlikely that a larger amount of lymph is normally present in the tissues of the feet than obtains in other parts, in consequence of gravity increasing the intra-capillary pressure and thus augmenting exudation, and at the same time retarding the onflow of lymph. It would, therefore, seem that massage applied to the toe merely disperses this excess of tissue-lymph and enables the observer to ascertain the quality of the blood as it actually exists in the vessels. Exactly the same thing is not unfrequently observed in anæmia; the proportions of the corpuscles and hæmoglobin rising very considerably after the application of massage for a few minutes to the finger. Probably, therefore, there is often, if not generally, an excess of tissue-fluid even in the finger in anæmia, and consequently in this condition the sample of blood obtained in the ordinary way without previous massage does not always afford a true reading of the actual state of the blood. The existence of this diminutive degree of œdema in the insufficiently nourished tissues of the anæmic is, moreover, rendered probable by the experiments of Lazarus Barlow. This observer says, "This explanation of œdema as the result of anæmia I have confirmed in the following way. By means of an Esmarch's bandage I rendered the limb of a dog bloodless, while at the same time of course most of the lymph was removed from the part. After keeping the limb thus anæmic for from two to three hours I removed the bandage, and now by means of the specific gravity method I found that œdema came on. The arterial blood rose in specific gravity, the blood in the femoral vein rose in such a way as to show that more fluid was being lost during the passage through the limb than normal; the muscles and skin fell in specific gravity. Starvation of the tissues therefore plays an important part in the causation of passive œdema."*

Posture.

The remarkable effects of gravity on the composition of the blood is well illustrated by passively elevating a limb (arm or leg) for fifteen minutes. Figs. 9 and 10 show that the proportion of corpuscles is thus markedly reduced. This result was invariable in both subjects. It will be observed (fig. 10) that even the blood derived from the great toe, though poorer in corpuscles than that of the finger, becomes still poorer after passive elevation of the leg for fifteen minutes, and the blood afforded by the finger before resumption of the erect posture becomes richer in corpuscles than that observed before the leg was elevated. These rapid alterations in the proportion of the corpuscles

* "The Pathology of Œdema," *British Medical Journal*, 1895, vol. i., p. 635.

is much in keeping with the effects of gravity on the blood-pressure (see Chap. V.). It may, therefore, be inferred, that the variations in the percentage of the corpuscles are in keeping with similar alterations in the intra-capillary pressure; that when there is an increase of it (as in the lowered parts, fig. 10) there is probably augmented normal exudation, and when there

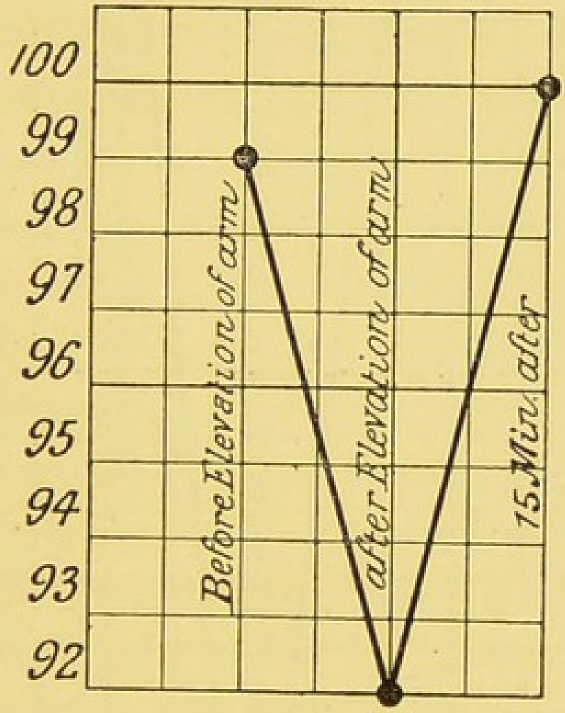


FIG. 9. Percentage of corpuscles before and after passive elevation of arm.

is a reduction of it (as in the elevated limb, fig. 8) there may be an arrest of normal exudation, or probably there is an osmotic inflow of tissue-fluid into the blood through the capillary wall.*

* Professor Starling's experiments support this explanation. "Whereas capillary pressure determines transudation the osmotic pressure of the proteids of the serum determines absorption. With increased capillary pressure we shall have increased transudation until we get equilibrium established. . . . . With diminished capillary pressure there will be an

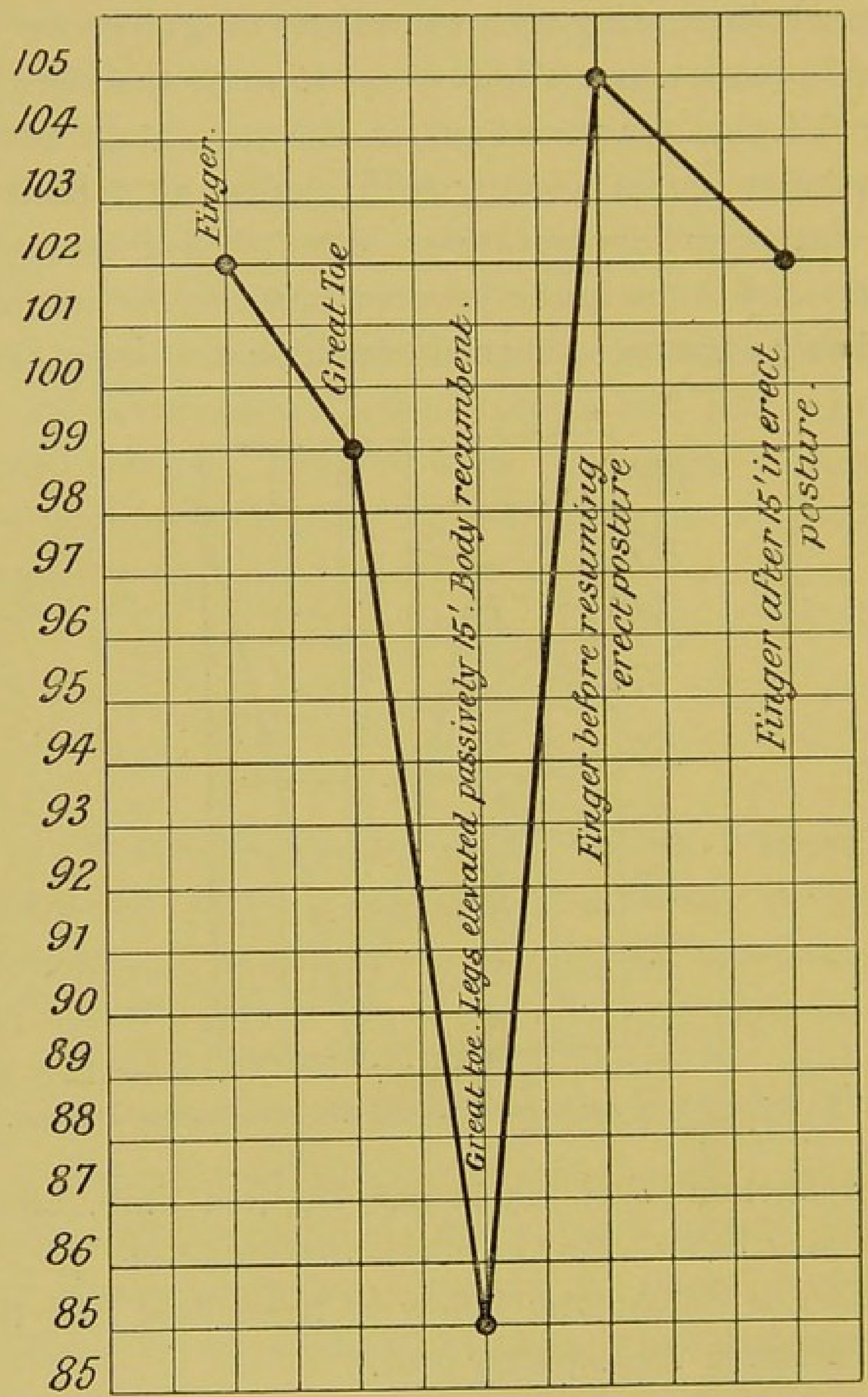


FIG. 10. Percentage of corpuscles in finger and toe. Effect of posture. Passive elevation of legs.

osmotic absorption of salt solution from the extra-vascular fluid until this becomes richer in proteids." "The Arris and Gale Lectures," *The Lancet*, May 16, 1896.

Apart from this view of fluid exchange (transudation and osmotic absorption) another theory has been suggested in explanation of quickly induced blood changes such as these; namely that of Cohnstein and Zuntz.* These observers conclude from experiments on animals that the capillaries are normally poorer in corpuscles, and therefore richer in plasma, than the larger vessels, and consequently when the arterioles leading to the capillary field are contracted the blood in that field becomes still poorer in corpuscles and that elsewhere still richer; and when they are dilated the capillary blood contains a larger proportion of corpuscles and the plasma previously present in it in comparative excess is now distributed and dilutes the rest of the blood. According to this theory widening of the arterioles and the extra filling of the peripheral vessels under the increased blood-pressure induced by gravity will augment the corpuscles, whereas the shrinking of them under the diminished pressure caused by elevation will increase the plasma and will therefore reduce the corpuscles.

Whichever theory be accepted, the fundamental position, however, remains, that the alterations in the blood are closely associated with similar differences in the intra-capillary pressure; and this is further illustrated by the fact, that when a limb is maintained in the vertical position by muscular action the proportion of the corpuscles is not only not reduced, but is actually increased (fig. 11). Fig. 12 further illustrates this fact,

* Pflüger's *Archiv.*, 1888.

for it shows that elevation of the leg by muscular effort may raise the percentage of corpuscles in the blood of the toe to that of the finger, and that on

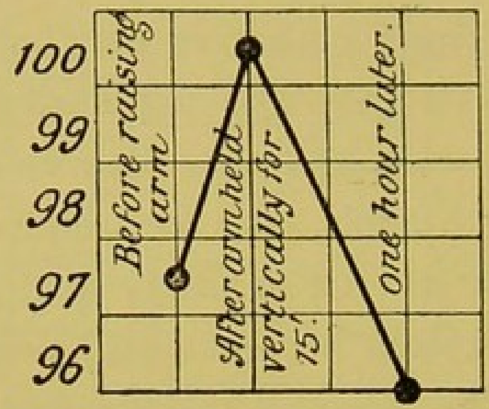


FIG. 11. The percentage of the corpuscles in the finger before and after raising the arm vertically for fifteen minutes by muscular effort.

passively maintaining the elevated position of the limb the usual fall of that percentage then takes place.

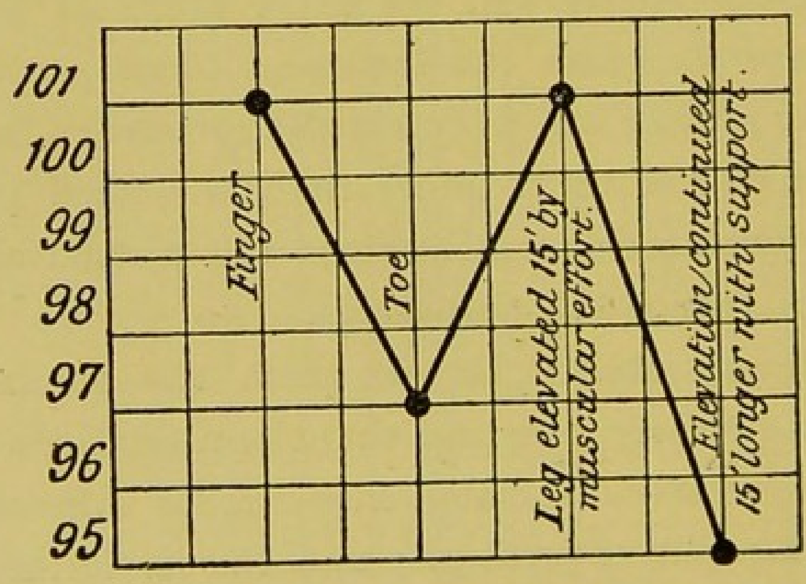


FIG. 12. Percentage of corpuscles in finger and in toe before and after active elevation of leg followed by passive elevation.

From these observations it would seem, that the intra-capillary pressure of the elevated limb is not only prevented from falling, but is increased by the afflux of blood which occurs when the muscles are brought into play, and that, when the muscular action is withdrawn and the vertical limb is passively supported, the intra-capillary pressure promptly falls.

The observations on the influence of gravity on the composition of the blood and the thwarting of that influence by muscular action illustrate the wisdom of passively supporting a part when in a state of inflammation or inflammatory congestion; for such a procedure not merely tends to reduce the blood-pressure but to diminish the percentage of the corpuscles also.

Exercise.

Exercise, whether local or general, produces a very appreciable alteration in the blood, especially in regard to the proportion of the corpuscles to the plasma.

1. **Local exercise** may be active or voluntary, as when the hand is flexed and extended on the forearm until fatigue is induced, or when the muscles of the arm are thrown into a state of tonic contraction, as in the resistive movements and extension exercises (Chap. VI.); or it may be passive as when produced by faradism or massage. It has been found that local muscular action, *however induced,* causes an immediate, decisive and proportionate rise in the corpuscles and in the hæmoglobin. Fig. 13 illustrates this effect produced by flexion and extension of the forearm, and the same result is induced by resistive

movements, by massage, and by faradism. Fig. 14 shows, that the rise caused by local exercise may be extended by faradism. In all cases the increased

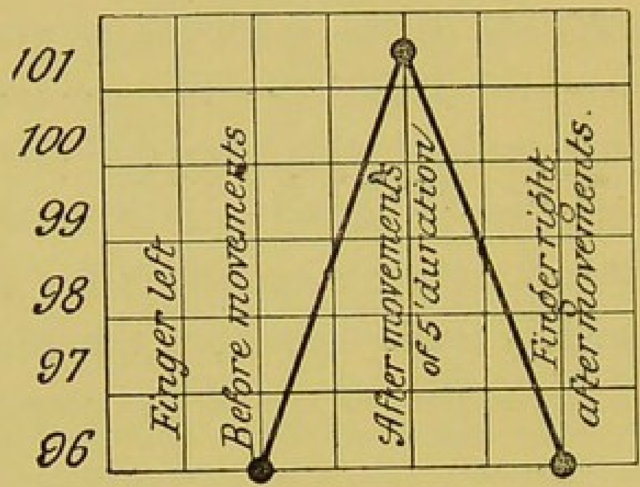


FIG. 13. Percentage of corpuscles before and after local exercise.

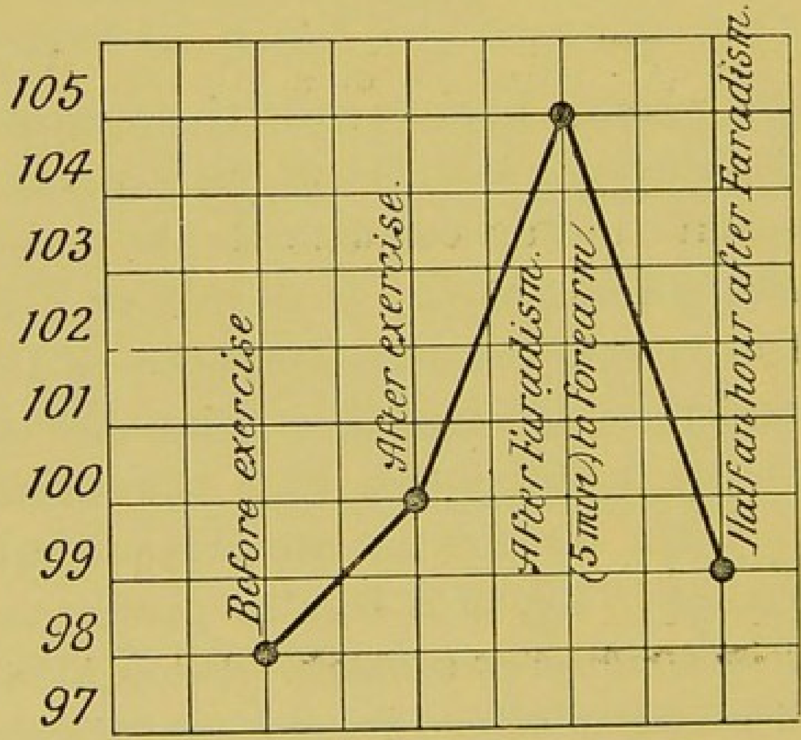


FIG. 14. Percentage of corpuscles before and after local exercise, and after faradism following the exercise.

proportion of the corpuscles was found to be purely local; for at the termination of the procedure the blood yielded by the opposite finger furnished the same reading of corpuscles as was observed before the muscles were brought into action (fig. 13). Though the rise was rapid it did not subside so quickly; for the disappearance of it generally required from thirty to sixty minutes, and in the case of massage it lasted longer than after voluntary exercise or faradism. It was observed that galvanism of the forearm (contraction of the muscles being avoided), faradism of the finger and massage of the finger* did not disturb the reading of the corpuscles. The invariable antecedent of the rise of the corpuscles was either muscular contraction or manipulation of the muscular tissue, which in producing this effect is equivalent to muscular contraction.

Inasmuch as the rise in hæmoglobin is proportionate to that of the corpuscles, this common effect of active and passive exercise of the muscular tissue for short periods is obviously due to an increased proportion of the chromocytes to the plasma. How is this temporary and strictly local apoplasmia produced?

It is elsewhere shown (Chap. V.) that there is some probability in the view, that the increased volume of blood which circulates through the muscular tissue when brought into action, and the consequent increase of the intra-capillary pressure within that tissue, may lead to the effusion of watery fluid from the blood

* This observation only holds good when the circulation is normally vigorous; for when it is enfeebled, and especially when the blood is poor in corpuscles and hæmoglobin, massage of the finger may produce a marked rise of the chromocytes.

into the substance of the muscles. But inasmuch as the blood supply of the finger is not immediately connected with that of the muscles, it is somewhat difficult to see how muscular exercise can thus affect the blood in the finger. This, however, is not the only explanation available, for it is known, that in a state of rest there is no lymph-flow at all,* and that muscular contraction is necessary to propel the lymph from the lymph-spaces into the lymphatics; therefore, when all the muscles of a limb are thrown into action, there will be an immediate acceleration of the circulation of lymph from the whole limb, including a considerable area of non-muscular tissue, accompanied by an augmented exudation of fluid from the blood to the tissues (non-muscular as well as muscular). The muscular action of a limb therefore accelerates the circulation of all the fluids in the limb, and the increased intermediary transfer of fluid from the blood through the capillary wall to the lymph spaces and from these to the lymphatic vessels must reduce the volume of the plasma in all the vessels of the limb. There is one experiment recorded which may have a bearing on this explanation (fig. 15). The left arm was firmly constricted above the elbow, but not so constricted as to stop the pulse, and the muscles of the forearm were thoroughly faradised for three minutes, but the blood drawn from the left forefinger afforded no evidence of change. Faradism was then applied in exactly the same manner and duration to

* Starling, *op. cit.*

the right forearm free from constriction, and the blood of the right forefinger showed the usual marked rise of corpuscles. The inference seems to be, that in the former case the lymph flow was arrested by the constriction, and the accumulation of tissue-fluid nullified the rise of the corpuscles. Moreover, when treating on general exercise an observation will be adduced, which shows that exercise does cause an increased transfer of fluid to the tissues, which, however, lodges

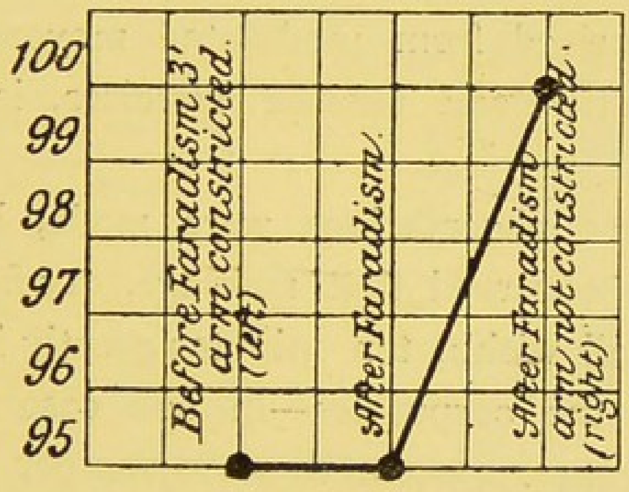


FIG. 15. Percentages of corpuscles before and after faradism with one arm constricted and the other non-constricted.

in a limb until it is removed by massage or by muscular contraction.

Cohnstein and *Zuntz* might refer this effect of muscular contraction on the blood to the increased filling of the whole peripheral area of the circulation in the exercised part—the normal relative excess of plasma in that part being thus diminished. But elsewhere it is shown (p. 87) that when the non-muscular part of the periphery is well filled by the agency of warmth the corpuscles are found to be reduced. All the facts seem to be best explained by supposing that muscular contraction stimulates the circulation of all the fluids and aspirates, as it were, the lymphatics of the non-muscular and remote parts of the limb, and thus reduces the storage of tissue-lymph in them. Moreover this view explains to a large extent the wide-reaching effect of exercise on the nutrition of all the tissues by promoting that most important part of the circulation of fluids, the intermediary circulation. In this way in all probability some of the benefit which is derived from modulated movements, such as the resistive and tension exercises, is to be explained.

Since these observations were made, I find that Chéron has observed that massage, dry friction, and electricity will within ten minutes greatly increase the number of the corpuscles—in one case of anæmia raising it from 2,430,000 to 4,080,000 per c.mm. He ascribes this rise to the concentration of the blood induced by the increased transudation of fluid resulting from augmentation of the blood-pressure.*

2. **General exercise** may be passive, as in massage of the limbs and trunk, or it may of course be active.

(*a*). *Passive general exercise.*—Massage, when applied to all the somatic tissues, raises the percentage of the chromocytes, just as when it is confined to a limb, and Edgecombe has demonstrated that it likewise increases the hæmoglobin in exactly the same ratio—so that

* *Compt. rend. de l'acad. des sciences*, 1895, vol. ii., No. 6.

general massage does not impair the "worth"* of the corpuscles. Fig. 16 "shows in graphic form the result of two typical experiments. In no case was a fall in the worth of the corpuscles observed after massage. Moreover, a prolonged course of massage (one hour twice a day) on a subject whose blood decimal, or

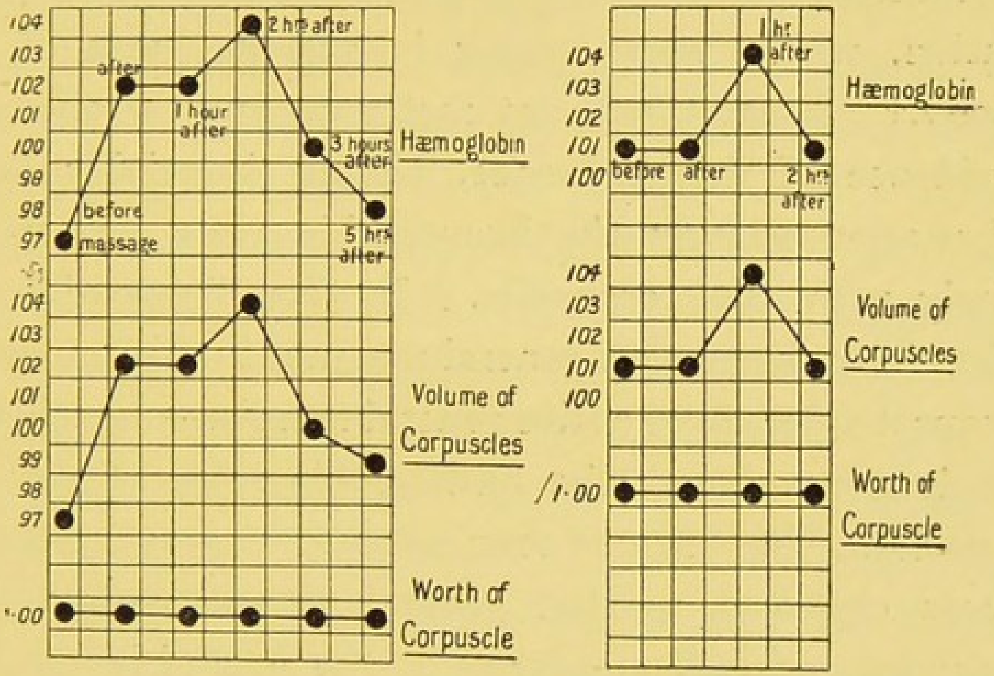


FIG. 16. Massage: A. Heavy movements (40 mins. to limbs and body). B. Light movements (40 mins. to limbs and body).

worth, was normal, had no effect in either raising or lowering it. Before the course the blood averaged $\frac{88HG}{88C}$ = 1·00 worth; after three weeks' massage it rose to $\frac{109HG}{109C}$ and after six weeks' massage it fell to

* The "worth" of the corpuscles in hæmoglobin is expressed by the figure obtained by dividing the percentage of the hæmoglobin by that of the corpuscles.

$\frac{98HG}{98C}$ about which point it remained."* After massage J. Mitchell noticed an increase of the chromocytes, which attained its maximum an hour after the cessation of the process, but without a corresponding rise in the hæmoglobin. He explains this anomaly by suggesting that massage may dislodge a number of corpuscles poorer in hæmoglobin than those in circulation, which were resting in various parts of the body.† So far I have not met with any corroborative evidence of this inference, having invariably found that after massage the hæmoglobin rises correspondingly with the corpuscles. In fact observation has definitely shown that general massage in this important respect differs from active general exercise—namely that it does not impair the hæmoglobin value of the corpuscles. The obvious conclusion to be drawn from the facts observed is that general massage—like local exercise or faradism—drives on the flow of lymph, and increases the transudation of fluid from the blood through the capillary wall; in a word, that it diminishes the volume of the blood by reducing the amount of water in the plasma, and in this way raises *pari passu* the percentages of the corpuscles and hæmoglobin in

* "The Effect of Exercise on the Hæmoglobin with Reference to the Value of Rest in the Treatment of Anæmia," by Wilfred Edgecombe, M.D., F.R.C.S. Eng., Harrogate. *Brit. Med. Journ.*, June 25th, 1898.

† "Massage and the Blood." *Amer. Jour. of Med. Science*, May, 1894.

proportion to the increased concentration of the blood.

(*b*). *Active general exercise.*—In animals I have observed that active exercise produces an increase in the percentage of the corpuscles, and a less pronounced increase in that of the hæmoglobin—the result being a fall in the hæmoglobin worth of the corpuscles. For instance, an hour's run in a dog, that had been kept in the laboratory for several weeks, raised the corpuscles from 99·5 to 110 points, and the hæmoglobin from 104 to 109 points, and reduced the "worth" from 1·04 to 0·99. It has been shown by Löwit that the binding down and tying of animals—especially when long continued—induce severe changes in the composition of the blood.* I have likewise observed that the struggling of a rabbit for a few minutes, as when the animal is carried by the ears, or is tied up, will impair the validity of the results of any observations of the blood made for the purpose of determining the proportions of the corpuscles and hæmoglobin. For instance, in one case before such strenuous muscular effort, the corpuscles read 92, but immediately after it, 110 points, and in ten minutes afterwards, 105. Therefore it would seem that profound (though temporary) alterations in the blood are immediately induced by active general muscular contraction.

In attempting to determine the effects of general exercise on the blood, it is difficult to eliminate the

* "Studien zur Physiologie u. Pathologie der Blutes u. der Lymph," p. 9, quoted by Sherrington, *Proc. Roy. Soc.*, vol. lv.

rise in corpuscles due to perspiration. The general results, however, of the observations already made may be stated to be (1) a rise in the corpuscles, which, after a variable period somewhat subsides, but remains above the initial proportion while the exercise lasts, and (2) a similar though diminished rise and reduction of the hæmoglobin. The rise in corpuscles and hæmoglobin produced by an hour's active walk generally subsides after an hour's rest.

1. *The rise in corpuscles resulting from active general exercise* is due to the same increased transfer of fluid from the blood, and the same augmented lymph flow, as takes place in local exercise; but the concentration of the blood thus induced is, after a time, probably somewhat lessened by the return of some portion of that fluid to the blood. The following observation shows that in general exercise fluid is transuded through the capillary wall into the lymph spaces where it lodges, and where its presence can be demonstrated, so long as the muscles of the part are at rest. It was found that, when an arm is slung without constriction during general exercise, the volume of the limb increases, and the blood yielded by the finger falls in corpuscles, while that afforded by the free and exercised arm rises; and then, when the finger of the passive arm is well rubbed upwards and rolled for a few minutes, it furnishes a sample as rich in corpuscles as that obtained from the opposite finger. This observation was repeated in two subjects who ascended the Schatzalp (1020 feet) at Davos; and as

the results were the same in both, it is only necessary to give the figures furnished by one of them. On return from the ascent the blood from the finger of the slung arm contained 3 points fewer corpuscles, and that from the opposite finger 5 points more than on starting out, and after massage of the former finger the corpuscles rose 8 points, so that now they read exactly the same on both sides.* In this case the tissue fluid in the non-exercised limb was increased, probably from the rise in blood-pressure resulting from the general exercise, but in the absence of muscular contraction it was not removed from the tissues as in the exercised limb, so that the blood issuing from the finger of the passive arm was diluted by it, until it was dislodged by massage, when the true reading of the blood was ascertained, namely a rise in corpuscles equal to that observed in the exercised limb. It is, I think, not improbable that the apparent effect of general exercise on the percentage of the corpuscles is in different subjects modified by the amount of tissue lymph present when the exercise is taken. In those, for example, who do not take exercise habitually, or in whom the circulation is languid, or the blood is poor, the lowered intermediary circulation favours the storage of tissue fluid, and exercise may fail to incite an apparent rise in the corpuscles. On the other hand, those accustomed to regular active exercise

* For the sake of clearness I have omitted to give the hæmoglobin estimations. The fall in the worth of the corpuscles, the result of this effort, was 0·05.

have a smaller storage of tissue lymph, a permanently high specific gravity of the blood,* and a rich supply of chromocytes and hæmoglobin.

2. *The effects of active exercise on the hæmoglobin* are two-fold: namely, (*a*) immediate, reducing the "worth" of the corpuscles, and (*b*) remote, increasing it.

(*a*) The *primary* effect on the hæmoglobin, namely the destruction of a certain portion of it, is shown by the result of the examination of the blood before and after each spell of muscular exertion (fig. 17). But this fact can be demonstrated in another way. It is elsewhere shown (p. 64) that a normal diurnal fall in the value of the corpuscles takes place during the waking hours, the evening record showing a lower value than that of the morning. With the view of ascertaining the effect of exercise on this day fall in the worth of the chromocytes, Edgecome made a continuous series of night and morning observations of the blood of a healthy

* Lloyd Jones, *Journal of Physiology*, vol. xii., p. 318. This observer found that "the specific gravity of the blood falls with moderate exercise continued for a short time, but rises when this is continued longer. When perspiration becomes profuse there is a rapid rise, and it should be noted that the specific gravity rises then to a point higher than it was at starting . . . . . . Gentle exercise on a cool day not prolonged or leading to active perspiration led to a fall in the specific gravity, the same more prolonged led to a rise. On a hot day the fall was not always demonstrable." He gives examples of the fall and the rise, and among the latter instances the case of running 4½ miles raising the specific gravity from 1058·5 to 1061·0. *Journal of Physiology*, vol. viii., p. 9.

subject, extending over a period of three and a half months, on thirty-five days of which a considerable and varied amount of exercise was taken, and on the remaining days (sixty-five) it was not taken; and he found that the average daily fall in the worth on the exercise days

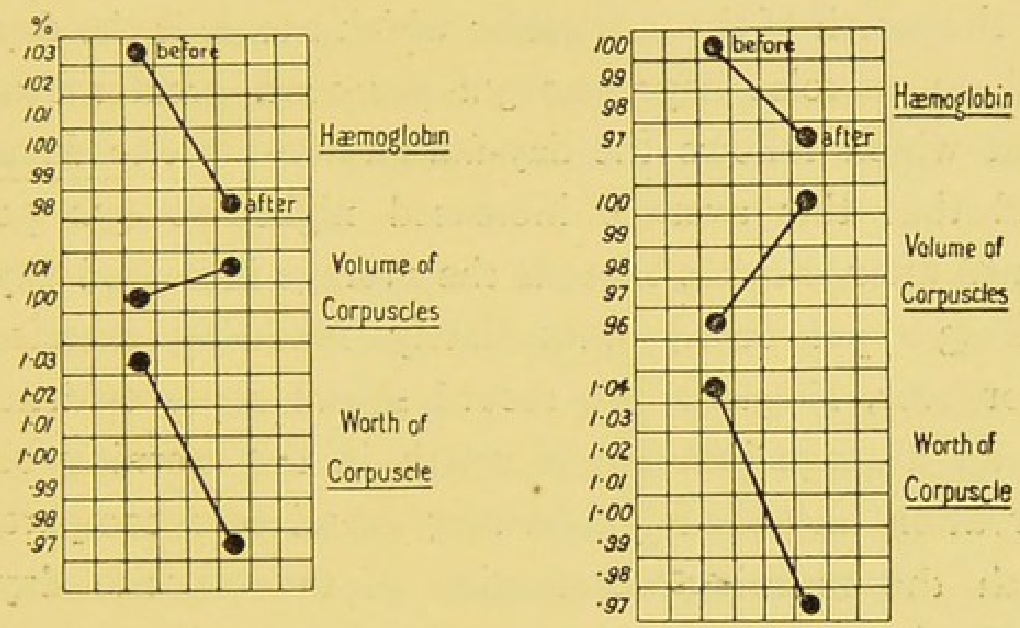


FIG. 17. Shows two examples of the result of exercise, the first (2 hours cycling and horse riding) without sensible perspiration, the second (2 hours hard tennis) with profuse perspiration.

In each case a fall in percentage of hæmoglobin took place, with a rise in percentage volume of corpuscles, and, consequently, a fall in the "worth" of the corpusle. Where profuse perspiration occurred the rise in percentage of corpuscles is considerable, due partly to concentration of the blood by withdrawal of fluid; hence the fall in worth in this case, the exercise being more violent, is greater than in that where no sensible perspiration took place. (Observed by Edgecombe, *op. cit.*).

was 9·1 per cent., while that on the exercise-free days was but 6·1 per cent., showing an increased fall of 3 per cent. attributable to exercise.*

(*b*). The *ultimate* effect of exercise on the hæmoglobin, in stimulating the formation of it, is indicated

* *Op. cit.*

by the rise in the worth of the corpuscles, which takes place some hours after the immediate fall indicating the using up of the hæmoglobin. Edgecombe has demonstrated this position by his continuous record of night and morning observations of the blood changes just referred to. He shows that the average night-rise in the worth of the corpuscles which succeeds the day-fall on exercise days was 3·2 per cent. greater than that which follows the day-fall on non-exercise days; and that this average increased night-rise (3·2 per cent.) after exercise exceeds the average increased day-fall (3·0 per cent.) immediately following exercise. Moreover, Edgecombe's record shows some evidence of an average increase of worth in the morning observation immediately following exercise as compared with the morning observation of the exercise days themselves; and, furthermore, it supports the conclusion, that during a period when frequent exercise is taken, the average level of the worth of the corpuscles is higher than that of a period of the same length during which little or no exercise is taken.* Therefore, the facts so far collected show that exercise in healthy subjects, though temporarily destroying hæmoglobin, induces a net gain in favour of the formation of it; and it would seem that this net gain is stored up as a reserve supply to meet contingencies.

The bearing of these conclusions on the adjustment of exercise in cases of anæmia requires a passing notice. It should not be inferred, that because active

* *Op. cit.*

exercise stimulates the over-production of hæmoglobin in subjects furnished with normal blood, it will likewise exert a similar influence when the hæmoglobin charge of the chromocytes is reduced; for it is more than likely that the destructive effect of exercise will then predominate, and the ulterior constructive influence of it apparent in health will not come into play at all. Clinical experience strongly supports this view, and teaches the importance of guardedly prescribing the amount of exercise, or of prohibiting it entirely, whenever the hæmoglobin charge of the chromocytes is diminished. Frequent examination of the blood affords the surest guidance on this point. The building up of hæmoglobin is best favoured in extreme degrees of anæmia by rest and the total prohibition of active exercise; in moderate degrees of anæmia by more rest than exercise, and this should only be permitted in its lighter forms; and in the milder varieties of anæmia by exercise limited in duration and degree.

It has already been pointed out that massage differs physiologically from active exercise in the fact, that it does not like exercise impair the worth of the corpuscles; it is therefore an ideal form of exercise in anæmia, and especially so in the hydræmic form, chlorosis, in which it concentrates the blood by stimulating the fluid transfer through the capillary wall.

Work and Rest. Diurnal Variation.

It has been shown that exercise, though it raises the percentage of the corpuscles and of the hæmoglobin, reduces the relative amount of the latter; it follows, therefore, that muscular work uses up a certain proportion of the hæmoglobin. It has likewise been shown that rest following exercise is attended by an increased formation of hæmoglobin—the hæmoglobin temporarily destroyed by exercise being replaced with a slight excess; in this way muscular work when followed by a due amount of rest stimulates the production of hæmoglobin.

Two series of 800* night and morning observations (made at bedtime and on rising) of the corpuscles and hæmoglobin in Subjects A and B have furthermore demonstrated that the daily work of the waking hours likewise produces a fall in the hæmoglobin value of the corpuscles; and they have moreover proved that rest and sleep not merely restore the hæmoglobin lost during the working portion of the day, but provide a slight excess beyond it, apparently to serve as a reserve store for the purpose of meeting exceptional calls upon

* Over 400 observations have been excluded because they were made before the methods of observation were quite settled; they, however, afford the same conclusions as those yielded by the observations which were accepted. Therefore the teaching afforded by the normal diurnal variations of the corpuscles and hæmoglobin may be said to be derived from over 1200 consecutive observations.

it. These important conclusions are supported equally well by the data furnished by each subject.

Night and morning variations in the percentage of the hæmoglobin (figs. 18 and 20).—The most striking fact is the rise during the night and the fall during the day. Taking the figures furnished by both subjects the rise took place in 90·5 per cent. of all the morning and the fall in 88·4 per cent. of the total evening observations. Only 5·1 per cent. of the morning and 4·4 per cent. of the evening observations were alike. Therefore in every 100 observations the night-rise of hæmoglobin was observed 90½ times and the night-fall only 4½ times; and the day-fall occurred 88½ times while the day-rise took place only 7 times.

In both subjects the average night-rise was 7·2 degrees, and the average day-fall was 7·4 degrees, and the maximum rise was 20 degrees and the maximum fall 21 degrees. It was observed that when the hæmoglobin fell in the night and rose in the day the average rise and fall were much less than when it followed the rule of rising in the night and falling in the day; for then the average night-fall was 2·1, as against 7·2 degrees night-rise, and the average day-rise 2·7 as against 7·4 degrees day-fall.

The night and morning variations in the volume of the corpuscles were observed to be similar to those of the hæmoglobin, only they were not quite so decisive, in both subjects the morning-rise and the evening-fall being less frequent. The day-fall was more frequently observed than the night-rise, the frequency of the former being 74·9 per cent., while that of

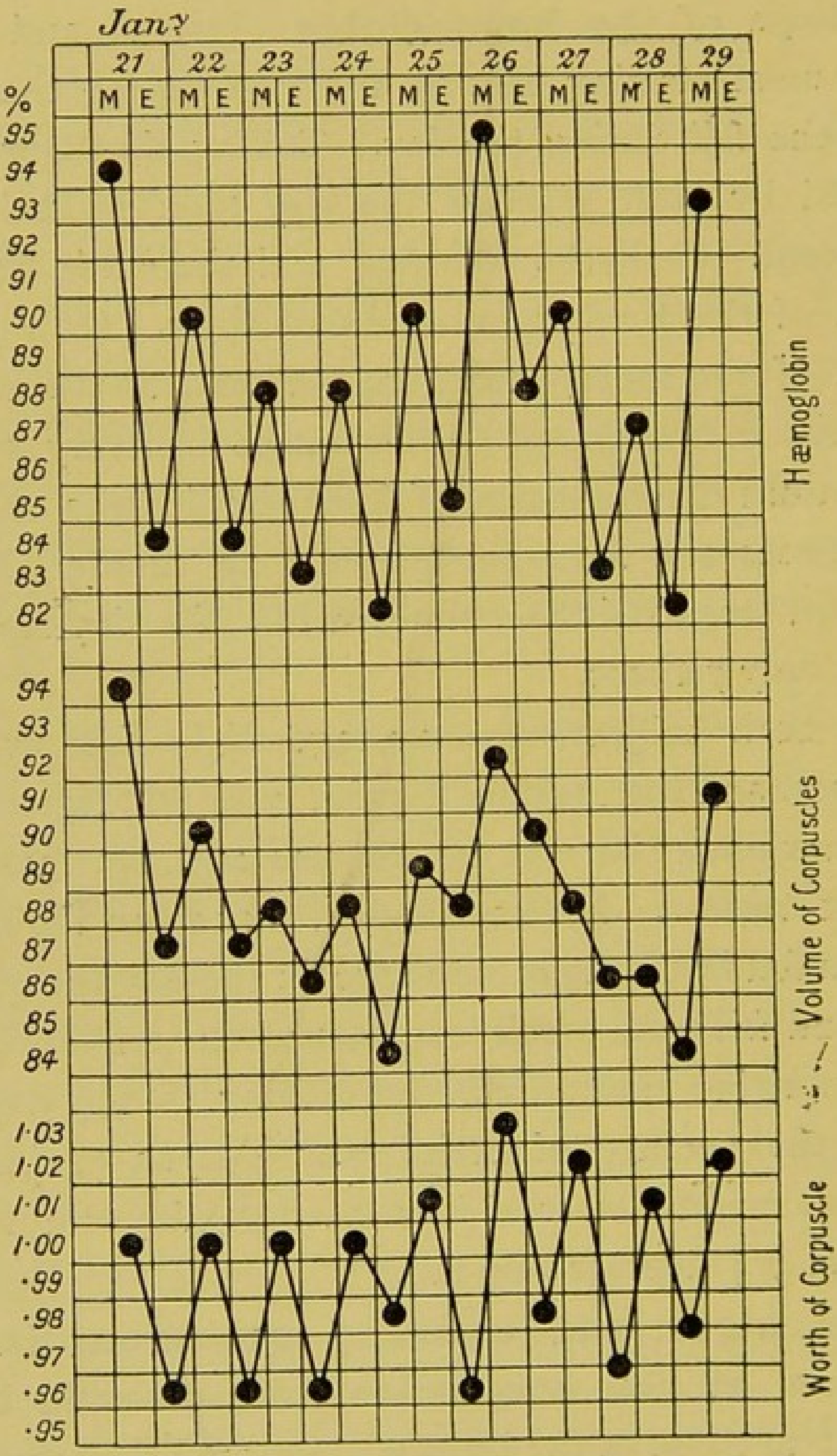


FIG. 18. Typical example of the normal daily and night and morning variations of the hæmoglobin, volume of the corpuscles, and the worth of the corpuscles. (Observations made by Edgecombe, *op. cit.*).

the latter being 68·5 per cent. Probably this difference indicates the influence of fluids taken during the waking hours. Moreover, the observations show that the range of variation in the volume of the corpuscles is less than that of the hæmoglobin, the difference between the night and morning and between the morning and evening observations being much smaller, and the number of the observations in which they do not vary at all being greater; for whereas the average variation of the hæmoglobin in 24 hours is 7·3 degrees, that of the corpuscles is not more than 4·3 degrees, and whereas the hæmoglobin was without variation in 4·8 per cent., the corpuscles were constant in 8·7 per cent. of the total observations in 24 hours. If it be accepted that the actual number of corpuscles in the same healthy subject remains fairly constant throughout 24 hours, it follows from these facts, that though the plasma is distinctly variable at different times during this short period, it is less variable than the hæmoglobin.

Inasmuch as the variations in the specific gravity of the blood depend chiefly on the proportion of the corpuscles to that of the liquor sanguinis, we should expect to find that the specific gravity will rise in the morning, when, as a rule, the number of the corpuscles is greater, and will fall at night, when it is less. The observations of Lloyd Jones have shown that the specific gravity of the blood is, as a rule, higher in the morning and lower at night.* This diurnal variation in the specific gravity (fig. 19) there-

* *Journ. of Physiol.*, vol. viii.

fore coincides with that in the corpuscles (figs. 18 and 20).

Night and morning variations of the "worth" of the chromocytes.—The data furnished by the night and morning observations show that in 74 per cent. of the morning observations the "worth" rises in the night, and in 73 per cent. of the evening observations it falls in the day, the average rise and fall (0·061 and

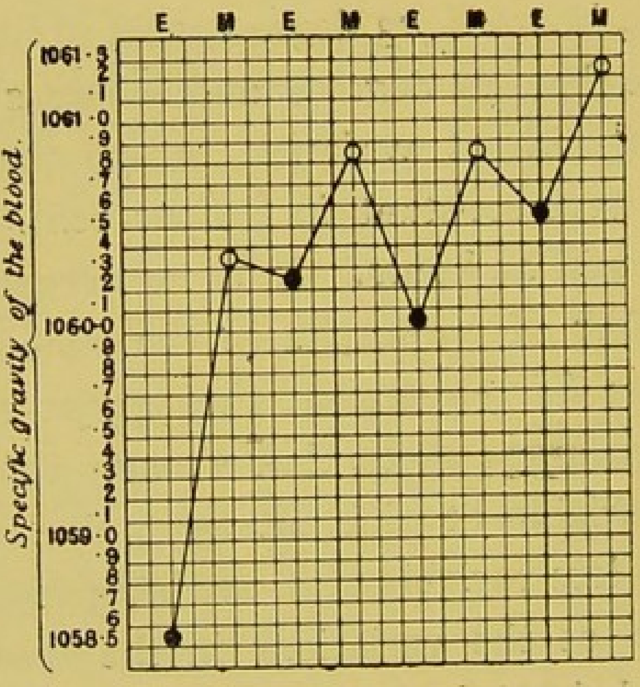


FIG. 19. The "diurnal variation" of the specific gravity of the blood (observations made by Lloyd Jones).

0·057 respectively) being nearly equal, but with a slight preponderance in the former. This average gain over loss of hæmoglobin provides the reserve to which reference has been made. The disappearance of a certain portion of hæmoglobin during the waking and working hours is due in all probability to actual destruction—the result of increased functional activity in oxidation. The reconstruction of the hæmoglobin lost in work during the periods of rest, which alternate with those of activity, is but an example of recuperation which proceeds in all the tissues when work is in

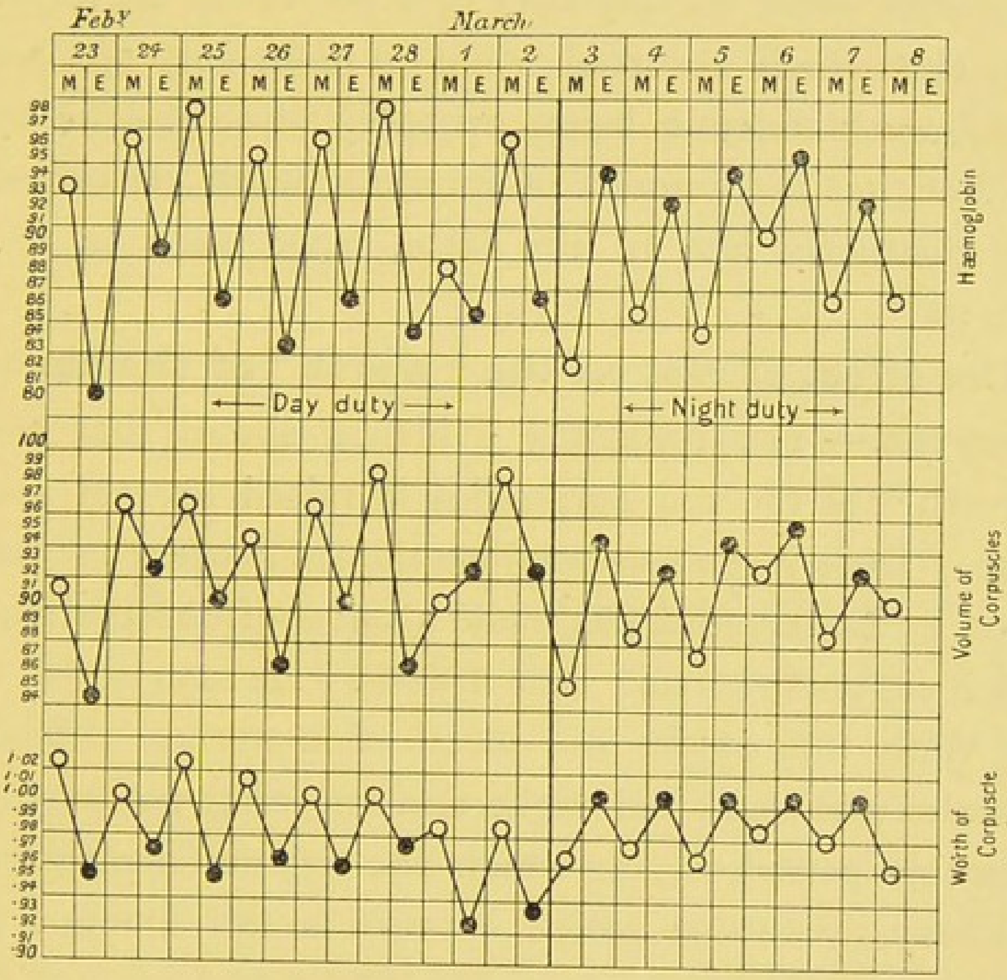


FIG. 20 shows the result of observations made on the blood of a hospital nurse aged 22 for a fortnight, the first half of which she was on day duty, the second half on night duty. (The readings were taken immediately after rising and before retiring to rest).

abeyance, the chromocytes being then recharged just as are the nerve-cells.

If this position be correct the diurnal changes in the corpuscles and hæmoglobin should be reversed when the night is devoted to work and the day is spent in rest and sleep. Edgecombe has found this to be the case (fig. 20). "When on day duty the blood showed the usual variation of day-fall and night-rise; when on night duty of day-rise and night-fall. It is interesting to note that the average fall in the worth of the corpuscle while on day duty (4·8 per cent.) is greater than that which occurred while on night duty (3·2 per cent.), the difference being probably accounted for by the fact that the amount of muscular work performed was distinctly less in the latter case than in the former."*

The effect of rest on the "worth" of the chromocytes.—The foregoing evidence shows that the "worth" of the red corpuscles is raised by rest and sleep. Does rest alone produce the same effect on the blood? Edgecombe has made a series of observations which support the view that it does. He says:—

"With this object the blood of a normal subject (female) was examined night and morning for a considerable period, during which she was performing her ordinary avocation, which entailed a fair amount of exercise, walking and cycling. She was then put to bed, and remained there for five days, after which she resumed her usual course (fig. 21).

"The general average of the readings is seen to be somewhat below the normal of 1·00. This is usually the case in female subjects. During the first period of ten days the hæmoglobin and corpuscles showed the customary variations of day-fall and night-rise, the

* *Op. cit.*

variation in hæmoglobin being relatively greater than that of the corpuscles, hence the variation in the worth of the corpuscles; the average day-fall for the ten days

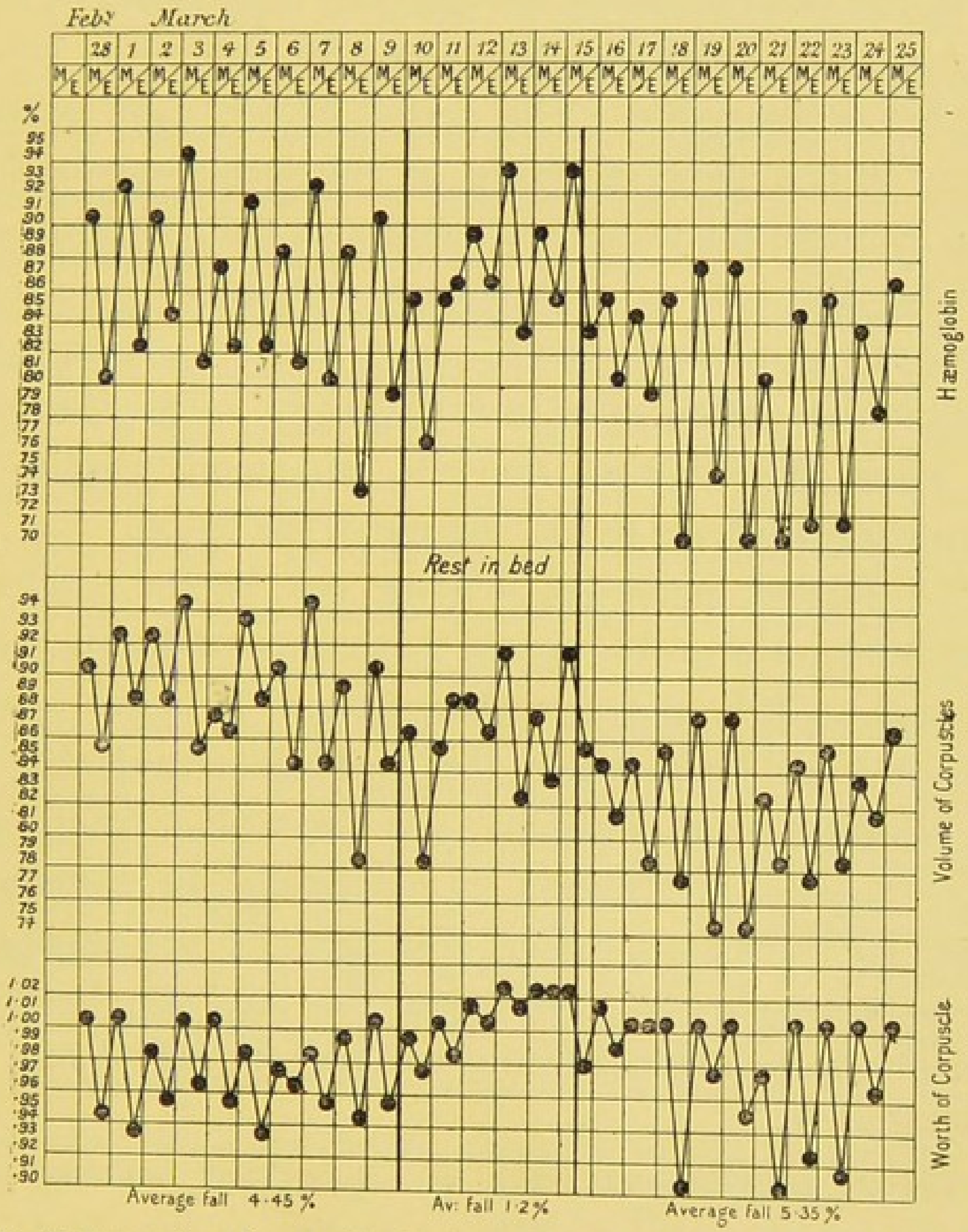


FIG. 21 summarises the results obtained. It is a portion of the complete chart of the subject in question, and embraces ten days previous to rest, five days in bed, and ten days subsequently.

being 4·45 per cent. During the period of five days' rest similar variations in hæmoglobin and corpuscles took place, but they are more nearly related to one another, hence the variation in the worth becomes less than before, the average fall for the five days being only 1·2 per cent. The factor of exercise being eliminated, the destruction of hæmoglobin that occurs in the day becomes much less than when the subject is leading her ordinary life. The period of ten days subsequent to rest shows a return to the normal condition, the average fall in worth being 5·35 per cent., rather greater than before. The general average of the readings of hæmoglobin and corpuscles fell somewhat during the period after rest, but as the worth remains at about its mean of 1·00 the fall merely implies a temporary increase in the volume of the blood.

"A further point of interest lies in the gradual steady increase in the worth that occurred during rest. Regarding the morning observations alone as being the readings taken when the blood is presumably at its steadiest point, a gradual rise takes place from 0·99 to 1·02, when it attained its maximum and remained there for three days, falling after activity was resumed to its mean of 1·00. Whether this high level would have been maintained through a long period of rest is doubtful."*

These conclusions have an important bearing on treatment of anæmia. When referring to the effects of exercise on the blood it was pointed out how they suggest the importance of limiting the amount of exercise within the hæmoglobin capacity of the blood in the management of cases of anæmia. In like manner the

* *Op. cit.*

work and worry incidental to the waking hours exert the same influence on the hæmoglobin as muscular exercise, and may prove just as injurious to the progressive building up of the hæmoglobin in anæmia as physical exertion is apt to do when carried beyond certain limits, which are largely determined by the hæmoglobin charge of the chromocytes. This position is amply confirmed by clinical experience in the treatment of anæmic cases, and the explanation is furnished by the observed destructive influence of work on the hæmoglobin. At the same time it is sometimes well not to overlook the fact, that work in healthy subjects stimulates the production of hæmoglobin as a remote effect, and that in slight cases of anæmia the modified exertions of daily life when relieved by frequent intervals of rest may favour the construction of the deficient hæmoglobin. The value of absolute rest in the treatment of severe forms of anæmia has been proved by repeated observation, and it would seem that this clinical fact finds its physiological explanation in the foregoing observations, which demonstrate the recuperative influence of rest in raising the hæmoglobin charge of the chromocytes.

CHAPTER III.

The Blood: Normal Variations in the Hæmoglobin and the Corpuscles (continued) and some Clinical Variations.

Digestion.

Observation of the effects of ninety-six meals (breakfast, lunch and dinner), each having an average supply of 17 oz. of fluid, shows that, as a rule, in from two to three hours, the proportions of the corpuscles and hæmoglobin fell in 70 per cent., rose in 23 per cent., and were without change in only 7 per cent. The evidence, therefore, preponderates in favour of a fall of the chromocytes* and hæmoglobin during digestion. The average "worth" showed but little alteration; for in 53 per cent. of the observations it slightly fell, while in 47 per cent. it either rose or presented no variation. Two other facts were also very frequently apparent; namely, a preliminary and very transitory rise in corpuscles shortly after the meal, and a rise with slight gain in "worth" subsequent to the lowest point of the fall. These stages of the effect of the digestive process

* Hayem states that his pupils, Dupérie and Cadet, found a diminution of from 200,000 to 300,000 corpuscles per c.mm., during digestion. *Du Sang et de ses alterations anatomique*, Paris, 1889.

on the blood taken from the systemic periphery are probably the resultants of several causes, of which perhaps the most prominent may be fluid-transfer and the hæmolytic and hæmopoietic functions of the organs accessory to primary digestion. The preliminary rise may be due to the copious outpouring of the digestive juices, producing a temporary concentration of the blood. But this effect is so transitory that it may be easily missed, even though the meal is a solid one; therefore it would seem that it is quickly compensated, either by the absorption of fluid, as from the tissues, or perhaps by a cytolytic process. The digestive fall appears to coincide with an increase in the volume of the blood, and with a reduction of the specific gravity as observed by Lloyd Jones,* and the subsequent rise with a reduction of the blood-volume through renal elimination, and a corresponding increase of the specific gravity. It has been observed that these variations are not caused by the water taken with the meals; for they are quite as pronounced when it is withheld.

Time and opportunity have so far failed me to ascertain the effects of certain diets on the blood-decimal—such as one exclusively vegetable or animal (*e.g.*, red meat and hot water—the Salisbury diet) and the osmotic effect of water and especially of mineral waters.

* *Op. cit.*

Altitude.

The remarkable effect of altitude in raising the proportions of the corpuscles and hæmoglobin has furnished one of the most interesting physiological problems in relation to the blood; a problem which has of late years attracted many observers who have now collected a large body of data with a view to its solution. All these observers (including Viault,* Egger,† Mercier,‡ v. Jaruntowsky and Schröder,§ Miescher,‖ Wölff and Koeppe¶) are perfectly agreed as to the facts; namely the presence of a larger number of chromocytes in the inhabitants of mountainous regions than in the residents of lower altitudes, and a rapidly induced increase of them in those of the latter who resort to the mountains—an increase which, however, as rapidly passes away when they return to the plains. Among the residents Viault enumerated 8,000,000 per c.mm. on the Cordilleras (14,274 feet), and Egger 7,000,000 per c.mm. at Arosa (6,100 feet) in Switzerland. It has been observed in those who visit the higher levels that the increase begins shortly after

* *Compt. rend.*, 1890, T. iii., p. 917.

† *Verhand. des xii. Congr. f. inner med.*, Wiesbaden, 1893.

‡ *Archiv der Physiol.*, B. 26, 1894.

§ *Münch. Med. Wochenschrift*, 1894, No. 48.

‖ *Corresp. Jl. Schweitz. aertzte*, xxiii., 1893, n. 24.

¶ *Münch. Med. Wochenschrift*, 1893, Nos. 11 and 43.

arrival. Egger estimates that in healthy subjects it amounts to 702,000 and in tubercular subjects 982,000 per c.mm. in 14 days. Wölff and Koeppe at Rieboldsgrün (2,257 feet) observed that in from 24 to 36 hours after arrival an average rise of 1,000,000 per c.mm. takes place, and this is followed first by a decline, and then by a further increase, until an average 5,970,000 per c.mm. is attained. They found, moreover, that the hæmoglobin proportionate to the corpuscles at first fell and afterwards rose. V. Jaruntowsky and Schröder at Görbersdorf (1,740 feet) observed the same fact; and, moreover, found that mild phthisical cases acquired a larger number of corpuscles per c.mm. than are present in healthy persons in the same altitude, and that severe cases attained even more than are generally found in normal individuals residing in lower parts. The lessening of the percentage of the hæmocytes on return to the valleys and plains is just as rapid as is the increase of them produced by visiting the higher altitudes. Miescher gives an example of the progressive daily fall of 250,000 per c.mm. for a series of six days; so that in this case, at the expiration of this short period, 7,200,000 per c.mm. enumerated on leaving Arosa had fallen to 5,700,000.

With the view of observing for myself this interesting effect of altitude, I spent 23 days at Davos Platz (5200 feet) in the spring of 1896 and 25 days at Arosa (5800 feet) in January and February 1899. During both visits the same mode of life was followed as at home in regard to exercise and the daily supply of fluid. In the first visit observation of the blood was made night and morning, before breakfast and at bedtime, in one subject (aged 55) throughout; and in the second visit the hæmoglobin and corpuscles were estimated daily

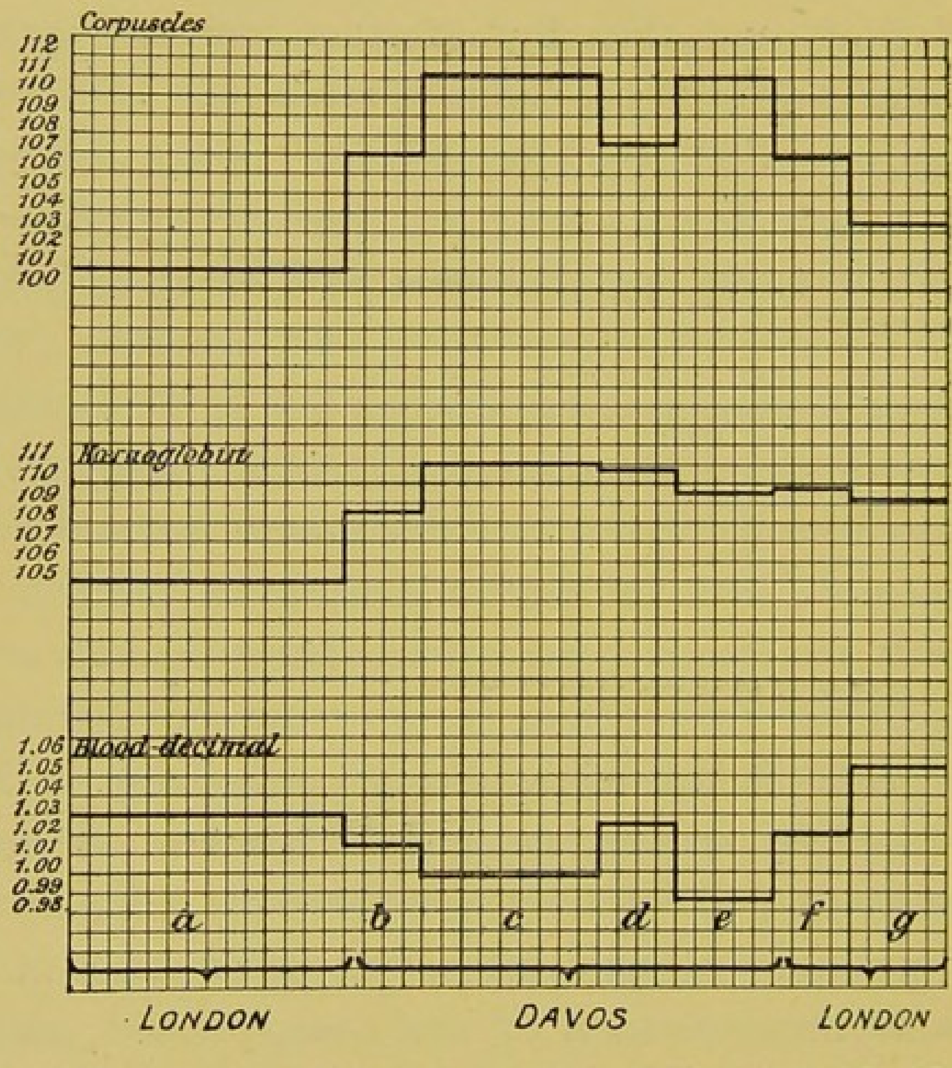


FIG. 22. The percentages of corpuscles and hæmoglobin and the blood-decimal at Davos Platz and in London before and after the visit.

before breakfast in two subjects, A and B (aged respectively 23 and 57). During both visits many observations were likewise made on residents and visitors.

The leading results are shown in the figs. 22 and 23.

In fig. 22 the night and morning determinations of the chromocytes and hæmoglobin and of the worth of the corpuscles during the visit to Davos Platz in May, 1896, and during two weeks before and ten days after that visit are indicated in horizontal lines, the estimations

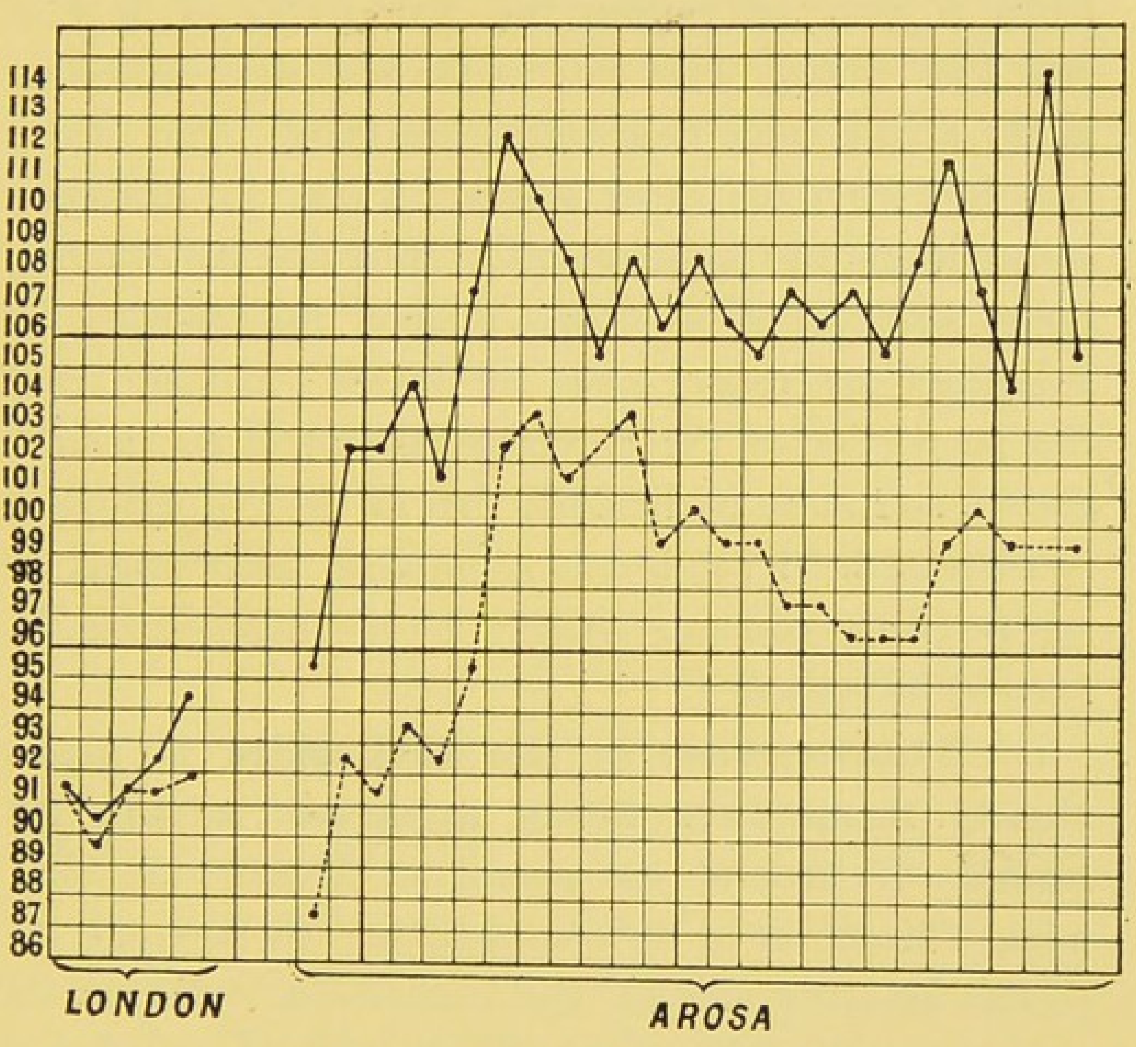


FIG. 23. Consecutive daily (morning) observations of the corpuscles and hæmoglobin in Subject A, æt. 23, in (1) London (5 days), and in (2) Arosa (25 days). The continuous line denotes the corpuscles, and the dotted line the hæmoglobin.

being arranged in stages of a certain number of days each; namely (*a*) 14 days preceding the visit (affording the basis of comparison), (*b*) the first 4 days of the visit, (*c*) the 9 following days, (*d*) 4 days in which the daily consumption of water was increased from 50 to 75 oz., (*e*) 5 days in which the ingestion of water was reduced to the regulation quantity, and (*f* and *g*) 9 days in two stages of 4 and 5 days after returning to London. Fig. 23 gives the actual daily observations of the corpuscles and hæmoglobin in one of the subjects, A (æt. 23) during the visit to Arosa in Jan. and Feb. 1899. The determinations were invariably made at the same hour before breakfast. The record obtained from the other subject, B (æt. 57) furnished substantially the same results. Moreover the observations made at Arosa corroborated the conclusions suggested by those made at Davos: namely, that the proportion of the chromocytes and of the hæmoglobin, and more particularly that of the chromocytes, is increased. I will briefly summarise what seems to me to be the teaching afforded by the observations at Davos and Arosa.

(*a*). **The increase in the corpuscles is practically immediate, being apparent within 24 hours.**—It attains its maximum within the first week. Moreover it is considerable; the average increase afforded by all the continuous observations on the three subjects at Davos and Arosa being over 10 per cent. in excess of the average proportion of the corpuscles observed before the visits. I have, however, repeatedly observed that the corpuscles may rise on the lowlands to quite as high a level as they attain in elevated regions; but the rise due to altitude differs from that which I have hitherto observed on the plains in this, that it is remarkably well maintained throughout the sojourn at higher levels, whereas that observed below is as a rule quite transitory (fig. 24). It would seem that the persistence of so pronounced a rise in high altitudes is a fact of more significance than the mere increment of the corpuscles; for it points to the enduring character of the cause, whatever that may be; and this inference is likewise supported by the fact, that the daily variations are somewhat smaller than those observed near the sea level (compare fig. 23 with figs. 24 and 25). Descent to the lower levels produces a rapid fall in the chromocytes. According to my observation the decline as a whole is not, however, as rapid as the rise; and though the higher portion of it speedily disappears an increment over the initial average of chromocytes persists on the plains for some time. On approaching the sea level the fall is characterized by the temporary character of any decided rise that may appear in its course.

Perhaps it should here be noted that before applying the cytometer tube to this enquiry previous observers had relied on the enumeration of the red discs. Now during the past year or so Gottstein, Meissen and Schroeder have thrown suspicion on the accuracy of enumeration with the ordinary Zeiss-Thoma hæmocytometer at low barometric pressures, for they have shown that the capacity of the chamber is affected by comparatively slight differences of atmospheric pressure. They therefore infer that the large counts hitherto recorded of the numerical increase of the red corpuscles in high altitudes may be partly ascribed to this fallacy. Schroeder has lately made some observations with a hæmocytometer specially designed to meet this error, and his results seem to suggest considerable modification of the large enumerations which were previously ascribed to high altitude. He demonstrates a modified increase.* Under this uncertainty as to the reliability of ordinary enumeration in high altitudes, the evidence furnished by the cytometer tube, which is not open to the error ascribed to diminution of atmospheric pressure, may therefore prove useful as a corroboration, though it certainly does not provide the high readings of increase which previous observers relying on ordinary enumeration have recorded. Quite recently Dr. Pacht, using the cytometer tube, confirms this conclusion.†

(*b*) **The rise in the corpuscles is accompanied by a similar—though reduced—increase in the hæmoglobin** (figs. 22 and 23‡) an increase which only subsides as the corpuscles diminish in number when the descent is made to lower levels. According to all the continuous observations on the three subjects at Davos and Arosa the rise in hæmoglobin was only 50 per cent. that of the corpuscles—the former being

* *Münchener Med. Wochenschr.*, 1898, Nos. 4 and 42.

† *St. Petersburg Medicinische Wochenschrift*, 1899, No. 51.

‡ In fig. 23 the first, second and third observations of the hæmoglobin did not show an increase. This failure is probably accounted for by the fact that the subject was upset by the through journey to Arosa.

over 5 per cent. and the latter over 10 per cent. in excess of the average observed at home before the visits. It therefore follows, that though there was an absolute increase in the hæmoglobin during the sojourn in the altitudes, there was a relative fall, and each chromocyte was somewhat poorer in hæmoglobin. But this condition of relative diminution entirely vanished when the corpuscles fell after the visits; for then the blood for some time not merely contained an increased proportion of chromocytes over the home average, but an equal increase in hæmoglobin, and was therefore richer. This after-effect suggests that the visits to Davos and Arosa impressed the blood favourably, notwithstanding the fall in hæmoglobin value during the immediate influence of the altitude. There is moreover another fact in regard to the effects of altitude on the hæmoglobin which was made apparent by the night and morning observations made at Davos. Before leaving London for Davos it was found that the night and morning variation in hæmoglobin amounted to 8·5 points, and that of the corpuscular value in hæmoglobin 0·06; at Davos, however, these variations were reduced respectively to 4·2 points and 0·02. It therefore follows, that though the night and morning value of the corpuscles in hæmoglobin was reduced, the amount of hæmoglobin was more uniformly present in the blood throughout the 24 hours at Davos than in London, and the hæmoglobin value during the day was approximated to that of the night.

From the observations made on visitors and residents at Davos and Arosa it would seem as if the effects of altitude on the blood become considerably modified by continued sojourn. Among visitors who had remained there during the whole winter the majority afforded quite normal readings of the corpuscles, several furnished subnormal readings, and only exceptional cases somewhat high readings; whereas some comparatively recent arrivals afforded readings quite as high as these. But this is a matter on which much additional light will doubtless be thrown by the more extended observation of the local practitioners.

In explanation of the increased number of the red corpuscles induced by altitude there is a remarkable agreement among the different observers. They all regard it as due to rapid construction incited by the lessened supply of oxygen from the reduced atmospheric pressure; and they believe that this increased hæmocytosis compensates for the deprivation of oxygen. Grawitz, however, has criticised this position and shown it to be untenable.* He points out that the experiments of A. Fränkell and Gepert, in which dogs were subjected to an atmospheric pressure equal to that of an altitude of 16,000 feet, show that the blood contains at that greatly reduced pressure as much oxygen as at the ordinary pressure. Therefore it would seem that in altitudes below 16,000 feet there does not exist a need for a compensatory increase of the chromocytes.

* *Berliner Klinische Wochenschr.*, 1895, pp. 713 to 740.

Besides this, the theory of new formation is highly improbable from the extreme rapidity of the rise, and from its being still more rapid and greater in the phthisical than in the healthy. Moreover, when on returning to lower levels the percentage falls, there are no signs of wholesale destruction of chromocytes, such as hæmoglobinuria, icterus and bilirubinuria. The observers have described the appearance of a number of small forms in the blood after 7 or 8 days which they regard as young chromocytes ; and as they assert that these increase in number as the ordinary regular sized corpuscles decrease, they conclude that during the first week the old corpuscles undergo destruction and new ones are formed. Grawitz on the other hand, believes that this microcytosis arises from the lessening of the red discs in consequence of the loss of water, there being a diminution and a concentration of the serum (oligoplasmia) from the same cause. I am inclined, however, to doubt if this explanation of Grawitz will account for the appearance of the microcytes; for shrinking of the chromocytes from loss of water would probably lead to alteration in their appearance, such as crenation, which would scarcely escape observation. The blood was frequently observed during my visits; but the presence of microcytes was never detected nor were any changes observed in the appearance of the corpuscles. Perhaps the microcytes described by previous observers were such as are met with in anæmia. It is obvious that this is a matter requiring further investigation. Grawitz points out that the investigators who hold the view of the new formation of corpuscles, have not mentioned the presence of nucleated red discs and the increase of leucocytes which are generally met with when the blood cells are being formed after hæmorrhages, &c. He refers the solution of the problem to increased loss of water from the blood through the skin and respiratory tract in consequence of the great diminution of humidity in the atmosphere. There are many facts in support of this view. Meteorologists find that the reduction of humidity is more rapid than that of the atmospheric pressure; and certainly a fall of from 40 to 50 per cent. of the absolute moisture present on the sea level must greatly increase the abstraction of water from the blood by transpiration through the skin and the oro-respiratory mucous membrane. In high altitudes it is therefore a fact that the absolute atmospheric moisture is very much less than at lower levels, and it is not improbable that this great reduction in humidity is a potent factor in concentrating the serum and in thus raising the percentage of the corpuscles. If this be so, it is but reasonable to suppose that the increased consumption of water should counteract this influence of dry air on the blood; and at Davos I found that an extra supply of water reduced the concentration of the corpuscles 3·5 per cent. (fig. 22, *d*). Furthermore, at Arosa, in support of this view, I obtained some evidence which tended to show that in a general way variations in the relative humidity had some effect on the proportions of the corpuscles. It is true there was no detectable relationship between the daily changes in the relative humidity and those of the corpuscles; but such a relationship seemed to be apparent when the average relative humidity of one period—less or more dry—was compared with the average corpuscle record of that period. As regards differences of relative humidity the visit was divisible into two periods—namely, the first week, which afforded a daily average of 63 degrees, and the second and third weeks, which were drier, the relative daily humidity being only 48 degrees. In the first period the average daily record of the corpuscles was 101 in Subject A. and 105 in Subject B.; in the second period it was 107·5 in Subject A. and 108 in Subject B.

AROSA.*

	Average Daily Corpuscle Record.		Average Daily Relative Humidity.
	Subject A.	Subject B.	
Jan. 24 to 31 . . .	101	105	63°
Feb. 1 to 15 . . .	107·5	108	48°

Furthermore some support to the same conclusion was afforded by observations made at Florence immediately following those at Arosa (fig. 24); and by

* My thanks are due to Herr Dr. Phil Janssen, Villa Frisia, Arosa, for the daily record of the relative humidity derived from the night and morning readings of the wet and dry bulb during the visit to Arosa.

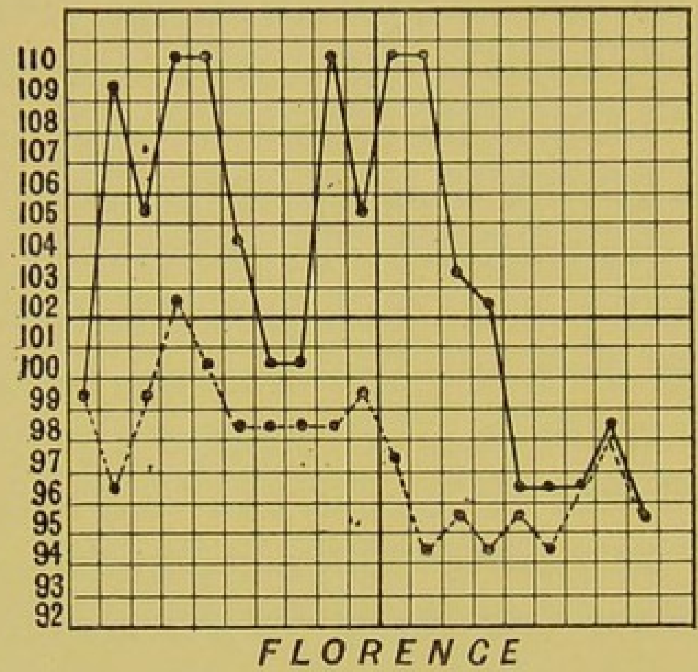


FIG. 24. Consecutive daily (morning) observations of the corpuscles and hæmoglobin in Subject A., æt. 23, in Florence (19 days). The continuous line denotes the corpuscles, and the dotted line the hæmoglobin. These observations are continuous with those recorded in figure 23.

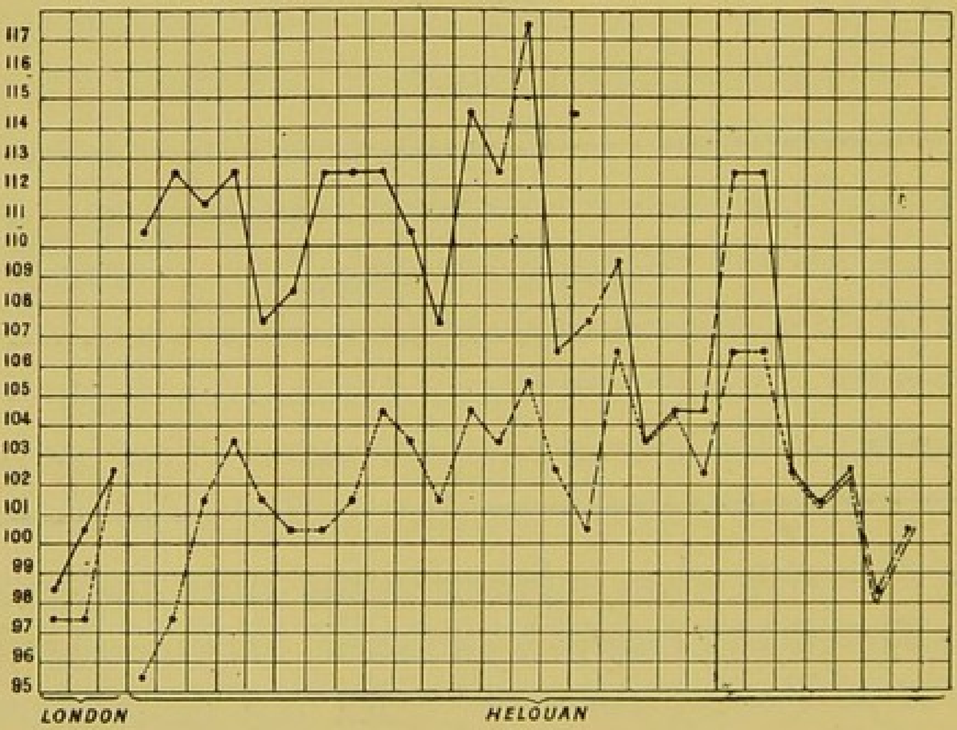


FIG. 25. Daily (morning) observations of the corpuscles and hæmoglobin in Subject B., æt. 58, in (1) London (3 days) and in (2) Helouan near Cairo (64 days). The first observation at Helouan was made three days after arrival. The continuous line denotes the corpuscles, and the dotted line the hæmoglobin. The observations were consecutive, except where the line is interrupted.

observations made subsequently at Helouan near Cairo (fig. 25).

During the visit to Florence lasting nearly three weeks there were two periods of low relative humidity (41·2 and 55·8 degrees respectively), during which the dry tramontana wind prevailed, when the corpuscles read 107 and 107·5 in Subject A. and 109 in Subject B.; and two periods of higher relative humidity (65·4 and 61·2 degrees respectively) in which the corpuscles read 100 and 97 in Subject A. and 102 in Subject B.

FLORENCE.*

	Average Daily Corpuscle Record.		Average Daily Relative Humidity.
	Subject A.	Subject B.	
Feb. 24 to 28 . . .	107	109	41·2
Mar. 1 to 3 . . .	100	102	65·4
Mar. 4 to 8 . . .	107·5	109	55·8
Mar. 9 to 14 . . .	95	102	61·2

Fig. 24 records the observations made on the blood of Subject B., æt. 58 at Helouan on the Desert near Cairo from January 14 to March 16, 1900. The reading of the corpuscles remained high until February 21, a period of 21 days; the average of all the observa-

* My thanks are due to the Director of the Meteorological observatory at Florence for the daily record of the relative humidity derived from the night and morning readings of the wet and dry bulb during the period of these observations.

tions up to this date being 110 degrees instead of 100 before the visit. On February 22 it fell, and remained within the limits of variation observed in England until March 16, when observation ceased. The normal proportions of the corpuscles and hæmoglobin for the individual were therefore readjusted after the lapse of a month—notwithstanding the continued dryness of the atmosphere. The average daily humidity of the atmosphere was 62 degrees from January 12 to February 21, and 60 degrees from February 22 to March 16.* Subject A., æt. 24, remained under observation at Helouan only a fortnight—from January 14 to 28—and furnished similar data; the average reading of the corpuscles being 103, while at home it was 91. This rise in the corpuscles was maintained to the last day of observation; but in this case the duration of the visit was doubtless too short for adjustment of the blood to take place.

These observations at Davos, Arosa, Florence, and Helouan have demonstrated the fact, that the proportion of the corpuscles may be increased quite as much at places on or near the sea level where the humidity of the atmosphere is low as at resorts located several thousand feet above that level. Therefore it would seem that the observed effects of altitude on the blood in increasing the number of the blood corpuscles per c.mm., and to a less degree the amount of hæmo-

* I am indebted to Dr. Page May of Helouan, for the daily record of the relative humidity derived from the night and morning readings of the wet and dry bulb.

globin, are not due to altitude *per se* but to the low proportion of humidity present in the atmosphere—a fact common to elevated localities at all times, and to places even on the sea level either always or at intervals.

Temperature. Warm and Cold Baths.

Hot and cold baths, whether local (as hand baths) or general, produce contrary effects on the blood; the former lowering the percentage of the corpuscles and hæmoglobin and the latter raising it. The fall produced by a warm bath of 15 minutes' duration may be 7 per cent., and the rise caused by a short immersion (3 minutes) in cold water may be 4 per cent.* Lloyd Jones has shown that cold baths raise the specific gravity of the blood; in one case from 1060·2 to 1061·8, and in another from 1059·8 to 1061.† This alteration merely arises from a disturbance of the relation between the corpuscles and the plasma, for the blood decimal remains unaffected. It would, therefore, seem that temperature, which is the predominant influence in bathing,

* Bristowe and Copeman have shown by enumeration that in paroxysmal hæmoglobinuria the number of the chromocytes is reduced by exposure to cold air, or to a cold bath, or by plunging the hands in cold water. *Trans. Med. Soc.*, Lond., vol. xii. This interesting result is, however, one thing, and the effect of cold immersion in healthy subjects is quite another; for it is highly probable that in hæmoglobinuria the normal resistance of the stroma is greatly reduced.

† *Op. cit.*

alters the composition of the blood by retarding or accelerating the rapidity of fluid transfer through the capillary wall; warmth slackening it and probably favouring the lodgement of tissue-lymph and cold stimulating it. In all probability this influence is mainly exerted through the effect of warmth and cold on the intra-capillary pressure. These results confirm the observations of Winternitz and Kellogg on the effect of warm and cold bathing on the blood. These observers refer the rise produced by cold bathing to general causes, increased activity of the heart and circulation, improved nerve tone, and the driving out of red corpuscles from the organs in which they had accumulated. The immediate effects of warm and cold bathing are, however, purely local; being as readily observed in blood derived from the finger after a hand bath as in that obtained from the same source or from elsewhere after a general immersion bath.

On Variations in the Plasma and the Circulation of Water.

It has been shown on the one hand, that the hæmoglobin value of the corpuscles rises with rest and falls with systemic exercise and work; and on the other, that the corpuscles are continually varying in their relation to the plasma. Though the latter fact has been already amply illustrated, it will I think repay a little further examination.

The concurrent variations in the percentage of the corpuscles and hæmoglobin, which have been repeatedly pointed out, are indeed volumetric indications of the circulation of water into or from the blood: into it from the digestive tract and the tissues, and from it through the kidneys, skin, and lungs and probably into the muscles during exercise. In illustration of this

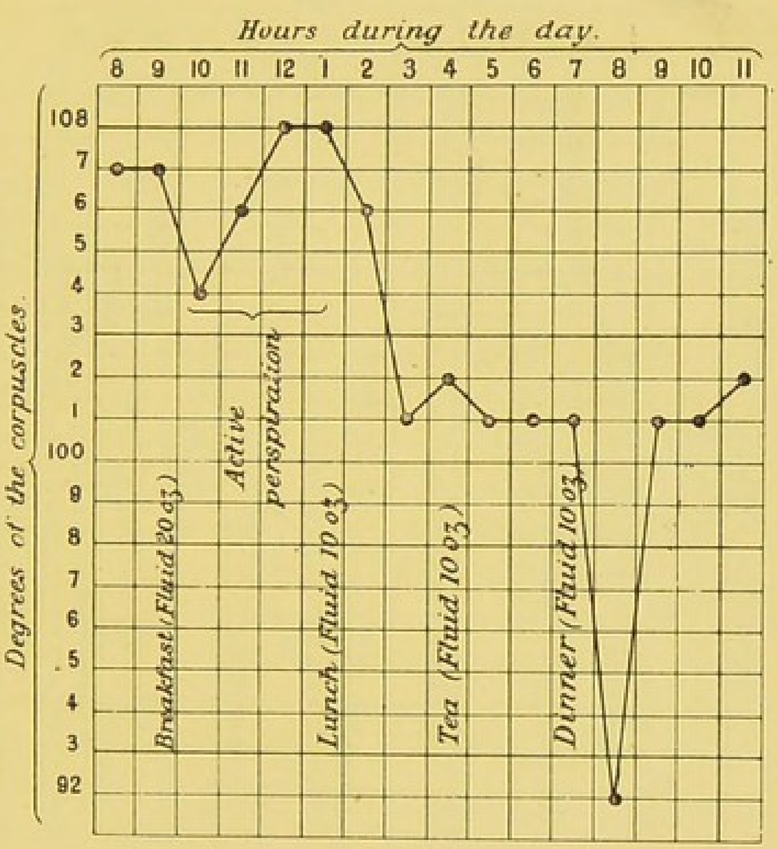


FIG. 26. An example of the hourly variations of the corpuscles.

position it is found that the proportions of the corpuscles fluctuate from hour to hour (fig. 26) and from day to day (figs. 18 and 20) and that the corresponding variations in the specific gravity of the blood are equally rapid (figs. 19 and 27). It would therefore seem from these observations, that the proportion of water in the plasma is constantly varying within certain physiological limits, even though the blood is continually tending to balance its income and output of water, and is thus always striving after a mean. It is true the variations observed are individually of comparatively short duration; but in this respect they resemble all the other rapid oscillations of function which

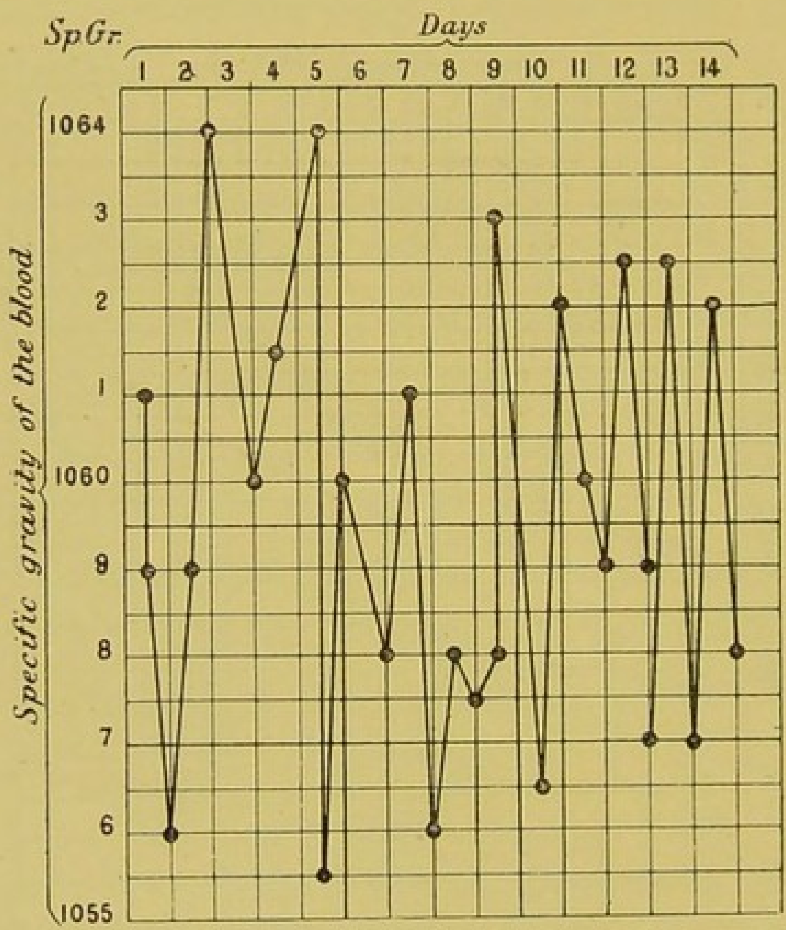


FIG. 27. An example of daily variation of the specific gravity of the blood (Lloyd Jones).*

characterize health, such for instance as those continually taking place in the arteries and in the blood-pressure (see Chap. V.). Then again, when the output of water, whether by the kidneys, skin, or bowels, far exceeds the income, the volume of the plasma is for

* *Journal of Physiology*, vol. xii.

the time reduced and there is a proportionate rise in the corpuscles. Fig. 28 illustrates such a temporary apoplasmia induced by a Turkish bath.* All such

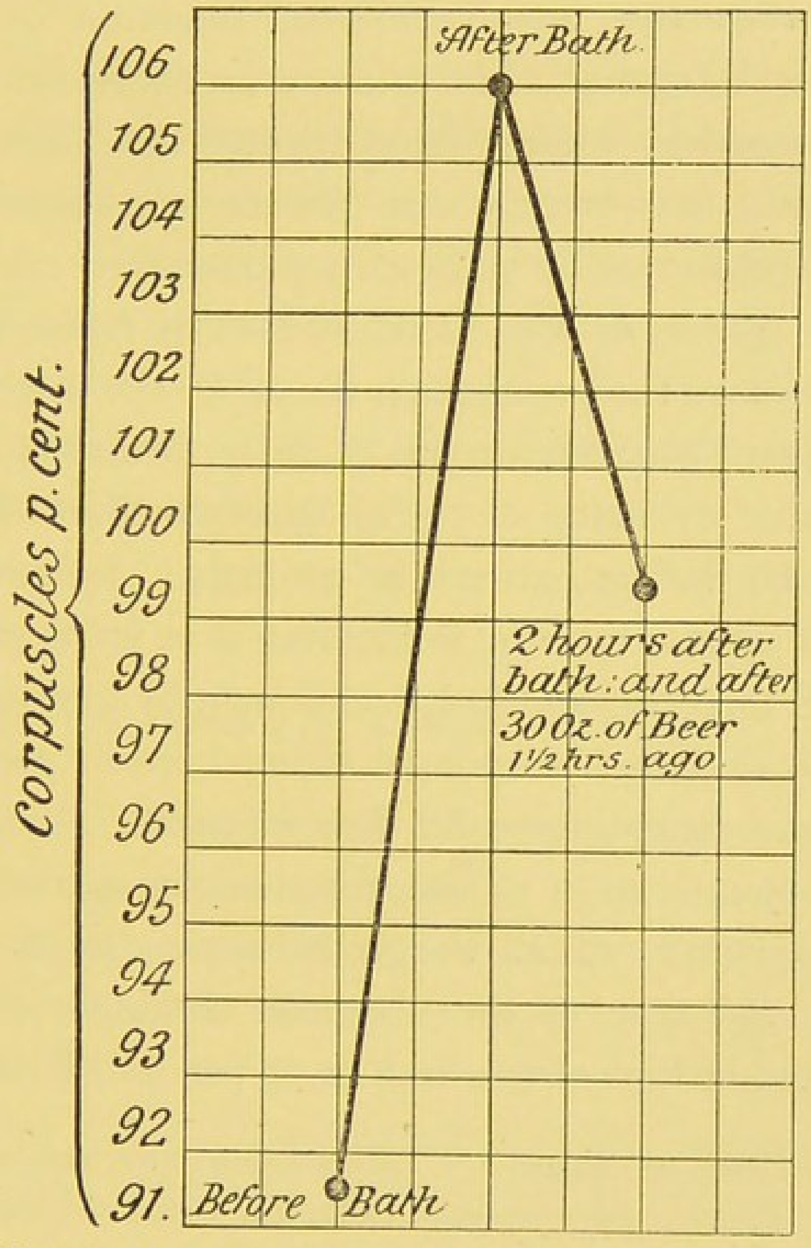


FIG. 28 illustrates the temporary apoplasmia produced by a Turkish bath (40').

transitory examples of concentration of the corpuscles can only be due to the shrinking of the plasma from

* Lloyd Jones has shown that this bath raises the specific gravity of the blood (*op. cit.*).

loss of water.* But this question does not rest merely on examination of the blood derived from the finger. It has been conclusively proved by experiments on animals. Bezzo-Zero, Golget† and others have observed that the intra-peritoneal injection of blood produces in from 20 to 60 minutes an enormous rise in the corpuscles; and William Hunter has shown that this result was merely due to concentration of the plasma (as shown by an equally pronounced rise of the specific gravity of the blood) caused by rapid effusion of serum into the peritoneum set up by the injection.‡

Professor Sherrington has likewise furnished equally conclusive evidence of the apoplasmic effect of operations and inflammations in animals. Inflammation was set up in a limb by immersing it in water at 52° C. for five minutes, and in the abdomen by applying to a knuckle of intestine sponges steeped in salt solution of the same temperature for five minutes. Taking the initial enumeration of the chromocytes as 100, in the average results of all the experiments the maximum rise in the case of the abdomen amounted to 75 per cent. and in that of the limb to 35 per cent.§ In some

* Apoplasmia (as indicated by polycythæmia) from abstinence from food and fluid has been recorded by Hayem, Reyne and others. It is rapidly induced, for abstinence for 24 hours in man determines a rise in corpuscles of from 400,000 to 500,000 per c.mm.; and the augmentation is said to continue in the guinea-pig and dog until death.

† *Centralblat. f. d. Med. Wiss.*, 1879, p. 917.

‡ *Journal of Physiology*, vol. xi.

§ It has been pointed out that, as a rule, apoplasmia in man reduces "the worth." Out of the six protocols relating to these experimental cases the duration of the apoplasmia was considerable, even five days. Sherrington and Copeman "have noticed that in the rabbit the operation of ligation of the vessels of the spleen and various other forms of experimental interference with the contents of the abdominal cavity, including even the simple opening of the cavity by an incision through the linea alba, are all followed by an increase in the specific gravity of the blood."* Such striking results as these suggest that some caution should be exercised in accepting any conclusions respecting the function of the spleen derived from observation of the blood during the first week after splenectomy.

The Limits of Normal Variations.

The scales of the hæmoglobinometer and the hæmocytometer have been so adjusted from a large number of observations of normal blood as to read alike; for example, blood furnishing 100 points hæmoglobin (HG) should yield 100 points (or thereabouts) corpuscles (C).† The "worth" of the corpuscles in hæmoglobin, obtained by dividing the figure repre-

inflammations of a limb and of the abdomen, "the worth" fell decidedly in four, slightly in one, and was unchanged in one.

* *Proceedings of the Royal Society*, vol. lv.

† The samples selected for this purpose were derived from healthy subjects in the early morning when the blood is most constant and is uninfluenced by work.

senting the hæmoglobin by that denoting the corpuscles, should therefore be represented by the unit, 1; and all variations from this normal "worth" will be indicated by decimal points—*e.g.*, $\frac{80 \text{ HG}}{100 \text{ C}} = 0{\cdot}8$. In health the average variation of "worth" extends from 0·95 to 1·05; but it may fall to 0·90 or rise to 1·10.

The average range of individual and physiological variation in the reading of the corpuscles and of the hæmoglobin in health, whether in the same subject at different times, or in different persons, may be said to embrace from 95 to 105 degrees in men, and from 90 to 100 in women. The mean of this range (*i.e.*, 100 in men and 95 in women) may be accepted as the average reading afforded by normal blood in the early portion of the day (on rising and before lunch). As has been already pointed out, in the evening the readings of the corpuscles and of the hæmoglobin in normal blood generally fall—the volume of the corpuscles being, as a rule, three or four points and the hæmoglobin six or seven points lower.

Clinical Variations.

In the clinical field marked departures from the limits of physiological variation are met with. The volume of the corpuscles may fall far short of the lower limit, the condition being one of oligocythæmia; or it may exceed the higher limit, when the blood may be described as polycythæmic; or the corpuscles may afford normal readings, while the hæmoglobin may furnish subnormal ones. Pathological variations fall broadly into the two groups—oligocythæmia and polycythæmia.

1. In **oligocythæmia** the volume of the corpuscles and the hæmoglobin may read alike, or the former may exceed the latter. When the readings coincide the blood may be said to be spanæmic, and when the oligocythæmia is marked by a lower reading of the hæmoglobin than that of the corpuscles the condition is that of anæmia.

In *spanæmia*, though the corpuscular "worth" in hæmoglobin is normal, the blood is subnormal in the volume of the corpuscles. Whether in this state of the blood there is merely a dilution of the normal corpuscles—*i.e.*, an excess of plasma to the normal corpuscles—or whether there is an absolute paucity of the volume of the corpuscles and of the hæmoglobin cannot be determined; for we are not acquainted with any means of estimating the volume of the blood by which such a moot point can alone be decided. Spanæmia is very common, and more especially in women. In a large number of women the reading of the corpuscles and hæmoglobin cannot be advanced by the most approved hæmatinic treatment beyond 80 or 85 degrees. Though the blood in such cases is spanæmic when compared with normal blood, it would seem nevertheless to be normal for such individuals. Spanæmia, as a rule, implies a lowered nutritive condition of the blood; for all spanæmic subjects are very prone to become anæmic, and when anæmia has been improved to a certain point by treatment the blood is apt to remain obstinately spanæmic. It is, furthermore, frequently associated with a low blood-pressure, and therefore with a reduced intra-capillary pressure, which diminishes the intermediary circulation of fluid and the elimination of water. This fact is well illustrated by the very definite observations of Grawitz on the effects produced on the composition of the blood by loss of cardiac compensation and by the restoration of that compensation. This observer shows that in the former condition the percentages of the corpuscles and of the dry residue of the blood and of the serum diminish, whereas when compensation is restored they again increase in proportion as the renal elimination of water is improved.*

Spanæmia is benefited by all those hygienic measures which increase the volume of the corpuscles, such as cool or cold bathing, and especially saline bathing, percussive baths (douches, needle and shower), regulated exercises, massage, and especially massage of

* *Deutsch. Archiv. f. Klin. Med.*, B. 54 and 6. Stengel has lately observed that in loss of cardiac compensation there is considerable variety in regard to the proportion of the red corpuscles—the blood being sometimes oligocythæmic and sometimes polycythæmic even in a high degree (the increase of corpuscles amounting in one case of marked loss of compensation to 500,000 per c.mm.). He refers this variability to disturbance of the distribution of the corpuscles. *Proc. Path. Soc. of Philadelphia*, 1899.

the abdomen, faradism, and sojourn at health resorts located in high altitudes; and by the various forms of tonic medication.

In *anæmia* of the common or oligocythæmic type in its more severe forms, the reading of the hæmoglobin may be as low as 15 or 20 degrees while that of the volume of the corpuscles may be 30, 40, 45 or 50 degrees; and when moderate the hæmoglobin may range from 40 to 60 and the corpuscles from 60 to 80 degrees. The rapid hæmometric methods employed in this enquiry have frequently afforded useful aid in detecting the existence of anæmia of moderate degree in even florid subjects and in cases in which the ordinary clinical evidence failed to indicate it; and furthermore in readily determining the effects of different modes of treatment in anæmia, and in tracing the stages of improvement. As a rule favourable progress is first indicated by a rise in the volume of the corpuscles; and then this is followed by a relatively increased rise in the hæmoglobin until the readings of the corpuscles and hæmoglobin approximate when the blood becomes spanæmic. When treatment is discontinued at this stage the anæmia, as a rule, relapses. Treatment should not be abandoned until a normal reading of the corpuscles and hæmoglobin is reached and is steadily maintained. Hygenic directions are of great importance in the treatment; such as cool saline baths, baths of the percussive type, exercise (when permitted) strictly regulated and limited with intervals of absolute rest in the recumbent posture according to the degree of anæmia indicated by the readings of the corpuscles and hæmoglobin, recumbent rest along with massage, passive exercises and faradism when the anæmia is severe, an open air life at sea or on the coast and as the anæmia diminishes a resort to moderate altitudes.

2. In **polycythæmia** the rise of chromocytes may in extreme cases exceed the normal limits by 20 per cent. and in moderate cases by 10 or 15 per cent. In this condition of the blood the volume of the corpuscles and the hæmoglobin rarely read alike; for as a rule, the hæmoglobin falls as the corpuscles rise. Whatever the cause of the polycythæmia this fact has been almost invariably observed—namely, a reduction in the hæmoglobin value in the corpuscles, constituting a state of virtual anæmia. As a rule the actual reading of the hæmoglobin rises; but it does not do so *pari passu* with that of the corpuscles, and the disproportion between the two is sometimes considerable—10 or 15 per cent. or more. This disparity in certain cases of polycythæmia is so pronounced that it undoubtedly indicates a form of anæmia differing from the common form in being characterized by an excess of chromocytes comparatively poor in hæmoglobin. Probably it was to such cases as these that Becquerel and Rodier referred nearly fifty years ago—cases of chlorosis in which the blood was not modified and was of higher specific gravity than normal,* and recently Lloyd Jones alludes to similar cases—pale girls with a relative

* "Traité de clinic pathologique," Paris, 1854.

excess of corpuscles and a high specific gravity of the blood.* Usually those suffering from this type of anæmia are somewhat badly nourished and thin, and do not present the puffiness and obesity of chlorosis. Hæmic murmurs are not usually present, but the mucous membranes are apt to be pale as in ordinary anæmia. In such cases the observer expecting to record a low reading of the hæmoglobin is surprised to find that it is normal, or perhaps slightly in excess of normal, while the volume of the corpuscles is excessive. The pathogenic cause is not always obvious; it may, however, be frequently traced to a reduced ingestion of water and occasionally to the increased elimination of it probably under neurotic influence. In all such cases the volume of the blood is probably reduced and the blood is polycythæmic because there is a lessened proportion of water in the liquor sanguinis. In ordinary chlorosis it is held by some that the blood is hydræmic;† whereas in this type of anæmia it is concentrated and thickened from the reduction of water. The volume of the plasma being lessened the condition may be described as one of apoplasmia.

* *Op. cit.*

† "Chlorosis," by E. L. Jones, M.D., p. 24. Rubenstein, *Wen. Med. Presse*, 1893. Lorain Smith, applying the carbonic oxide method recently described by Haldane and himself, has shown that in chlorosis "the volume of the blood is markedly increased" and "the decrease of the number of red corpuscles and in the amount of hæmoglobin cannot be regarded as due simply to the increase of the plasma." The same conclusions apply also to pernicious anæmia. *Journal of Physiology*, vol. xxv., 1900.

Apoplasmic anæmia is not very uncommon in women, especially in young women of neurotic type. It is not unfrequently met with in chronic interstitial nephritis —especially in the earlier stages—in diabetes mellitus, in chronic gout with increased arterial blood-pressure and in those who are disposed to hæmorrhage (epistaxis, &c.). In this connection it is interesting to find that Lloyd Jones observed that in arterio-sclerosis and in chronic interstitial nephritis the specific gravity of the blood was "highest in those in whom there is no œdema and in those who have cerebral hæmorrhage," and was "high in those who had had one attack of cerebral hæmorrhage and who are likely to have another."* Moreover, Becquerel and Rodier long ago found a high specific gravity of the blood and a great increase in the number of the corpuscles in 12 cases of cerebral hæmorrhage; and these observers add that the increase of the corpuscles "appears indeed to precede the cerebral hæmorrhage."† It is, therefore, not improbable that the ready and convenient method of determining the corpuscles by the hæmocytometer tube will prove of practical value and utility in detecting a rise in the corpuscles, which may indicate a disposition to cerebral hæmorrhage. Observation has shown that an apoplasmic state of the blood is amenable to control by increasing the supply of fluid in certain cases—as in ordinary apoplasmic anæmia and in chronic goutiness; whereas in others—as in chronic

* *Journal of Physiology*, vol. xii.

† *Op. cit.*

interstitial nephritis and in diabetes mellitus—it does not yield to this or to any other mode of treatment. Whenever the apoplasmia is reduced and the reading of the corpuscles falls within the normal limits the hæmoglobin value of the corpuscles rises and becomes normal, as in the following example :—

SUBJECT, FEMALE, ÆT. 23.

DATE 1895.	AUGUST 3.	AUGUST 7.	AUGUST 19.
Corpuscles . . .	110	98	90
Hæmoglobin . .	100	96	91
Hg. value . . .	0·95	0·98	1·01

In apoplasmic anæmia dry massage and Turkish and Russian baths are physiologically contra-indicated; and I am doubtful if dry massage exerts a favourable influence. I have, however, recorded excellent results from courses of warm massage douche baths and from Turkish and Russian baths.* Warmth is an important element in the treatment—warmth in baths, climate and clothing. High altitude resorts should be avoided, and a preference should be given to watering places near or on the sea level. As a rule the cases of this type are greatly benefited by

* It is not improbable that Turkish and Russian baths, by further concentrating the blood, may incite the intermediary circulation of water, so that the blood may ultimately take up more water.

corrective treatment of the liver by mercurials and salines, and by a course of mineral waters of the muriated class.

CHAPTER IV.

The Circulation; Apparatus for Determining the Blood-pressure (Arterial and Venous) the Variations in the Arterial Wall and the Distribution of the Blood.

Our physiological knowledge of the circulation is imperfectly applied in clinical work:—It will be conceded by most practitioners, that clinical observation of the circulation falls far short of a satisfactory application of the teaching and knowledge furnished by physiological enquiry; in a word, that we fail to realize or to apply in daily work, much that we have acquired in the laboratory in this department of physiology—much that would indeed tend to advance the efficiency of clinical work, could we but utilize it fully in practice. This imperfect realization of elementary physiological knowledge in clinical observation has doubtless arisen from the want of suitable and reliable apparatus by which the unaided limitations of the sense of touch may be extended and rendered more definite.

It is true the sphygmograph was introduced with the object of rendering this very service; but the hope it inspired of fulfilling this end has unfortunately not been fully realized. Though all observers (physiological and clinical) admit, that it has been of great educational value, and has led to a considerable advance in our knowledge of the causes of the various circulatory events, comparatively few practical physicians will allow that it can afford more than a somewhat equivocal aid in clinical work, or that it will reveal anything beyond the facts it has already brought to light, facts which are incorporated in current clinical knowledge. It must, however, be admitted that there are some physicians who find it to be a useful clinical guide; and that the records it furnishes are sometimes valuable as records. But as a clinical instrument, and as an instrument of enquiry, it estimates but imperfectly two leading facts—namely, the blood-pressure and the variations incidental to the arterial wall. The object of this research is to devise means of gauging these important features of the circulation, and thus to supplement and to extend the instrumental aid afforded by the sphygmograph in physiological enquiry and in clinical work.

Apparatus employed.

The apparatus employed in this enquiry on the circulation in man were:—

1. The hæmodynamometer,* by which the blood-pressure (arterial and venous) was determined.

* In determining the mean arterial pressure Hill and Barnard's Sphygmometer was frequently used as well as the hæmodynamometer.

2. The arteriometer, by which the calibre of the radial artery was measured with the view of estimating variations in the arterial wall.

3. A simple phythysmometric method, by which the volume of a limb was ascertained before and after baths and exercises.

4. A method of gauging the capacity of the splanchnic area.

I. THE HÆMODYNAMOMETER OR BLOOD-PRESSURE GAUGE.

Previous attempts in hæmodynamometry in man:—During the past sixty years or more various instruments have been suggested at home and abroad to indicate the resistance of the pulse, the radial artery having been selected for the purpose.

In a list of sixteen such attempts given in "Pulse-Gauging" p. 97, scarcely one can be said to have well survived its early promise. History does not, therefore, apparently afford much encouragement to further effort in this direction. But this conclusion will be somewhat modified, when it is remembered that most of the instruments proposed, and especially the earlier ones, merely rendered the pulse visible, and were not standardized on physiological lines; they were therefore not likely to aid the observer in the discovery of new facts, or to prove useful to him in the course of clinical work.

The difficulties encountered in determining the blood-pressure in man:—There are some practitioners who are disposed to doubt whether the blood-pressure in man can be determined by instrumental aid with a sufficient approximation to accuracy for practical guidance in different cases—they regarding the physical difficulties as too great and too varied to allow of a reliable reading of that pressure to be obtained in man. Such physical difficulties undoubtedly exist; but they are apt to loom large, and to acquire an undue ascendency over the judgement, when viewed merely from the *à priori* aspect. They can only be reduced to their proper proportions by well-directed observation. They may be ascribed to two causes: namely, to variations in (1) the resistance of the tissues in different individuals, and (2) in the calibre of the vessel.

The blood-pressure in man cannot be correctly estimated through a solid medium.—The clinical instruments hitherto devised for ascertaining the blood-pressure may be divided into two classes, namely, those furnished with solid pads, and those provided with a liquid medium to be applied over the vessel. I have had ample experience of both kinds of media—solid and liquid; for, during the past six years, I have used both adapted to my pulse-pressure gauge. According to my observation the reading of the arterial blood-pressure obtained by using the solid pad is vitiated by variations in the tissue resistance of different individuals, and by variations (congenital, physiological and pathological) in the calibre of the radial artery—and especially by the latter. The calibre of the artery may be congenitally smaller or larger than a certain average size; and it will subsequently be shown (see Chap. V.) that it is constantly fluctuating in health, and is often considerably reduced or enlarged by pathological changes (see Chap. VI.). All such variations have been determined by the arteriometer; and the readings thus obtained, when compared with those furnished by the pulse-pressure gauge provided with a solid pad, have shown that the latter are vitiated by differences in calibre below or above the accepted average. The trend of the evidence supports the general conclusion, that a reduction in calibre diminishes the record of the blood-pressure obtained by a solid pad, and the enlargement of it increases that record—even though the blood-pressure may have actually increased in the former case or have diminished in the latter. In support of the same conclusion there is also the fact, that a solid pad provides in the same subject, and on the same hydrostatic level, readings of the arterial blood-pressure which vary *pari passu* with corresponding differences in the calibre of the arteries, whereas that pressure is known to be practically uniform throughout the arterial system (see p. 138). For example, in one observation a solid disc, sufficiently large to embrace the carotid artery, afforded widely different readings of the mean arterial pressure when applied on the same gravity level to the radial and the carotid, namely 65 mm. Hg. in the former, and 145 mm. in the latter; that pressure when correctly estimated through a fluid medium being 95 mm. Hg. the same in both.

It therefore follows that accurate or reliable physiological or clinical data pertaining to the blood-pressure cannot be obtained through the intervention of a solid pad applied to the vessels in man.

Digital estimation of the arterial blood-pressure derived from a peripheral artery, like the radial, is open to the fallacies of the solid pad of a pulse-pressure gauge.—The combined use of the arteriometer and the hæmodynamometer has repeatedly proved that the sense of touch in forming an estimate of the arterial blood-pressure in an artery of variable calibre, such as the radial, like the other senses has its illusions, which may mislead even the well-trained finger. The evidence these instruments have furnished has shown that it is the varying calibre of the artery which is the main factor in misleading the clinical observer in regard to his tactile estimation of the arterial blood-pressure, and especially when the calibre is greatly reduced; for then the appreciation of the blood-pressure affords to the finger the impression of a marked fall in that pressure—even though it may have actually risen considerably. I have met with many instances in which the tactile estimation of the blood-pressure in the contracted radial artery was either normal or even sub-normal, when it was in reality high as determined by the hæmodynamometer, or by the finger applied to the external carotid; and in such cases other indications of increased arterial blood-pressure were apparent.

The facts elicited by the employment of the hæmodynamometer with a solid pad applied to arteries of different calibre in the same subject, and by the concurrent use of it with the arteriometer applied to an artery of variable calibre (the radial), throw some light on this apparent discrepancy between the impression of the blood-pressure acquired by the finger from the radial artery, and the actual blood-pressure pervading the arterial system; for the finger-tip is a solid, and as such it will be liable to under-estimate the blood-pressure when the calibre of the artery is diminished.

It would therefore seem that digital estimation of the blood-pressure should be more reliable when derived from a large central artery, which is somewhat less variable in calibre than the radial, richly endowed as this vessel is with muscular tissue; such an artery, for example, as the external carotid, which is conveniently placed for digital examination and for compression on a firm bed. I have found it useful to refer to the digital estimation of the blood-pressure in the carotid whenever a discrepancy is apparent between the readings of the hæmodynamometer (furnished with a fluid pad) and the finger applied to the radial; for in this way the discrepancy is proved to be only apparent, and due to the inadequate appreciation of the blood-pressure by the finger applied to a radial of reduced calibre.

The blood-pressure can only be correctly estimated through a fluid medium.—The recognition of this fact is due mainly to the work of Roy,* von Bach,† Leonard Hill and Barnard.‡ It marks a great advance in the construction of instruments for the physiological and clinical study of hæmodynamometry in man; for the adoption of a fluid medium enables the recorder to determine the blood-pressure with accuracy, and obviates the unavoidable fallacies of the solid medium.

I will adduce a few facts, which I have observed, in support of this position.

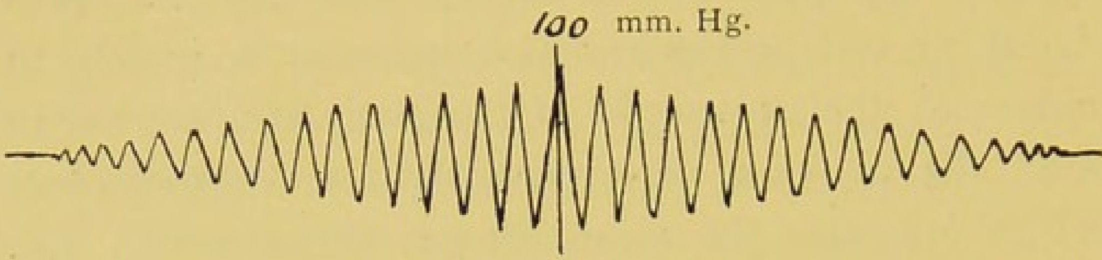
1. **Variations in the resistance of the tissues do not vitiate the correct reading of the mean arterial blood-pressure.**—This fact is apparent in the observation of a uniform reading of the mean arterial blood-pressure afforded by all the accessible arteries—covered as they are by varying thicknesses of tissue—in the same subject, providing of course that that pressure is determined through the fluid medium on a uniform hydrostatic level. It may, moreover, be demonstrated in another way, namely, by increasing and varying at will the resistance over the artery by superposing layers of material (such as chamois leather, &c.) on the skin; when the point on the

* *Practitioner*, London, vol. xlv.

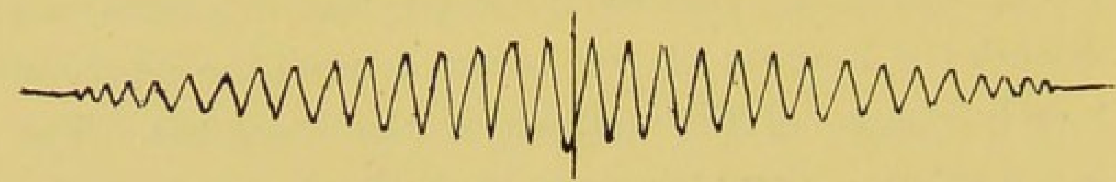
† "Abhandlung ueber den Sphygmomanometer und seine Verwerthung in der Praxis," Berlin, 1887.

‡ *Brit. Med. Journ.*, London, 1897, vol. ii.; *Lancet*, London, 1898, vol. i.

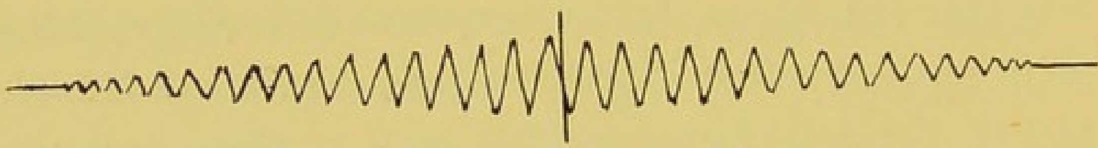
scale at which the mean arterial blood-pressure is read when the skin is uncovered remains exactly the same after the addition of each layer. The only effect produced by interposing resisting material is merely to reduce all the excursions of the indicator, and not to alter the position of their maximum development, which indicates the mean arterial pressure (fig. 29). In the same way it has been found that the use of thicker rubber to enclose the fluid medium does not disturb the reading of the mean arterial pressure—it merely lessens all the motions of the indicator. The mean arterial blood-pressure is read when the oscillations of the indicator attain their greatest range, and when the pulsations of the artery remain free beyond the point of observation; therefore the vessel is not closed, and all the solid structures (the wall of the vessel, the superjacent tissues and skin, and the rubber enclosing the fluid medium) intervening between the blood and the fluid of the pressure-gauge merely move together in unison with the pulse wave, and with that extent of motion which their resistance permits—the point of maximum motion remaining the same for all degrees of resistance. It therefore follows that the varying resistance of the tissues in different individuals only modifies the extent of the motions of the indicator, and does not vitiate the reading of the mean blood-pressure. But on the other hand, that varying resistance would have been a disturbing influence had it been necessary to close the artery by external pressure in order to determine the blood-pressure; then no reliance could have been placed on the records obtained in different individuals.



The pad on the bare skin.

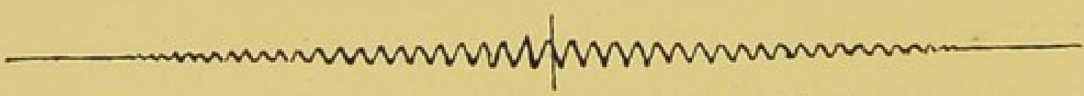


The pad on two intervening layers of chamois leather.



The pad on four intervening layers of chamois leather.

The pad on six intervening layers of chamois leather.



The pad on eight Intervening layers of chamois leather.

FIG. 29.—Diagram showing that the maximum excursion of the indicator of the hæmodynamometer appears under the same pressure, whether the pad be placed on the bare skin over the artery, or on one or more layers of material interposed between it and the skin.

2. **Variations in the calibre of the arteries do not disturb the reading of the mean arterial pressure.**—This fact is proved by all the arteries

available for observation affording an identical blood-pressure when estimated through a fluid medium on the same hydrostatic level. It is likewise obvious when the hæmodynamometer is used along with the arteriometer on the radial artery. When, for example, the arteriometer indicates a reduction in the calibre, the hæmodynamometer may show a rise or a fall in the blood-pressure—in the former case suggesting contraction as the cause of the lessened calibre, and in the latter mere passive shrinking; and when an enlargement of the calibre is read, the hæmodynamometer may also reveal a rise or a fall in the blood-pressure—in the former case the enlargement being due to distension of the arterial wall, and in the latter to relaxation, or the abeyance of tone. The blood-pressure gauge, furnished with a fluid pad, is therefore capable of discriminating between an increase or a decrease in the blood-pressure irrespective of the calibre of the artery.

3. **The adoption of the fluid principle obviates the errors due to the malposition of the solid pad and to abnormal conformation.**—The solid pad necessitates great accuracy in regard to the position of it on the axis of the artery—slight deviations therefrom affording erratic readings; therefore the personal equation in making observations with a solid pad is large. But the fluid pad does not require any such nicety for its adjustment; for, so long as the indicator responds to the pulsations, a correct reading is obtained, whatever may be the position of the pad

in regard to the artery. When the centre of the pad is placed over the artery the pulsations of the indicator are larger than when it is on one side of the vessel; yet the reading of the mean arterial pressure remains the same. It therefore follows, that with the fluid pad the observer is not liable to fall into error from malposition of the pad. Nor is the abnormal conformation of the parts about the artery a source of error; for the external configuration of the surface has been experimentally altered in various ways without producing any variation in the reading.

The adoption of the fluid medium, therefore, removes all the leading difficulties encountered in attempting to determine with reliability the blood-pressure in man; obviating, as it does, the disturbing influences exerted by the tissues, by the varying calibre of the vessels and by abnormal physical conformation on the solid pad, and moreover rendering the observation of the blood-pressure much more easy, and much less liable to error, from want of aptness and technique in the observer, than when he attempts that observation through a solid medium.

*The Blood-Pressure Gauge.** (Fig. 30).

The hæmodynamometer consists of two principle parts:—(1) the pad and (2) the recorder.

* This instrument was described by me at the meeting of the Physiological Society, held at University College, London, on March 12, 1898.

The pad (fig. 30, *a*) is made of thin rubber, is small, and of cylindrical shape, and is encircled by a metal rim, which limits lateral expansion when the instrument is used. The lower end of it projects beyond the

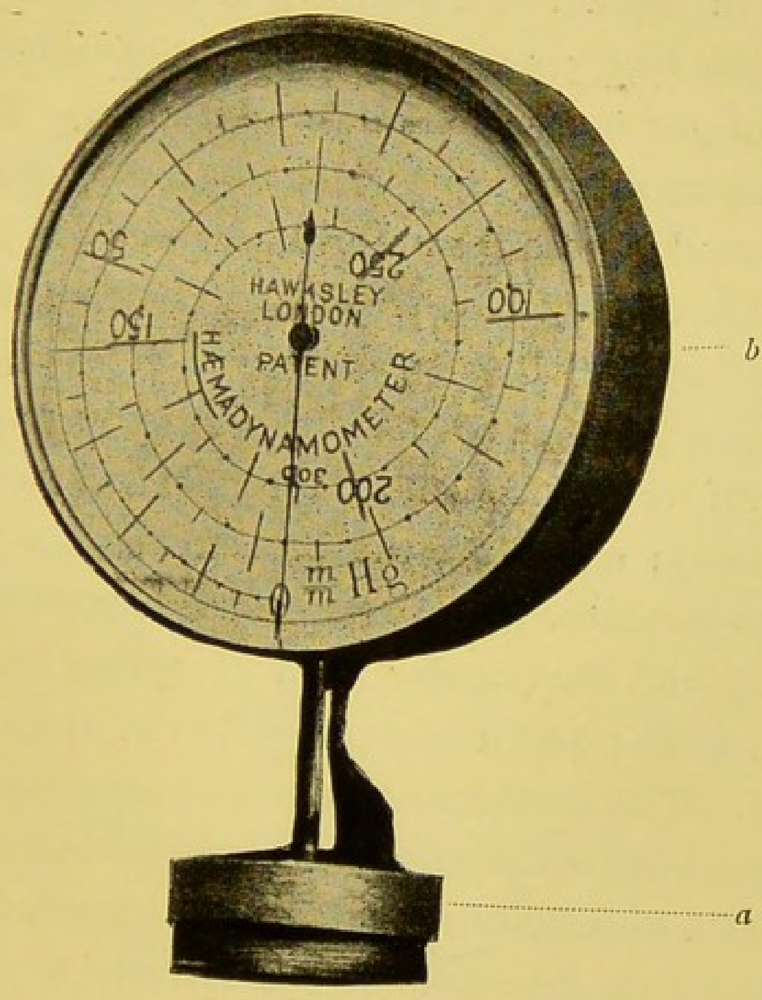


FIG. 30.—The hæmodynamometer. *a*. The pad encircled by metal rim. *b*. The recorder.

rim, so that, when it is applied over the vessel, nothing but the soft rubber is brought in contact with the skin.

It may be convenient to those who have purchased my old pulse pressure gauge to know that Mr. Hawksley, 357 Oxford Street, London, W., will convert it into the new form with fluid pad.

The upper end of it is kept in apposition with a solid disc, which is connected by a stem with the circular spring of the recorder. It is charged with water containing a little glycerine.*

The recorder (fig. 30, *b*) is a circular box, two inches in diameter, containing a circular spring (fig. 31) which receives the pulsations transmitted through the fluid pad by the solid disc and stem. The spring is of course free in the box but is fixed above. A very fine thread passes from the lower end of the spring round the cylinder of the axle, and is maintained in a state of tension by a piece of watch hair-spring; so that when pressure is brought to bear on the pad, the axle with its attached indicator acquires a corresponding motion; and when the pressure ceases the spring and the indicator resume their former position (fig. 31). I have found the circular form of spring very satisfactory in work; and it is superior to the spiral or other variety. The instrument has been standardised from the mercurial manometer, and corroborative readings have been obtained in the dog. The scale, in the form of a helix or involved circles, extends to 250 or 300 mm. Hg, and is of ample length, being over eleven inches, to enable the observer to make accurate readings of five or even two and a half mm. grades.

How the instrument determines the mean

* Those who have experience of rubber for medical purposes tell me that immersion in water is the best mode of preserving its properties intact—even for years. Glycerine is added with the view of further maintaining the sensitive suppleness of the rubber.

arterial blood-pressure.—The pad having been placed over the artery, the observer merely requires to press forward the dial part (the recorder) of the instrument, when the indicator begins to pulsate slightly at the lower part of the scale; and, as the

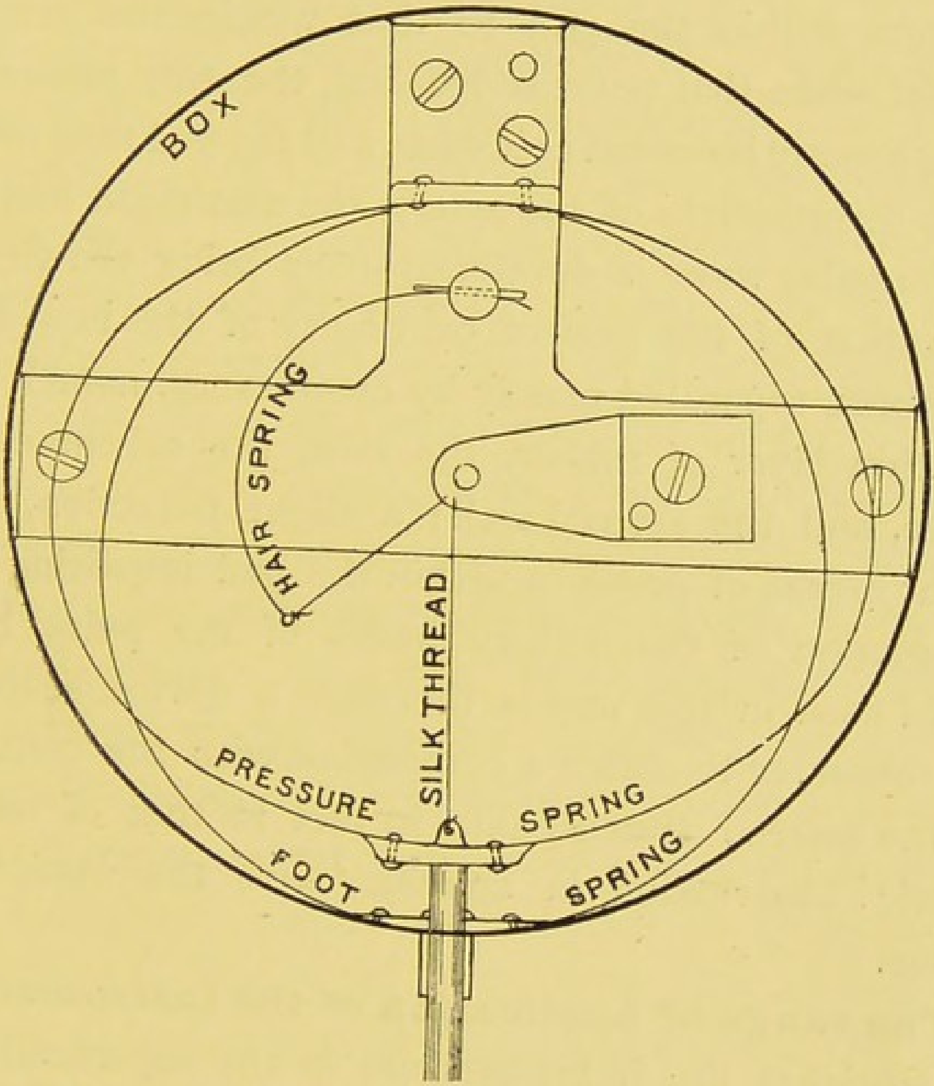


FIG. 31. Section of the recorder of the Hæmodynamometer.

pressure is being steadily increased, the pulsations gradually become larger until they attain to a maximum excursion; and then, as the pressure is carried further, they as gradually diminish—the progressive rise and fall of the motion being perfectly equable throughout. The mean arterial blood-pressure is indicated when the maximum motion is attained—the reading being made at the point midway between the two limits of the excursion.

The principle followed is to equilibrate the fluid pressure within the pad to that within the artery, so that when that point is reached, the two pressures being exactly balanced as it were, and the pad then being but a diverticulum of the artery, the maximum motion of the pulse wave is developed—this being the visible indication of the perfect continuity of the two fluid pressures, separated merely by membranes, namely, by the thin layer of rubber, the skin, the subcutaneous tissue, and the arterial wall; a slight reduction, or a slight excess of pressure within the pad impairing the conduction of the motory waves of the pulse beat. Fluid used in this way is therefore a device enabling the observer to obtain a connection with the contents of the arterial system, akin in fact to that of manometric observation in animals, save the breach of tissue.

The range of application of the instrument.—It furnishes the blood-pressure in any superficial and accessible artery, and in the veins. In the arteries observation may be made on the carotid, temporal, radial, ulnar, posterior tibial, arteria dorsalis pedis, or even on such small arteries as the arteria-superficialis volæ, or the digital arteries. The radial is the most convenient for clinical work. Observation of the venous blood-pressure is most easily made on the veins of the dorsum of the hand.

The sensitiveness of the instrument in responding to the pulsations.—As a rule, the maximum excursion of the radial pulse is sufficiently ample, being in an average case from 5 to 8 mm., and when the beat is somewhat voluminous it may attain from 10 to 15 mm. This amplitude of the motion unfolds the character of the pulse—a point of some clinical importance; but, on the other hand, it impairs the exactitude of the reading of the mean pressure, for then it becomes more difficult to determine the point when the maximum development is reached. Whenever the excursions attain this limit, *e.g.*, 6 mm., it has been found conducive to accuracy in reading the pressure to reduce the motion by covering the radial with a layer or layers of chamois leather, or the finger of a glove—a procedure which merely limits the excursions of the indicator, and does not alter the correct reading of the blood-pressure (see p. 111). To attain the same end there is of course the alternative of selecting a smaller artery, such as the ulnar or its terminal portion in the hand, or the arteria-superficialis volæ, or even one of the digital arteries at the base of the finger. The delicacy of the instrument is shown, not only by affording the blood-pressure in the smallest arteries, but in detecting all the degrees of gravity variation in arterial pressure, a difference of two or three inches in level being, for example, quite apparent.

How to observe the arterial blood-pressure.—The instrument may be conveniently and accurately applied without the aid of any mechanical rest or accessory, especially if the observer rests his hand on the table and extends his fingers against an adjacent part of the arm (for the radial) or the clavicle (for the carotid) ; the gentlest variations of pressure can thus be applied with precision. At the same time a simple

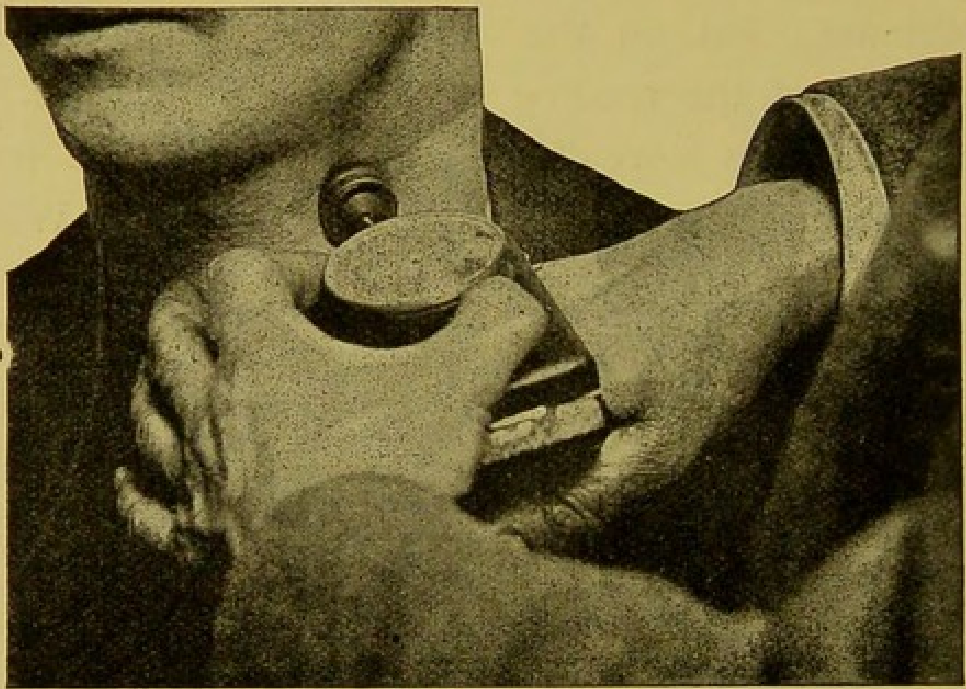


FIG. 32. Mode of applying the hæmodynamometer to the carotid artery, on the box covering the hand as a rest.

form of rest on which to slide the instrument towards the artery conduces much to accurate and easy observation ; such as the box in which it is carried, which serves this purpose admirably, the lid being inclined by means of a prop, thus providing a graduated platform for all depths of wrist, or the hand resting on the clavicle and shoulder for observation of the carotid pressure may be enclosed in it (fig. 32). Figure 33 shows how the instrument should be held so as to secure the steadiness and accuracy of a rigid rest. The pad is placed over the site of the artery, and

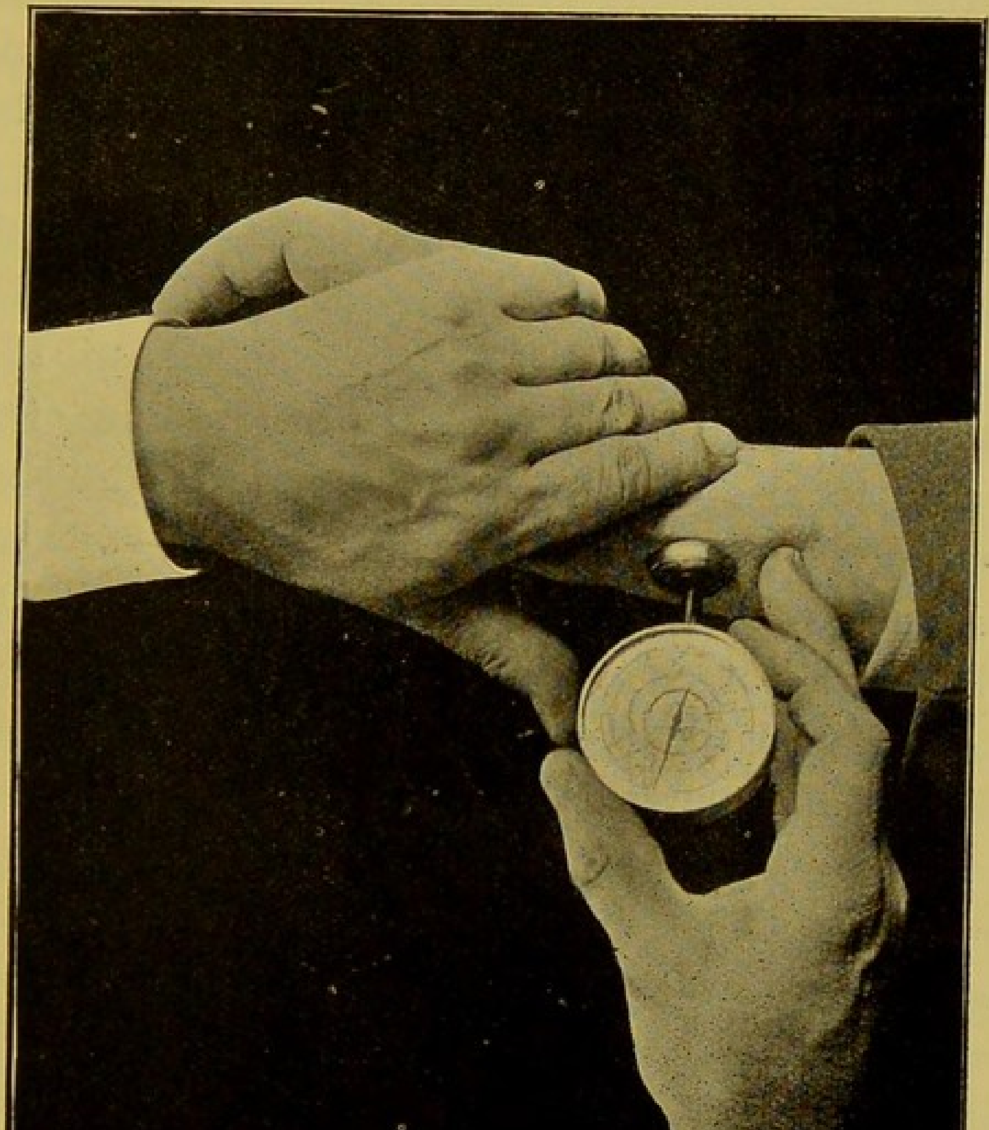


FIG. 33 shows how the hæmodynamometer should be applied to the radial or ulnar artery in order to secure all the advantages of a mechanical rest.

the wrist is bent at an angle of 45°, so as to slightly project the vessel on its bed, while the arm rests on its ulnar side. Pressure is then made by gently pushing forward the body of the instrument, when the indicator will rise on the dial, and show the exact degree of pressure brought to bear on the pad and the vessel. As already mentioned, the reading of the mean arterial blood-pressure is made at that part on the scale in which the pulsations of the indicator acquire their fullest development; then the observer has gradually raised the fluid pressure within the bag to the point at which it exactly balances that within the artery—the two fluid pressures being equal. The graduation at the mean of the maximum oscillation of the indicator is taken as the correct readings of the mean arterial pressure. In order to settle with accuracy on the position of this point on the scale, the observer should vary the pressure so as to bring the indicator above and then below the area in which it is obviously located, and then he should narrow the field of ample movement until the reading is obvious. In reading the mean arterial pressure differences of 5 mm. are quite easily made, and those of 2½ mm. are discriminated without much practice in the use of the instrument. It is not necessary to attempt to make finer distinctions than 5 mm., for ordinary clinical purposes. The intermediate markings of 2½ mm. are, however, useful in guiding the eye in discriminating the point at which the widest swing of the indicator is attained.

In order to eliminate as much as possible the influence of gravitation on the blood-pressure, it is important in making observations to preserve approximately the same relation of the position of the wrist to the base of the heart in the erect and recumbent postures; and for this purpose it is a good rule to place the wrist on a level with the ensiform cartilage in the erect (sitting or standing) positions, and on a line with the back in the recumbent posture.

It should be mentioned that the observation does not, as a rule, demand more time than one minute—not more in fact than is usually expended in the ordinary digital examination of the pulse; and, moreover, the observer determines a definite fact, instead of gathering an ill-defined impression, which may or may not be verifiable when subjected to strict investigation. Furthermore, the instrument can be applied with facility and with but a very small personal equation of error, so that any medical man, not previously conversant with the use of it, may make reliable observations.

How to observe the venous pressure.*—Select a piece of vein free from branches or anastomosis on the back of the hand, or on the arm. Press the pad over the peripheral end of it until 50 to 100 mm. are recorded. Empty the vein by drawing the finger over it in the direction of the heart. The vein will then remain collapsed when provided with an efficient valve; but if it refills a finger must be kept over the central end of the collapsed vein, or another length of vein furnished with a competent valve must be

* I proposed this method in 1898, and it was demonstrated before the Physiological Society. See *Journal of Physiology*, 1898.

selected. Then gradually reduce the pressure on the pad until a point is reached when the vein begins to refill, when the exact pressure indicated must be read.

In observing the venous pressure it is of course of

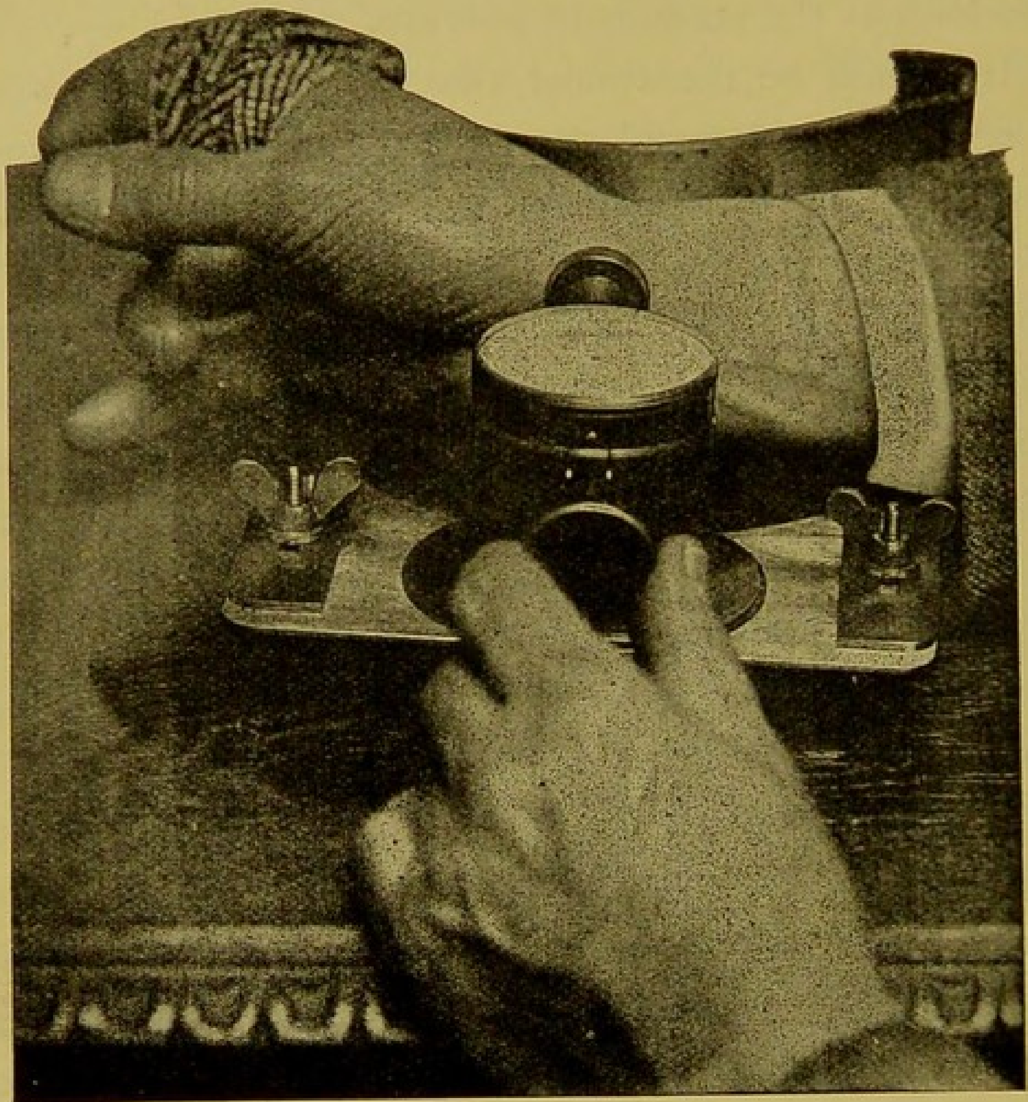


FIG. 34. Mode of applying the hæmodynamometer to the radial artery on a rest, with screw adjustment.

importance to adhere strictly to the directions already given in regard to the position of the site of observation in relation to the heart in the erect and recumbent postures; for the record of the venous pressure being low as compared with that of the arterial pressure, the influence of gravity is *relatively* greater—though it is *absolutely* the same on both sides of the circulation.

The hæmodynamometer applied on a mechanical rest.—In furnishing many of the data

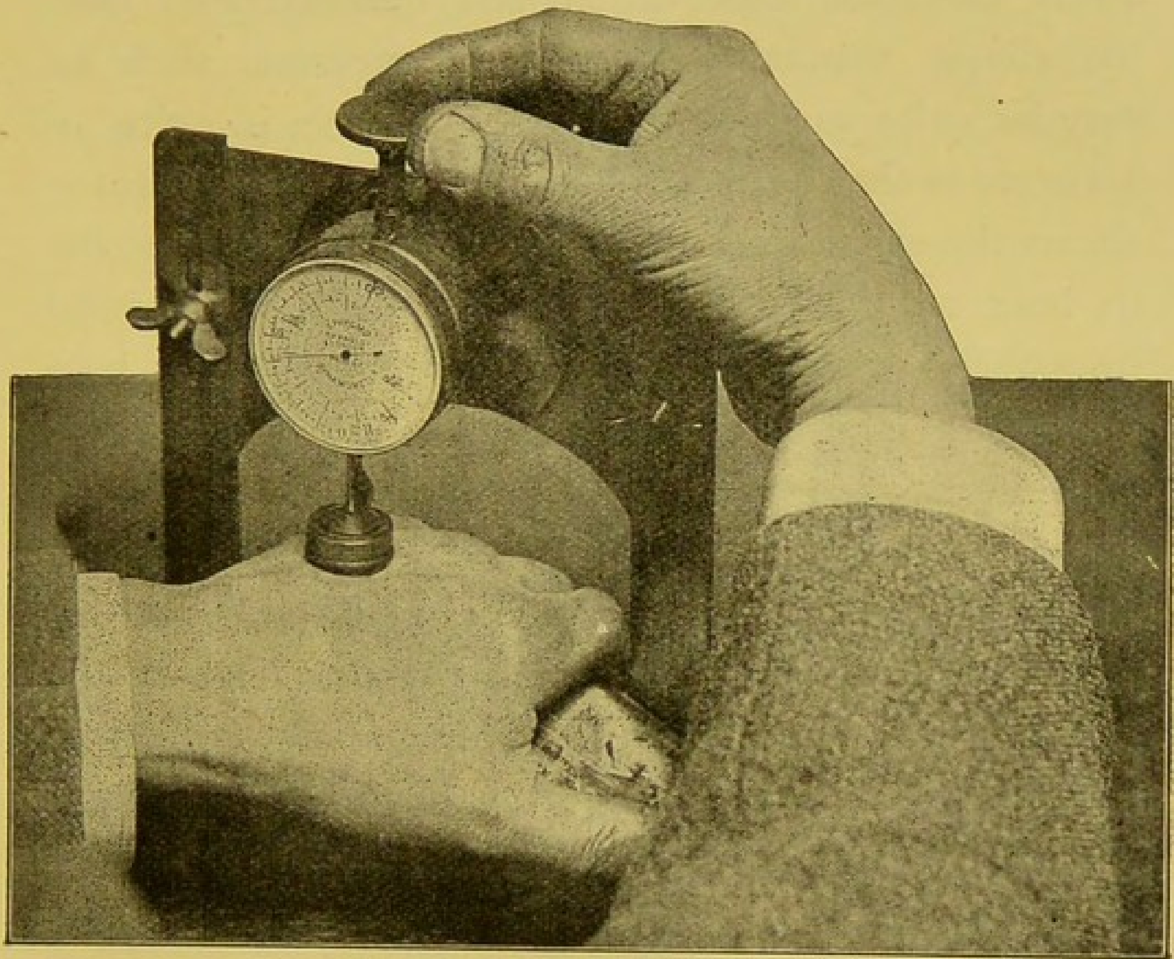


FIG. 35. Mode of determining the venous pressure with the hæmodynamometer applied by means of a screw adjustment.

relating to the arterial and venous blood-pressure collected in this physiological and clinical research the instrument was employed on an adjustable rest, and the pressure was turned on and off by means of a screw, as shown in figs. 34 and 35. It was used horizontally in determining the blood-pressure in the radial or in any of the small arteries of the hand (fig. 34); and vertically in reading the venous pressure (fig. 35). Though it seemed advisable in prosecuting this enquiry to resort in the first instance to a purely mechanical method of applying the instrument, subsequent extended observation has demonstrated that the simple manual adaptation of pressure, such as may be quite easily employed by anyone, is quite as accurate as that furnished by a screw; for the indicator shows the exact amount of pressure which is brought to bear on the pad at any moment, it being quite immaterial whether it is exerted by the hand or by a screw, providing it is applied steadily, and providing the indicator is made to travel definitely from point to point, where it is allowed to rest in order to determine the amplitude of the oscillations. The proof of this position is furnished by the fact, that, so long as the blood-pressure remains uniform, the reading cannot be varied by the manual use of the instrument, whether thus applied by different observers or by the same observer. Therefore the application of the instrument by the hand is certainly all that is necessary to ensure accuracy in clinical work, or even in physiological observation.*

* I find that those who have had no experience of the application of the instrument by the hand and by instrumental aid are apt *à priori* to regard the manual use as probably open to error; careful observation has, however, definitely excluded this suspicion.

II. The Arteriometer.* (Fig. 36).

This little instrument is designed to solve the problem—how to measure the bore or calibre of a collapsable tube, like the radial artery, from the outside.

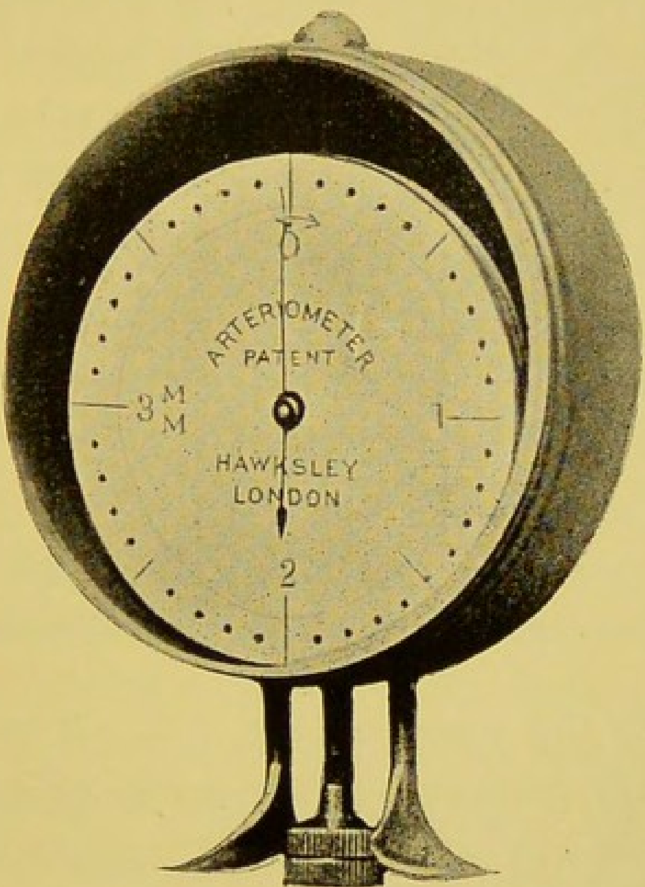


Fig. 36.—The Arteriometer.

The mechanism is enclosed in a small circular box (inner box, fig. 36) which presents below three stems—

* This instrument was described by me at the meeting of the Physiological Society held at King's College in March, 1894. The arteriometer and the hæmodynamometer are made by Mr. Hawksley, Surgical and Physiological Instrument Maker, 357 Oxford Street, London, W.

one on each side fixed to the box and carrying the foot rests, and one between, to which the pad or button is screwed, being free to settle over the site of the artery. This central stem is fixed to a frame, which slides in grooves to maintain the exact vertical direction of the up and down movement. This movement is communicated to the hand on the dial by a silk thread attached to the lower part of the frame and maintained in a state of uniform tension around the axle by a piece of hair-spring, so that the exact position of the pad in relation to that of the foot-rests is

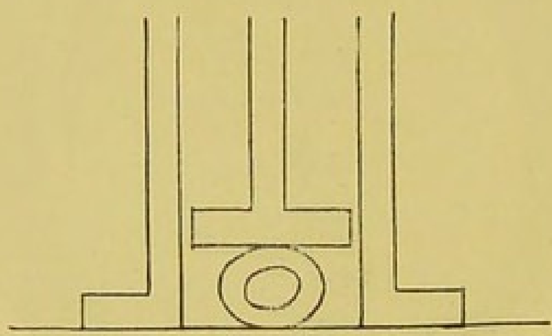


FIG. 37. Diagram showing the principle of the writer's arteriometer.

indicated by the hand on the dial. If now the two foot-rests are planted by the sides of a piece of rubber tube, the pad will settle on it (fig. 37) and the hand on the dial will indicate the position which it has assumed as the starting point of the measurement to be made; and all that is necessary in order to determine the internal diameter of the tube is some arrangement that will push forward the pad until it closes the tube, when the hand on the dial will travel from its initial position, and furnish the required measure. That arrangement is secured by a rod attached to the outer case enclosing the instrument, which merely thrusts before it the frame carrying the pad, when that case is pushed downwards. As the outer box is pressed forwards a point is reached when air can no longer be blown through the tube, and in the meanwhile the diameter is recorded on the dial. In this way a much more exact measurement of the bore of the tube can be obtained than by direct observation of the cross section of it, for the mechanism magnifies the space to be measured, and enables the observer to read down to a tenth of a mm. or even less. The outer box serves a most important purpose in making such a delicate measurement as that of the radial calibre. It is separated from the instrument by the intervention of springs, which glide towards the rod as it is pressed downwards, so that a uniform pressure is thus maintained on the foot-rests throughout every observation, and the observer cannot unconsciously or in any way modify the reading obtained. The personal equation is thus much more satisfactorily met than it could be even by more elaborate mechanical arrangements. The dial provides for the measurement of 4 mm., and is graduated in tenths of a mm., and it automatically revolves with the indicator, so that every reading is made from zero, and not from a variable part of the scale, as would be the case were the dial to remain fixed. Lastly, it will be obvious that the force used to close the artery always exceeds that of the blood-pressure, otherwise the indicator would not travel on the dial.

How to apply the arteriometer.—Of the superficial arteries the radial is best adapted to the purpose in view, for the calibre of it is sufficiently large to provide an ample scale for the definite recording of variations; and, moreover, the vessel occupies an accessible position on a bony floor, and is flanked by firm structures. The temporal artery is somewhat too small for general selection, though the measurement of its calibre may now and then prove useful, when the radial arteries are not available for trustworthy observation.

Two conditions must be observed in order to make the reading as reliable as possible:—(1) The wrist must always be extended at a uniform angle; and (2) the same part of the artery must be observed on all occasions. The first condition is secured by placing the extended arm on a wrist-rest providing an angle of 45°*; and the second, by marking with an aniline pencil the site of that portion of the artery selected for measurement. A preliminary examination by the finger quickly enables the observer to decide where the bed of the artery is most even and resistant, and therefore best adapted to the observation; and, as a rule, this is found to be on a line with the prominent point of the styloid process.

Figure 38 represents the most convenient way of

* This angle of extension generally secures a slight and uniform traction of the tissues, which favours definite observation; for example, the tendon of the flexor carpi radialis thus becomes a resistant platform for one of the foot-rests.

applying the arteriometer. The instrument is held by the index finger and thumb of the right hand; the foot-rests are planted, one on the styloid process, and the other on the flexor tendons rendered firm by the extension just referred to; and the pad is made to occupy the exact site of the artery. The index finger

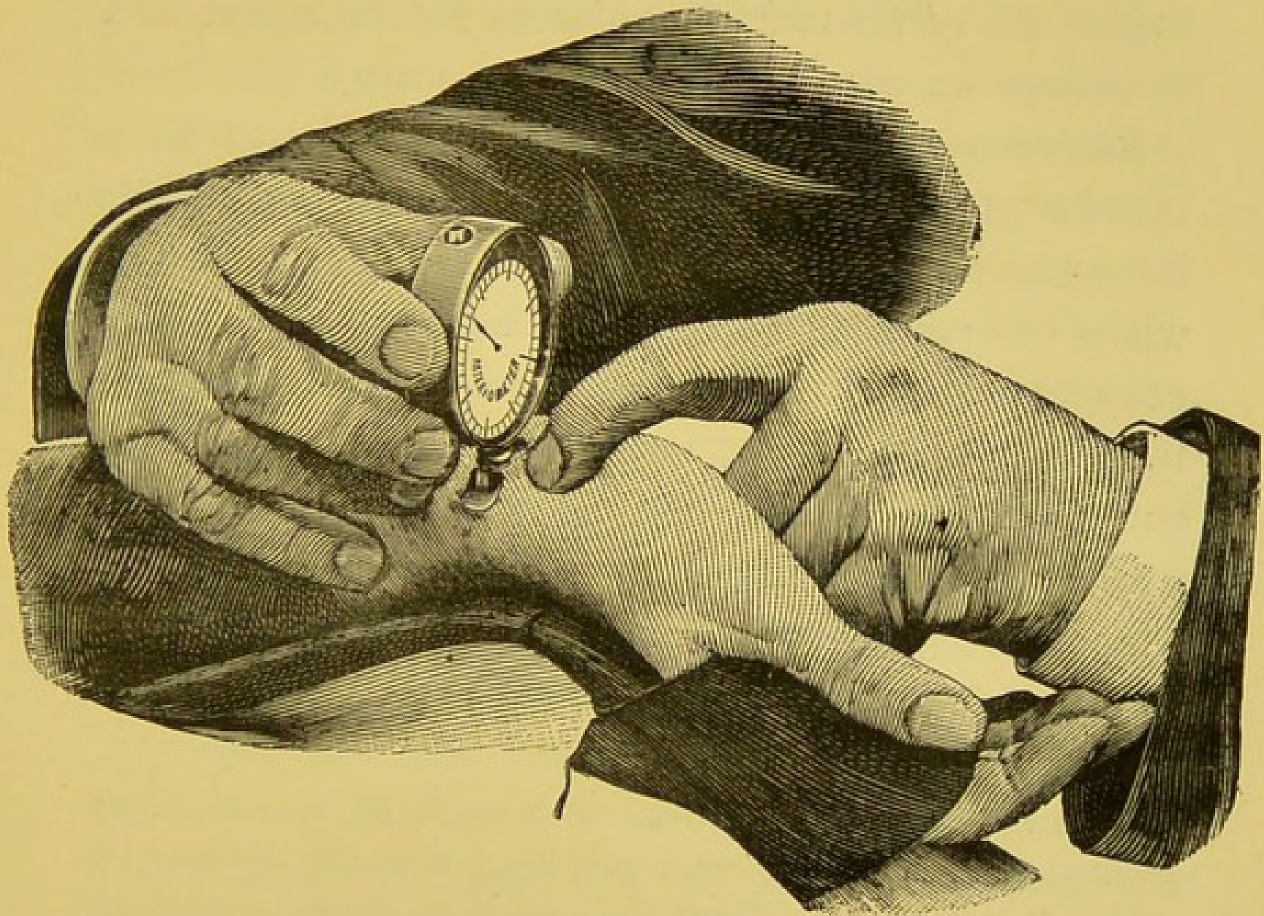


FIG. 38. The mode of applying the arteriometer—the wrist being extended on a wrist rest.

of the left hand is placed over the artery beyond the pad; and the outer case is drawn slowly downwards. At first the indicator travels until it reaches a certain point, when it turns in the opposite direction; this point should be carefully noted, for then the pad begins to close the artery, and the reading of the measurement should commence. As the artery is being closed, the pulsation felt by the index finger after a time gradually diminishes, until it fails to be perceived, when the observation is at an end, and the travel of the indicator will furnish the measure of the calibre.* It is generally necessary *to raise slightly the radial side of the wrist* in order to secure a firm and even base on which to compress the artery.

Sources of fallacy.—There must always be a certain proportion of cases unsuited to any reliable instrumental observation of the radial artery; as when the vessel is abnormally distributed, or lies too deep, or when there is an excessive deposit of fat over it. Perhaps, however, not more than ten or fifteen per cent. of cases should be thus excluded. The instances in which the radius provides an insufficient support for compression of the artery, in consequence of shelving away too rapidly, are totally unfitted; but

* According to my observation, the finger is the best and most practical guide in deciding when pulsation ceases, and the artery is closed; it is, moreover, endowed with a surprising degree of sensitiveness, *e.g.*, on applying the arteriometer to determine the bore of a small rubber tube, through which water was intermittently propelled under a pressure resembling that within the arteries of man—as indicated by an attached mercurial manometer—the left index finger could definitely detect pulsation beyond the pad until the pulsatile movement of the mercury and the flow of water actually ceased. I am disposed to think, that the left index finger is more sensitive than the right; perhaps because the epidermis on that side is slightly thinner—the more frequent use of the right hand tending to thicken it.

the finger can, as a rule, readily detect such cases. The fulness of any superficial veins over the site of the artery might increase the reading; but this source of error is easily removed by making slight traction on the skin before adjusting the pad.

In 1897 Leonard Hill, H. L. Barnard and J. H. Sequeira adduced some data to show that the venous pressure may be so raised as to vitiate the reading of the radial calibre by distending the venæ comites of the radial artery, and these observers likewise asserted that these veins may in this way become so enlarged as even to mislead the observer in his ordinary tactile examination of the pulse.* During the past three years, having meanwhile devised a method of determining the venous pressure in man (see p. 123), I have paid special attention to the detection of evidence in support of these views, especially in so far as they apply to ordinary clinical work; but I have so far failed to discover any such evidence. I have, for example, repeatedly met with low readings of the radial calibre when the venous pressure was exceptionally high; and I have failed to detect a direct relation between the evidence of a high calibre and that of a venous pressure above the average. I have likewise made several observations with the arteriometer after raising the venous pressure of an arm by constricting the veins, using Hill and Barnard's sphygmometer; and in no case was the reading of the arteriometer affected by a venous pressure below 80 mm. Hg., which according

* "Effects of Venous Pressure on the Pulse," *Jour. of Physiology*, 1897.

to my experience is about the highest limit reached in clinical observation.

When the arteriometer was brought forward I pointed out that the wrist should be invariably fixed at an angle of 45°, so as to ensure a certain uniform degree of traction on the tissues. This traction suffices to annul any distension of the veins—including of course that of the venæ comites. Therefore I regard this direction as of fundamental importance in ensuring accuracy of observation, and the failure to comply with it will lead to error. A wrist rest such as that shown in fig. 38 is useful in preserving this uniform position of the wrist.

III. The Volumetric Measurement of a Limb.

In order to determine the extra amount of blood which is incited to circulate in a limb by local exercise, by resistive movements, by massage, by faradism, and by baths I resorted to the following simple method of measurement of the volume of a limb afforded by the displacement of water.

A large trial jar was placed in an over-flow basin. It was then very carefully adjusted to an absolutely horizontal position by a spirit level, and filled exactly to the brim with tepid water (95° F.)—this point being indicated by the correct reflection of a window on the surface. The arm, around which an aniline line was drawn above the elbow, was immersed until the line was touched all round by the water. The overflow was then measured before and after the procedure thus tested, whether exercise, massage, faradism, or a bath.

IV. A Method of Gauging the Splanchnic Area.

It was found that when the abdomen was compressed by an equably distributed weight in the recumbent posture, the systemic blood-pressure (arterial and venous) was raised. It was inferred, that the rise was due to the displacement of blood from the splanchnic veins, or to the reduction of the splanchnic area from the equable pressure diminishing the arterioles supplying it; and that the extent of the rise was proportionate to the amount of blood thus displaced or diverted. In support of this position it was found, that the increase of the systemic blood-pressure induced by applying the same weight to the abdominal wall of the subject under observation varied at different times; being influenced by the digestive process (see p. 183), by exercise (see pp. 163-5, 170), by fatigue (see p. 174), and by the night's rest (see p. 193). Furthermore, it was obviously not due to temporary compression of the vena cava and aorta; for it was found to persist for some time after the removal of the weight while the subject remained in the recumbent posture, but to disappear at once after he assumed the erect position—sitting or standing (see p. 149).

The following was the mode of observation adopted.

The subject assumed the horizontal position with the arm extended on the plane on which the back rested; then the mean arterial pressure was determined by applying the hæmodynamometer over an artery which affords a small pulsation, and therefore renders the reading as definite as possible, such as the ulnar, or the superficialis volæ, or a digital artery, and the venous pressure was read from a vein on the dorsum of the hand; and then layers of sheet lead weighing about 14 lb. (or a layer of glycero-gelatin charged with shot of similar weight) were adjusted to the abdomen, and a 14 lb. weight was placed over all, when the blood-pressure was again read.

CHAPTER V.

THE CIRCULATION: PHYSIOLOGICAL VARIATIONS.

It is perhaps scarcely necessary to remark that the study of the blood-pressure in normal man is an indispensable preliminary to the clinical observation of it, at any rate if this is to be anything more than merely empirical. Moreover, this introductory physiological study is all the more called for, because our knowledge of particular facts in regard to the blood-pressure in normal man is but limited, and therefore there remains much of a definite character to be acquired, and settled by further direct observation. Furthermore, until quite recently the means of observation in man have been distinctly faulty, and consequently physiologists have preferred to rely on inferences derived from the general facts of the circulation acquired by experimentation on animals, rather than on the observation of data furnished by man himself. But apart from the mere settling of facts in this department of physiological observation, the study of them is particularly instructive to the observer whose practical inquiries are mainly clinical; for, observing how well the physiological equilibrium of the circulation is maintained, as a rule, at all points by quickly responding adjustments, his interest is quickened by all those slight failures in accommodation so apt to manifest themselves now and then in health: such failures being but transitory approximations towards the pathological, and affording an insight as to how the permanent aberrations in disease are brought about. In this outline of my observations of the blood-pressure in health, as determined by the hæmodynamometer and the arteriometer, I propose in the first place to briefly touch on some general questions relating to arterial, peripheral, and venous blood-pressures; secondly, to describe the effects of different physiological conditions on the arterial and venous pressures; then to point out some of the characteristic features of the venous pressure, which has not hitherto been determined in man; and, lastly, to indicate the average limits of normal arterial and venous pressures.

I. Some General Facts pertaining to Arterial, Peripheral, and Venous Blood-Pressures.*

1. **Observation shows that the arterial blood-pressure is practically uniform throughout the arterial system.**—The hæmodynamometer has indicated that the mean arterial pressure is uniform in all the arteries accessible to observation in the same

* Reference is here made only to some of the leading circulatory causes of variation in the blood-pressure.

subject. Inasmuch as the area of observation includes the carotid on the one hand, and such small superficial arteries as the digital on the other, this position may seem to be somewhat heretical, for the accepted teaching of physiologists is to the effect that the blood-pressure diminishes along the arterial tract from the heart towards the small arteries and capillaries—that it is higher in the large central arteries than in the small peripheral arteries. My observations do not, however, accord with this view, for they show that the mean arterial pressure does not appreciably vary in the different parts of the arterial system on which observation can be made—always providing, of course, that the influence of gravitation is excluded. In order to decide this point, the blood-pressure in all the various superficial arteries of the same subject has been repeatedly determined in the recumbent position, and it has always been found that when discrepant readings were detected, they were to be accounted for by deviations from this uniform level which had been overlooked, and not by variations of distance from the heart. Inasmuch as the hæmodynamometer can detect the effect of differences of level so small as two inches, the failure to discover the gradual reduction of the mean arterial pressure described in the books as taking place between the large arteries (as the carotid) and the small arteries (as the digital) is not due to want of delicacy in the instrument. It may therefore be concluded that the arterial blood-pressure is not appreciably different in various parts of the arterial system; that it is practically uniform throughout the area of arterial pulsation; and that the only recognisable cause of variation to which it is liable in the different arteries is the force of gravity.

This position, furnished by direct observation, is moreover rendered probable by theoretical considerations. It is assumed that, as the resistance increases as the arteries divide into smaller channels, the arterial blood-pressure is diminished in the still smaller vessels, and this would doubtless be the case were the sectional area of the arterial bed to remain without change or to diminish; but, inasmuch as it widens, the velocity of the blood is reduced, and the resistance to the flow in the narrowest channels is thus counteracted, and consequently the blood-pressure in them may not fall as is usually supposed.

It would seem that whatever in any part of the arterial system raises or lowers the mean blood-pressure does so throughout that system as a whole; and that the maintenance of a high fluid pressure in the smaller divisions of it may serve a useful purpose, and may not be a matter of mere theoretical interest, for whenever the arterial pressure becomes excessive, it may relieve itself by dilating the terminal arteries and arterioles—the outflow into the capillaries and veins being thus increased. Therefore it is not improbable that the conformation of the arterial system, securing a strong blood-pressure in its peripheral portion, and the more delicate walls of the smaller vessels, rendering them more amenable to dilatation, provide a mechanically self-adjusting arrangement by which the rise of arterial blood-pressure incited by physiological causes is modified and limited.

Moreover this position may also be regarded as having a pathological bearing, for aneurisms in the small arteries and hæmorrhage from them may be more readily accounted for when the arterial blood-pressure is raised and is maintained at a high degree in the peripheral portion of the arterial system—and especially when the increased pressure cannot compensate itself by dilating the terminal vessels because of organic changes in their walls.

2. **The blood-pressure is decisively reduced by the arterioles.**—Observation has failed to detect a fall of blood-pressure on the proximal side of the arterioles. Inasmuch, therefore, as it is known that the capillary pressure is only about twenty-five per cent. of the arterial pressure,* it follows that the fall of seventy-five per cent. takes place while the blood is passing through the arteriolar region. From this fact it is obvious that the blood-pressure is practically unaffected until the blood reaches the arterioles, where the flow receives its first decisive check.

3. **The blood-pressure is probably not reduced by the passage of the blood through the capillaries.**—The sectional area of the bed of the circulatory stream attains its maximum in the short capillary tract. This physical condition will certainly slacken the velocity of the blood-flow, but will not offer resist-

* Foster, "Textbook of Physiology," 1891, p. 209.

ance to it. Physiologists, therefore, now no longer regard the peripheral resistance as appreciably due to the capillaries.*

4. **The normal peripheral resistance is therefore mainly arteriolar.**—The foregoing positions point out the arterioles as the predominant, if not the sole cause, of peripheral resistance; and certainly, apart from the influence of the heart, they are the general determinants of variation in the mean blood-pressure—in the arterial pressure on the one hand, and the venous pressure on the other.

5. **The general relation between the arterial, peripheral, and venous blood-pressures.**—In health the blood-pressure is fundamentally the outcome of muscular action. On the arterial half of the circulatory apparatus we have a predominance of muscular tissue and a proportionately high fluid pressure; and on the venous side we have a minimum amount of the contractile tissue and a correspondingly low pressure. In the former the large preponderance of muscular fibre is, on the one hand, massed in the left ventricle, while, on the other hand, it is distributed in probably at least an equal aggregate amount among all the arterioles; and between the incessant clonic contractions of the former, and the tonicity of the latter, there is maintained a high and uniform arterial blood-pressure. But beyond the muscular inhibition

* The reader is referred to an instructive article by Harry Campbell on "The Resistance of the Blood-Flow," *Journal of Physiology*, vol. xxiii., 1898.

of the arteriolar region, the blood flows onward into the capillaries and veins robbed of three-fourths of its pressure, and in a stream of uniform but gradually diminishing force. The arteriolar influence is not, however, solely confined to the mere maintenance of a relatively high arterial and a relatively low capillary and venous pressure; for by variations in contractility it is a regulating factor in raising or in lowering the mean blood-pressure in the arteries and in the veins. On the one hand, by further contracting, it augments the mean arterial pressure and diminishes the venous pressure; and, on the other hand, by contracting less, or in ceasing to contract, it lowers the arterial, and allows the venous pressure to rise. It, therefore, follows that observation of the venous pressure, when made alongside that of the mean arterial pressure, affords a useful criterion of the degree of peripheral resistance exerted by the arterioles; and such observation is, moreover, likely to prove useful in the clinical estimation of that resistance. The venous pressure is, therefore in the main but the residuum of the arterial pressure, a remainder that survives the arteriolar resistance, and is inversely proportionate to that resistance.

6. **The determinants of the mean arterial pressure are arteriolar and cardiac.**—Though the arterioles exert a leading influence in lowering, or in raising the mean arterial pressure, there is another variable factor which contributes its share in the result; namely, the behaviour of the heart muscle.

The arteriolar contraction remaining the same, a more frequent and a more forcible action of the ventricle, which secures an increased output, will raise the mean arterial pressure, and a less frequent and a less energetic contraction, which lessens the output, will lower it. The output of the ventricle, as well as the degree of contraction of the arterioles, therefore, contributes to determine the mean arterial pressure. The distensibility of the arterial wall may play a subsidiary part under conditions necessitating a very high arterial pressure, but such conditions only come into operation in the clinical field. It has been observed that the influence of one factor, even though in pronounced operation, may even be predominated by that of the other; for example, in exercise the peripheral dilatation may suffice to annul, or even more than annul, the effect of the cardiac stimulation on the mean arterial pressure; and again, heat, though raising the frequency of the heart's action and presumably increasing the output, lowers the mean arterial pressure by increasing the arteriolar onflow to a still greater degree than the ventricular output.

It would seem to be the rule, that when the mean arterial pressure is disturbed from any cause the effect of one factor (central or peripheral) is modified by that of the other, so that that pressure is maintained within the narrowest limits; for example, when the arterioles are constricted by cold the onflow of blood into the capillaries is of course diminished and the mean arterial pressure is raised, but this rise is modified by a diminution of the ventricular output induced by a fall in the frequency of the heart's action, and it may even be annulled by the peripheral dilatation (the reaction) to which the constriction may succumb under the stress of the higher degrees of arterial pressure.

II. Physiological Causes of Variation in the Blood-Pressure (Arterial and Venous).

I have made a large number of observations in healthy subjects on the effects on the blood-pressure of the following physiological conditions, namely :—

1. Gravitation.
2. Posture.
3. Muscular exercise.
4. Mental exercise and emotional excitement.
5. Fatigue.
6. Rest.
7. Excitation of respiration and effort.
8. Digestion.
9. Beverages.
10. Temperature.
11. Pulse-rate.
12. Diurnal conditions.

1. *Gravitation.*

In the textbooks on physiology—even in those published in recent years—there are but few references to the influence of the force of gravity on the circulation; nevertheless it is a fact which has been recognised for many years by physiologists.* Perhaps the paucity of these references is due to the self-evident character of the fact, which is moreover sufficiently confirmed by physiological and clinical observation. Recent workers have, however, brought it prominently under notice, and have furthermore demonstrated the potent influence of gravitation on the circulation, when the splanchnic vasomotor control is impaired.† Though the force of gravity is constantly acting on the blood-pressure in the arteries and in the veins, it neither favours nor retards the circulation through these vessels in any part of the body, so long as the vasomotor adjusting mechanism remains intact. As soon, however, as that mechanism becomes impaired (see pp. 227 and 228), the disturbing influence of gravitation declares itself in reducing the blood-pressure in the upper portions of the body.

The hydrostatic effect of gravity on the normal

* See Kirkes, "Textbook of Physiology," first edition, published in 1848.

† See Hill, *Journ. Physiol.*, Cambridge and London, 1895, vol. xviii.; Hill and Barnard, *ibid.*, 1897, vol. xxi.

blood-pressure in the arteries and in the veins can be accurately measured in man by the hæmodynamometer.* It should be 1·9 mm. Hg. (or approximately 2 mm.) for every inch; and this rate of gravity variation has been verified by observation.

The effect of gravitation on the arterial blood-pressure.—First, as to the evidence of the operation of gravitation afforded by the arteries. It has been already stated that the arterial blood-pressure is uniform in all the accessible arteries (*e.g.*, temporal, carotid, radial, ulnar, arteria-dorsalis pedis, &c.) when taken in the same horizontal plane; but a slight departure from that plane (such as two inches above or below it) suffices to vary the reading—the variation increasing exactly in proportion to the deviation. In an erect posture (sitting or standing) the same rule, of course, likewise holds good—the reading of the pressure in any artery, such as the radial, rising or falling according to the hydrostatic level at which observations are made. Furthermore, the pressure varies in the different arteries, according to their vertical relation to the source of that pressure (the ventricle); the temporal and carotid, for example, furnishing a lower reading than that of the radial—a reading which may not indeed exceed one-half that

* The arteriometer likewise indicates the effect of gravity in the arteries; for the radial calibre (which in the normal subject is determined by the blood-pressure) varies with the position of the wrist above or below the level of the heart—being diminished in the former case and increased in the latter.

which is afforded by the arteria-dorsalis pedis. In other words, in the standing posture the blood-pressure of the arteries of the head may be but one-half that of the arteries of the feet; and the pressure in the foot arteries in the upright position may fall to one-half when the subject assumes the recumbent posture, when gravity becomes negative.

The effect of gravitation on the venous blood-pressure.—The same fact is likewise apparent in the veins. The blood-pressure of a vein on the dorsum of the hand or foot varies exactly according to the level at which it is taken. In the horizontal plane the venous-pressure is equal in the hand and foot; but in the standing posture it rises in the foot to a very high degree. In an average case it will, for example, rise from 15 mm. Hg., in recumbency, to 135 or 140 mm. Hg. in the standing posture; the difference, being accounted for by the calculation on the basis of 1·9 mm. Hg. per inch, is therefore purely hydrostatic. Inasmuch as the venous pressure in the leg frequently exceeds in the standing posture the arterial pressure in the upper half of the body, it is certainly not surprising that the veins of the legs should so frequently become varicose. And, inasmuch as the length of the column of venous blood is probably a powerful factor in the production of varicosity, it is not improbable that there may exist a general causal relationship between the long bodied and the long legged and varicose veins.

Gravity may be employed to relieve syncope

by raising the blood-pressure in the brain.—Syncope is averted by raising the cerebral blood-pressure; as when the head is lowered below the level of the trunk, or when it is bent down between the knees. In the latter position the force of gravity is aided by compression of the splanchnic area (see p. 135). Then, again, observation has shown that when the limbs are supported in an upright position while the trunk and an arm (for observation) are recumbent the blood-pressure in the latter is at once raised; for example: —

	Mean Arterial Pressure, mm. Hg.	Venous Pressure, mm. Hg.	Radial Calibre, mm.
Before passive elevation of limbs	97	10	1·7
After " " " "	102	15	2·2

In this way the force of gravity may be made available for temporarily transferring a considerable volume of blood for circulation from the limbs to the rest of the body; a procedure which may prove useful in certain emergencies, such as in syncope from hæmorrhage, &c.

When the systemic blood-pressure is raised by compressing the splanchnic area in the horizontal position it is at once restored by the force of gravity when the body assumes the erect posture.—It has been repeatedly observed that the rise in the systemic blood-pressure, induced by applying weights to the abdomen (see p. 135), will remain from 15 to 30 minutes after their removal, though gradually diminishing meanwhile, so long as the body remains in the horizontal position; but will fall to the original reading in recumbency after the subject has assumed the erect posture for one minute. It would therefore seem that the splanchnic blood displaced by the weights in the recumbent posture, though lingering for some time in the systemic circulation while that posture is maintained, is quickly returned to the splanchnic veins by the force of gravity when the body is raised to the erect position.

The influence of gravitation to be excluded in estimating the blood-pressure.—The foregoing facts have a practical bearing on the reading of the blood-pressure; for it is obvious that observations should be invariably made as near the same level as possible. In taking the radial pressure in the erect posture (sitting), the xiphoid cartilage or the epigastrium is a convenient landmark; and in the recumbent position nearly the same gravity effect is obtained when the arm is extended on the same plane as that on which the body rests. Inasmuch as the small readings furnished by the veins are relatively more affected by gravity variation than the higher readings of the arterial pressure, it is particularly important to observe this uniformity of position of the hand in observing the venous pressure in the recumbent and in the sitting posture.

2. *Posture.*

The blood-pressure is higher in the erect posture (standing and sitting) than in recumbency.—When, in normal subjects, the blood-pressure is taken—the arterial from the radial artery and the venous from the dorsum of the hand—in the erect posture (sitting or standing), and in the recumbent position, a small range of difference is apparent—varying, however, in extent in different individuals and in the same individual at different times.

In subjects enjoying good health and condition, the erect position of the body (standing and sitting) furnishes higher readings of the arterial and venous pressures than obtain in the recumbent position. Of the two erect postures, standing provides the higher reading; but the difference is, as a rule, less between them than between sitting and recumbency. As sitting is altogether a more convenient posture for observation, especially in clinical work, it is preferred to standing. An immediate fall in the blood-pressures is observed when recumbency is assumed. The reduction of the arterial pressure is generally about ten mm.* and is often somewhat less or somewhat more.

* Other observers have ascertained that the arterial blood-pressure falls with change of posture from the erect position to recumbency. For example, Schaffers gives the difference between standing and horizontal as ten to fifteen mm. Hg., *Jahresb. u. d. Leistung* . . . in *d. Anat. u. Physiol.*, Berlin, 1881.

The arteriometer applied to the radial in the recumbent and sitting postures affords similar postural differences in the calibre of the artery; *e.g.*, a calibre of 1·5 mm. in recumbency becoming 2·0 mm. in the sitting position. This variation of the calibre in posture is apparently merely passive, being determined by the blood-pressure.

A far greater alteration of blood-pressure, in proportion to the total pressure, is produced by change of posture in the veins than in the arteries. For example, a venous pressure of 20 or 30 mm. in the sitting posture may fall to 10 or 15 mm. in recumbency, and may rise to 25 or 35 mm. in the standing posture.

It would, therefore, seem that in change of posture the blood-pressure rises or falls nearly equally on the arterial and venous sides of the circulation—the gain or loss apparent in the arteries being equally apparent in the veins.

The postural differences in the blood-pressure are due to variations in muscular contraction, in the vaso-motor tone, and in the cardiac output.—In the recumbent posture the reduction of the frequency of the heart's action and of the output of the ventricle suffices to account for the fall of the blood-pressure throughout the whole arterial system. In the erect postures, the enormous rise of pressure in the arteries of the lower parts of the body is obviously due to the force of gravity; but the increase observed in the arteries of the upper portions must of course be ascribed to some other cause. The unrestrained influence of gravity should lower the blood-pressure in these portions of the body when in the upright position. The experiments of Leonard Hill have demonstrated "that the important duty of compensating for the simple hydrostatic effects of gravity in changes of position must be ascribed to the splanchnic vaso-motor mechanism."* When the body assumes an upright posture, the efficiency of that mechanism, therefore, completely counteracts the lowering effects of gravity on the arterial blood-pressure in the upper portions. Observation, however, shows that that pressure is not merely maintained, but actually rises as the recumbent body becomes erect. How is this postural rise to be accounted for? It has been referred to over-compensation on the part of the vaso-motor mechanism. Some recent observations have, however, caused me to doubt if this be the sole cause, It has frequently been observed, in myself and others, that while sitting so supported as to ensure relaxation of the muscles, the arterial and venous pressures will fall as in recumbency, and will instantly rise on again maintaining the body erect by muscular action; and furthermore, while recumbent, the pressures being at their lowest point, will at once go up when the muscles are thrown into a condition of static contraction, and will as quickly subside when the muscles again become relaxed. It would therefore seem that mère passive change of position does not suffice to account for the postural

* *Journal of Physiology*, Cambridge and London, 1895, vol. xviii., p. 45.

variation in the arterial pressure ;* and that muscular contraction is a factor—if not a predominent factor—in the production of that variation. Moreover, the rise in mean arterial pressure in the erect postures is obviously not due to vaso-motor contraction, for the venous pressure is increased enormously, and the maximum arterial pressure† is raised to the same extent as is the mean pressure. These facts therefore point to cardiac stimulation and increased output of the ventricle rather than to over-compensation on the part of the vaso-motor mechanism, as being the main cause of the rise of the blood-pressure in the arteries of the upper parts of the body (*e.g.*, radial, temporal, carotid) in the active postures.

Recumbency furnishes the standard blood-pressure of the individual, and the difference observed between the blood-pressure in the erect posture and recumbency affords evidence of the integrity or failure of vaso-motor tone.—The foregoing facts have an important practical application. In deciding on the blood-pressure in any case, it is of course important to secure as much as possible uniformity in the physiological conditions.

* There is, however, a form of postural variation of the arterial pressure, which is solely caused by change of position, and is therefore an effect of gravitation (see pp. 174, 227, and 228).

† By the term maximum arterial pressure is meant the amount of pressure registered when the pulsations of the artery are obliterated—the finger being placed on the distal side of the pad. This pressure is not comparable in different individuals, because of the variations in tissue-resistance; but is comparable in the same subject.

Therefore the observation should be made in that posture which eliminates altogether the disturbing element of muscular contraction, namely, in recumbency; and if the radial artery be selected, the arm should be extended level with the back. The reading thus obtained after the lapse of a few minutes, should be regarded as the standard blood-pressure of the individual, the gravity condition being uniform, and all muscular action being in abeyance. But for clinical purposes this is not the only reading that should be taken, for it is often useful to compare with it the record obtained in the sitting posture—the wrist then being on a level with the epigastrium—for the two readings will afford evidence of the efficiency or impairment of the vaso-motor mechanism (see pp. 267-8).

3. *Muscular Exercise.*

It has been shown that change of posture affects the blood-pressure through the agency of muscular contraction rather than through the mere alteration of position. This initial effect of muscular action is but the prelude of the more pronounced influence which exercise exerts on the circulation.

There is one fact common to all forms of muscular exertion, which is obvious enough to the most superficial observer, namely, the stimulating effect of physical exercise on the circulatory organs, and the consequent acceleration of the blood-flow. And this fact is endorsed by the instrumental measurement of the blood-pressure (arterial and venous). Observation shows conclusively that this stimulation affects both extremities of the circulatory apparatus—the central and peripheral; inciting the ventricle to more frequent and more forcible contraction, and the arterioles to dilatation. Consequently a larger volume of blood per unit of time is propelled through every part of the circulatory tubing, and the blood-pressure is, as a rule, raised on both sides of the circulation.

The ventricle contracts with greatly increased energy.—This fact is shown by the invariable rise induced by exercise in the maximum arterial pressure; in other words, by the much greater external pressure then required in order to arrest the pulsations than during the intervals of repose. For example, obliterating pressures of from 160 to 180 mm. Hg. before moderate active muscular exercise of all kinds may at once rise to such higher readings, as from 180 to 200 mm. Hg.; and when the exercise becomes somewhat strenuous (as in cycling up hill) the maximum arterial pressure may even reach 250 mm. Hg. All observation shows that the strain of exercise is thrown on the left ventricle; and this fact agrees perfectly with clinical experience, which has taught us the golden rule—to adjust the amount of exercise to the physiological capacity of the ventricle.

The peripheral vessels are dilated and contain an increased charge of blood.—This fact, which is supported by experimentation on animals, is shown in man by observation directed to the volume of the limbs and to the venous pressure.

That the volume of an exercised limb is increased can be readily proved by applying the simple method of hydrostatic measurement previously described (p. 134). Fig. 39 illustrates an observation of this kind. In a subject, aged twenty-two, it was found that screw-

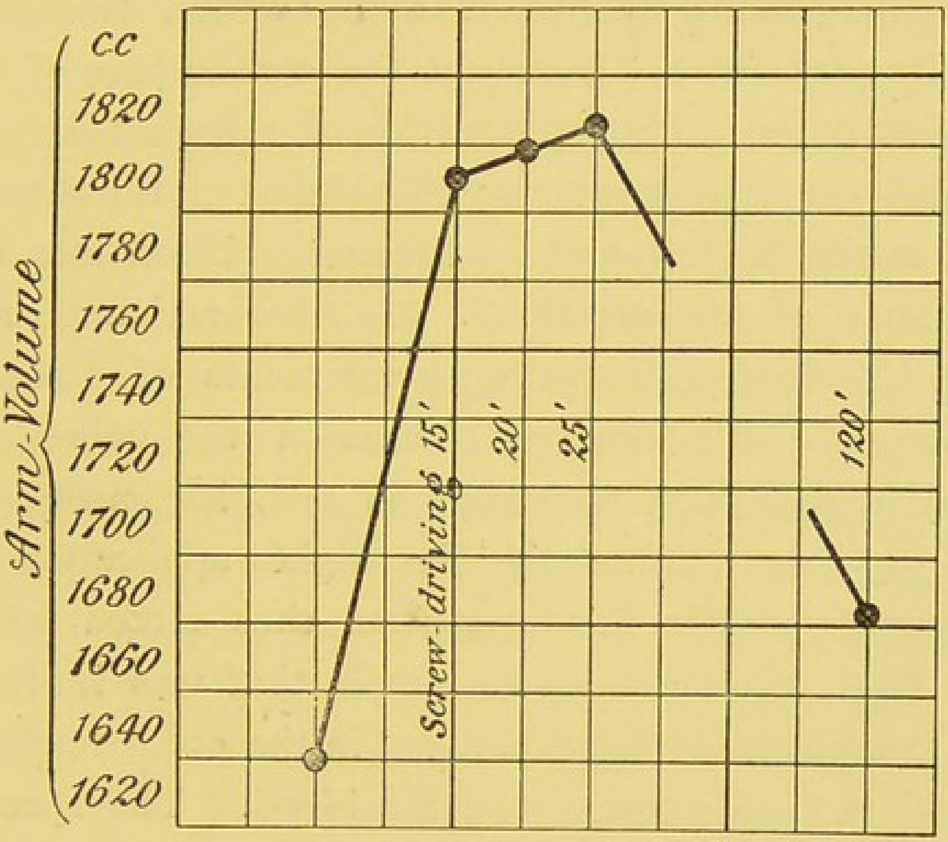


FIG. 39.—Arm volume before and after local exercise (screw-driving).

driving for fifteen minutes raised the volumetric measurement of the arm from 1632 c.c. to 1800 c.c., and for ten minutes more to 1818 c.c., and that after the expiration of two hours following the exercise, the volume of the arm still exceeded the original measurement by 88 c.c. The large and rapid accession of blood is obviously the cause of the immediate enlargement; but, though this may be accounted for by the turgescence of the vessels which accompanies muscular contraction, it is somewhat doubtful if the persistence of the swelling for several hours after the cessation of muscular action can be thus satisfactorily explained; for surely such a distension of the vessels should cease soon after the muscles become relaxed, and the enlargement due to it alone would, therefore, quickly pass away. Does not the continuance of the swelling point to the supervention of some other event beyond the mere temporary distension of the vessels, such as the exudation of fluid from the blood into the substance of the muscles? A corroboration of this view is afforded by some experiments of Lazarus Barlow.* This observer increased the volume of blood in two different ways; in one, he anæmiated one or more limbs by the tight application of Esmarch's elastic bandages, and thus forced whatever fluid, blood as well as lymph, that was in them into the general circulation; and in the other method, he injected salt solution into the blood. The specific gravity of the blood and of the blood-plasma was taken by Roy's method, and that of the muscles by a modification of that method before and after the volume of the blood had been increased. The results obtained show a rise of the specific gravity of the

* "On the Effects of Variations on the Volume of the Blood upon the Specific Gravity of Blood and of Muscle." *Proceedings of the Physiological Society*, May, 1894, *Journal of Physiology*, 1894.

blood and of the blood-plasma, and an invariable fall in the specific gravity of the muscle, the rise and fall being rapidly induced, the larger portion of them occurring within the first half hour. This observer, therefore, concludes that when the volume of the blood is increased the muscles take up water, which is derived from the blood. In exercise the volume of the blood circulating through the muscles is in all probability increased to as high a degree as obtained in these experiments, and therefore a favourable condition is presented by it for the rapid transudation of watery fluid from the blood into the muscular tissue. During the exercise a portion of this exuded fluid is no doubt driven onward into the lymphatics by the pressure brought to bear on the lymphatic spaces by the contracting muscular fibres; but it is quite conceivable that a large quantity of that fluid may remain in the muscles for a considerable time after all muscular action has ceased. This position is furthermore corroborated by the concentration of the blood observed as the result of muscular contraction and exercise (see pp. 45 and 53).

The venous blood-pressure likewise affords evidence of the increased determination of blood to the systemic periphery during exercise (see p. 168).

Exercise invariably raises the mean arterial blood-pressure in the first instance (the primary effect), and then, after a variable time, it lowers and may even abolish the rise, and may ultimately even lower the pressure

below the initial point (the secondary effect).—The effect of exercise on the arterial blood-pressure

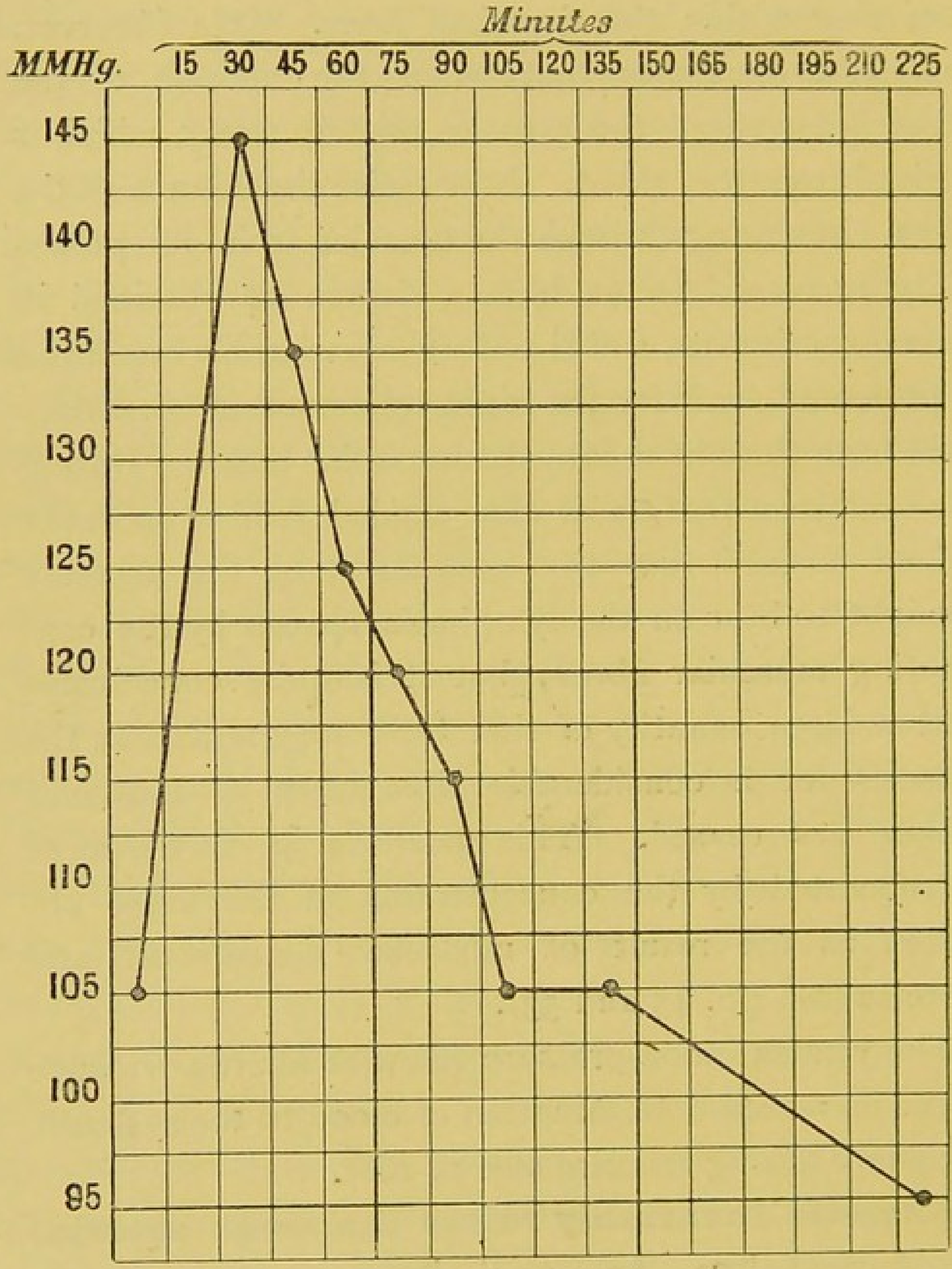


FIG. 40. The mean arterial pressure taken in the erect posture every fifteen minutes from the radial artery during an uninterrupted walk of 3 hours 45 mins. (2 hours 15 mins. equable rise and 1 hour 30 mins. equable fall) at Grasse on a warm day in April, 1900. Subject, Dr. R., æt. 22.

may be said to describe a curve which sharply rises to its maximum development and somewhat less abruptly

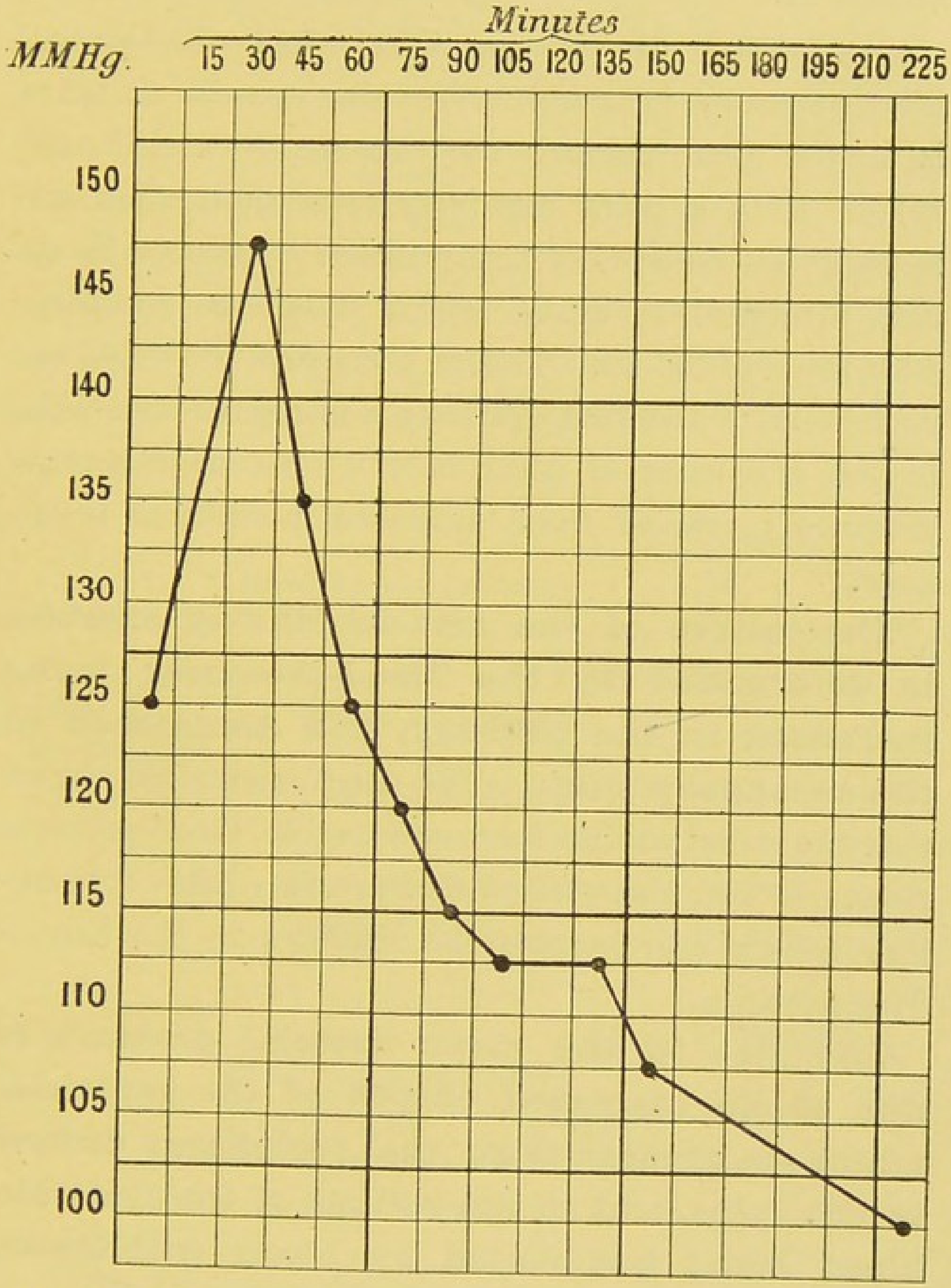


FIG. 41. The mean arterial pressure taken in the erect posture every fifteen minutes from a digital artery during an uninterrupted walk of 3 hours 45 mins. (2 hours 15 mins. equable rise and 1 hour 30 mins. equable fall) at Grasse on a warm day in April, 1900. Subject, æt. 58.

subsides during the continuance of the exercise. This fact is illustrated by the observations recorded in figs. 40 and 41.

Observation has shown that when the arterial blood-pressure recorded before the exercise is taken is higher than normal, the exercise may ultimately reduce it to a point relatively lower than when it is normal; an example of this position is afforded by the data furnished by fig. 41, which should be compared with those of fig. 40. This fact suggests the value and usefulness of habitual systemic and regulated exercise in the treatment of cases in which the mean arterial pressure is raised from increased peripheral resistance.

The calibre of the arteries during exercise is determined by the blood-pressure; being increased in the primary, and diminished in the secondary stage.—The arteriometer has shown that the radial calibre increases as the blood-pressure rises, and diminishes when that pressure falls; it therefore merely corroborates the readings of the hæmodynamometer.

The rise in the mean arterial pressure is due to an increased output of the ventricle, which is greater than the peripheral onflow to the veins, and to the volume of the systemic blood being augmented by blood withdrawn from the splanchnic circulation.—All forms of active exercise, though they induce dilatation of the peripheral vessels, which must tend to lower the mean arterial pressure, incite the ventricle to more frequent contraction, and to discharge such an output as suffices to raise that pressure. Observation has, moreover, shown that during exercise the volume of the systemic blood is augmented by an accession of blood drawn from the splanchnic circulation ; for when the mean arterial pressure is raised to a maximum degree by the exercise, it cannot be further increased by applying the same weight to the abdominal wall, which previous to the exercise produced an appreciable rise—as in the following concurrent observations in two subjects :—

		Subjects :—A	B
Mean arterial blood-pressure in mm. Hg.	*Before* exercise (walking)	102	106
	28 lbs. weight distributed over abdomen .	110	115
	Rise in mean arterial pressure from abdominal compression	8	9
	After walking 30 mins.	120	122
	28 lbs. weight distributed over abdomen .	120	122
	Abdominal compression fails to raise arterial pressure	0	0

		Subjects :—A	B
Mean arterial blood-pressure in mm. Hg.	*Before* exercise (bicycling)	105	112
	28 lbs. weight distributed over abdomen .	117	127
	Rise in mean arterial pressure from abdominal compression	12	15
	After bicycling two hours	117	127
	28 lbs. weight distributed over abdomen .	117	127
	Abdominal compression fails to raise arterial pressure	0	0

		Subjects:—A	B
Mean arterial blood-pressure in mm. Hg.	*Before* exercise (bicycling)	112	110
	28 lbs. weight distributed over abdomen .	130	127
	Rise in mean arterial pressure from abdominal compression	18	17
	After bicycling 2 hours 45 mins. . . .	130	127
	28 lbs. weight distributed over abdomen .	130	127
	Abdominal compression fails to raise arterial pressure	0	0

It has been invariably found, that though the abdominal compression produced a marked rise in the systemic blood-pressure before the exercise was taken, it failed to alter that pressure during the time it was markedly raised by the exercise. It may therefore be inferred that exercise diverts blood from the splanchnic to the systemic circulation, and that consequently it increases the volume and raises the pressure of the blood circulating through the somatic tissues.

The subsequent decline in the mean arterial pressure is due to the diminution of vasomotor tone which allows the blood withdrawn from to return to the splanchnic veins.—Repeated observation has shown that abdominal compression again raises the systemic blood-pressure as soon as that pressure begins to wane during the continuance of the exercise. The following concurrent observations in two subjects exemplify this position.

		Subjects:—A	B
Mean arterial blood-pressure in mm. Hg.	*Before* exercise (walking)	127	105
	28 lbs. weight distributed over abdomen	137	115
	Rise in mean arterial pressure from abdominal compression	10	10
	After walking 1 hour 5 mins.	125	105
	28 lbs. weight distributed over abdomen	137	117
	Rise in mean arterial pressure from abdominal compression	12	12

		Subjects:—A	B
Mean arterial blood-pressure in mm. Hg.	*Before* exercise (walking)	122	110
	28 lbs. weight distributed over abdomen	132	120
	Rise in mean arterial pressure from abdominal compression	10	10
	After walking 1 hour 30 mins.	115	105
	28 lbs. weight distributed over abdomen	135	117
	Rise in mean arterial pressure from abdominal compression	20	12

It may therefore be inferred, that the blood withdrawn from the splanchnic circulation during the earlier stages of exercise is allowed to gradually return to it by gravitation during the later stages, in consequence of the diminution of the tone of the splanchnic arterioles, which then supervenes; and that the fall in the systemic blood-pressure, which then takes place, is as closely associated with this ultimate enlargement of the splanchnic area as is the primary rise of that pressure with the diminution of that area.

The duration of the rise of the mean arterial pressure varies with the nature and severity of

the exercise, with the vaso-motor tone of the individual, and with the temperature of the atmosphere.—Observation shows that whatever reduces the vaso-motor tone, such as warmth of atmosphere, want of condition in the individual, &c., shortens the time during which the mean arterial pressure continues to be raised during any form of exercise; and *per contra*, that whatever maintains vascular tone, such as a cool bracing atmosphere, the individual habituated to exercise, &c. lengthens that time. But according to my observation the most powerful influence in modifying the duration of the rise of the systemic blood-pressure is the form in which the exercise is taken. This fact is best illustrated by comparing the data obtained from the same subjects undergoing at different times walking and bicycling exercise. It has been invariably observed that in walking the primary interval in which the arterial pressure is raised is comparatively short—being generally within an hour—and the secondary period of gradual fall in that pressure is relatively long; and that in bicycling the stage of maximum rise in the systemic blood-pressure is enormously prolonged—being as a rule extended to at least two or even three hours—and the waning interval of fall is either difficult to observe at all or is but slight. Observation has demonstrated that walking exhausts the vaso-motor tone much more quickly and more thoroughly than bicycling—its influence in this direction being, roughly speaking, at least threefold that of bicycling. In cycling the general gentle and continuous tension of the whole muscular system, including that of the abdominal muscles maintaining compression of the splanchnic area, probably accounts for the remarkably prolonged rise in the

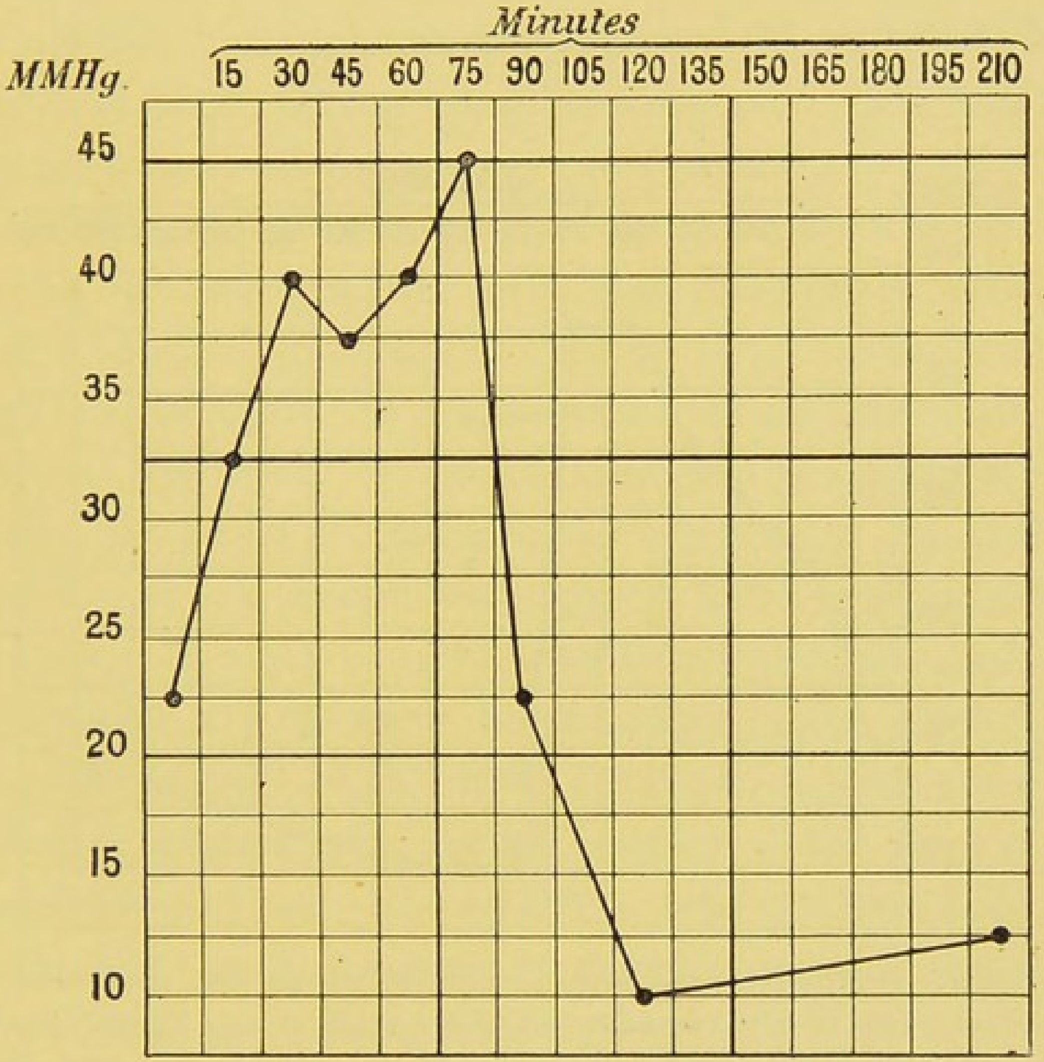


FIG. 42.—The venous pressure taken every fifteen minutes from the dorsum of the hand during an uninterrupted walk of 3 hours, 45 min. (2 hours, 15 min. equable rise and 1 hour, 30 min. equable fall) at Grasse on a warm day in April, 1900. Subject Dr. R., æt. 22.

systemic blood-pressure and the absence of splanchnic drain which characterise this form of exercise. Inasmuch as cycling maintains for some hours the rise in the systemic blood-pressure, which signifies a corresponding continued reduction of the splanchnic area, this form of exercise should be valuable, as it doubtless is, in the treatment of cases in which that area is abnormally loaded, either in consequence of the diminution of the systemic area, or in consequence of reduction of vaso-motor tone.

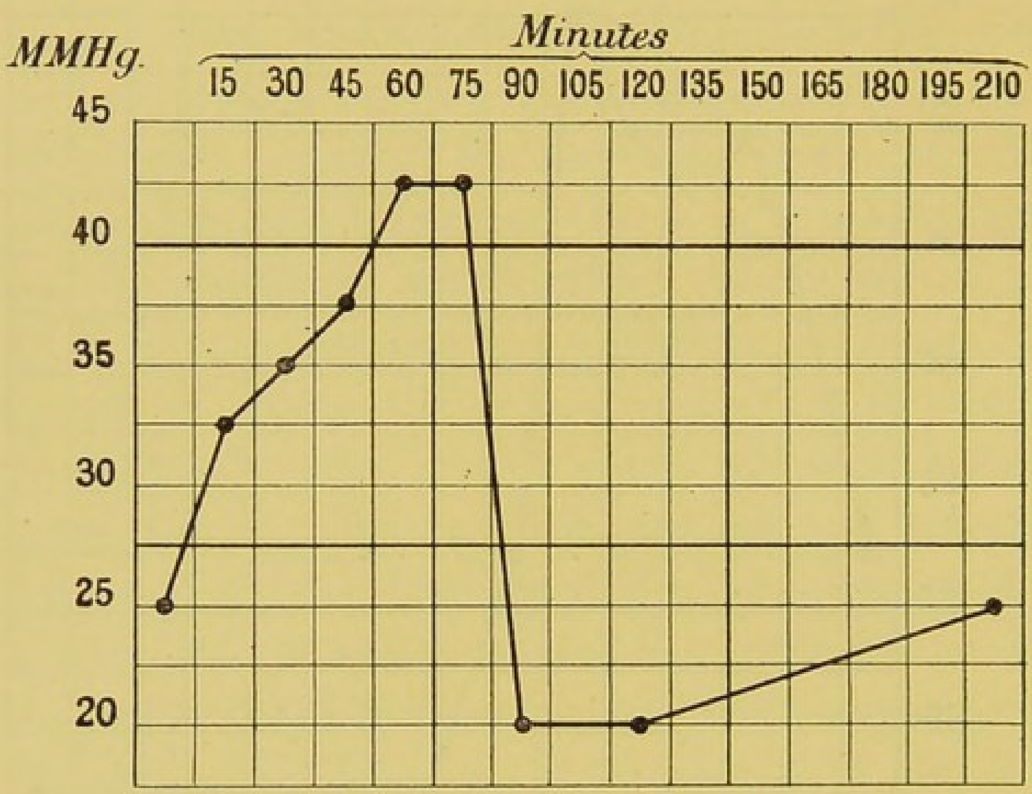


FIG. 43.—The venous pressure taken every fifteen minutes from the dorsum of the hand during an uninterrupted walk of 3 hours, 45 min. (2 hours, 15 min. equable rise and 1 hour, 30 min. equable fall) at Grasse on a warm day in April, 1900. Subject, æt. 58.

The venous blood-pressure is likewise raised by exercise for a time, and is then quickly lowered to a point below the initial reading.—The rise in the venous pressure shown in figs. 42 and 43 correspond with that of the mean arterial pressure indicated in figs. 40 and 41; though it is somewhat more prolonged. The rapid subsidence of the venous pressure coincides with the splanchnic drain, which results from the diminution of vaso-motor tone.

The effects of exercise quickly subside.—With complete repose after gentle or moderate exercise it is remarkable how quickly the disturbed blood-pressure readjusts itself. It has often been observed that, with due regard to rest, the normal pressure will be restored in from fifteen to thirty minutes—even before the rise in the frequency of the pulse has subsided.* But after strenuous or prolonged exercise it may, however, require an hour or so to elapse before the original blood-pressure reappears. When the heart and the periphery of the circulation are normal, the adjustment for rest after exercise is undoubtedly rapid; but when departures exist from the normal condition it becomes less responsive. It therefore follows, that in the clinical field care should be taken to secure a sufficiency of rest after active exercise before making observation of the blood-pressure. But even then, after moderate, or gentle exercise, the repose of a few minutes is, as a rule, all that is necessary for the purpose.

The after-effects of exercise on the blood-pressure.—Reasoning on the pendulum principle of stimulation and recoil we may surmise that exercise may be followed by a reduction of blood-pressure—that the pressure may settle after an interval of rest to a point lower than that which existed before the

* Leonard Hill has likewise observed this fact. See *Lancet*, vol. i., 1898.

exercise was attempted. Observation confirms this supposition; for after exercise the original mean arterial pressure settles somewhat—though the venous pressure may remain raised.*

4. *Mental Exercise. Emotional Excitement.*

The blood-pressure is raised by central activity.—The blood-pressure may be quite as powerfully affected by cerebral as by muscular action. It is at once raised by any mental occupation, and is still more raised by any form of emotional excitement. The venous as well as the arterial pressure is augmented.

The rise is due to blood derived from the splanchnic reservoir.—As in the case of muscular action, the rise in the somatic blood-pressure when the brain is excited to activity is produced by stimulation of the splanchnic vaso-motor mechanism, which lessens the splanchnic area; and by acceleration of the heart's action, which ensures the distribution of an increased volume of blood to the brain, and to all the other portions of the systemic circulation. This position is supported by the different effect produced on the mean arterial blood-pressure by applying the same weight to the abdomen before and immediately after

* Edgecombe and Bain have likewise drawn this conclusion. "The Effects of Baths, Massage and Exercise on the Blood-Pressure," *Lancet*, vol. i., 1899.

an effort of active mental exercise; before that effort the abdominal compression producing a pronounced rise in the somatic blood-pressure from the displacement or diversion of a considerable volume of blood from the splanchnic to the systemic area, and after it the compression failing to induce any such rise at all. The following observation is an example of this evidence, showing that mental occupation raises the systemic blood-pressure by reducing the splanchnic area.

Mean arterial blood-pressure in mm. Hg.	*Before* active mental exercise (1 hour 30 mins.)	120
	Abdomen equably compressed by weight of 28 lbs.	132
	Rise of mean arterial pressure	12
	After the mental exercise	132
	Abdomen equably compressed by weight of 28 lbs.	132
	Rise of mean arterial pressure	0

Leonard Hill has shown how the increased cerebral circulation demanded by excitation of the brain is maintained. He says "it is now clear that the splanchnic vaso-motor mechanism is of overwhelming importance in maintaining the cerebral circulation. We have in the vaso-motor centre a protective mechanism by which blood can be drawn at need from the abdomen and supplied to the brain. The respiratory centre renders important aid. At the moment that excitation from the outside world demands cerebral response, the splanchnic area is diminished, and more blood is driven through the brain. An anæmia of the brain excites the bulbar centres, these provoke acceleration of the heart, splanchnic constriction and increased respiration; the cerebral circulation is thereby restored. The brain has no direct vaso-motor mechanism, but its blood supply can be controlled indirectly by the bulbar centres acting on the splanchnic area."*

Cerebral exercise therefore produces the same effect on the splanchnic area and on the systemic blood-pressure as muscular exercise.— It is of importance to bear this fact in mind when prescribing the amount of physical exercise to counteract the effects of the sedentariness of those following professions and occupations which demand an undue and prolonged activity of the brain. Both forms of exercise, mental and physical, ultimately fatigue the system, and lower the vaso-motor tone; it therefore follows that harmful exhaustion may be induced in the brain worker by an amount of muscular exertion that is as a rule beneficial in ordinary subjects. It not unfrequently happens, that a state of chronic fag is maintained in those who are actively and persistently employed in mental work by resorting to strenuous physical exertion, taken with the view of counteracting the injurious effects of the cerebral activity and of the indoor life which it necessitates. In such cases the mental employment raises the systemic blood-pressure, which stimulates metabolism and favours the general

* *The Experimental Pathology of the Cerebral Circulation*, by Leonard Hill, M.B. Allbutt's "System of Medicine," vol. xii.

nutrition, and it is only needful to supplement this beneficial influence by such varied and gentle exercises as will ensure the removal of waste products and will maintain the tone of the muscles.

The emotional disturbance of the blood-pressure, which may vitiate clinical observation, may be eliminated with care.—The rise of the blood-pressure due to emotional causes, not unfrequently reaches the higher readings observed in disease; it is, therefore, necessary that the observer should be always well on his guard, so as to eliminate as much as possible this source of error. The experienced physician is always alive to it in his ordinary digital examination of the pulse, and observation and tact have taught him how best to elude it. The perturbation of the circulation due to emotion is, however, quite a passing affair, as a rule; and in all cases, while it lasts, the frequent pulse, and the obviously excited action of the heart, are sufficient warnings to indicate that the time has not yet arrived for the making of a trustworthy observation of the blood-pressure. There is no doubt, however, that now and then highly sensitive subjects are met with, in whom the readings of the blood-pressure cannot be relied on any more than that of the pulse-rate. But such cases are undoubtedly exceptional, for experience has shown that in the ordinary run of cases with due care the observation of the blood-pressure is not materially vitiated by emotional causes.

5. *Fatigue; the Physiological Impairment of Vaso-Motor Adjustment.*

Fatigue, impairing the vaso-motor tone, increases the splanchnic area and diminishes the systemic blood-pressure in the erect position of the body.—The study of the physiological effects of exercise has shown that after the lapse of a certain time—varying with the form and severity of the exercise, with the temperature of the atmosphere, and with the vaso-motor tone of the individual—the wave of rise of the systemic blood-pressure begins to wane, and the reduced splanchnic area gradually refills. A sense of fatigue is not, however, necessarily, or generally, experienced in the earlier stage of this physiological change in the distribution of the blood, and the amount of splanchnic down-flow in the erect position of the body may be but moderate, so that the postural variation of the blood-pressure may be merely abolished; but later on, when the subject feels fatigued, the increase of the splanchnic area and the fall in the systemic pressure become very considerable, and then, when the subject assumes the horizontal position, a wave of increase of the systemic blood-pressure is apparent. This temporary rise in the blood-pressure in the recumbent posture is due to the cessation of the copious downward drain of blood through the open and toneless arterioles into the capacious splanchnic veins caused by gravitation in the erect position, and the diversion of that blood to the systemic area.

The temporary physiological impairment of vaso-motor tone caused by fatigue is identical with the more persistent and the more pronounced forms of vaso-motor inadequacy produced by disease.—The study of the physiological effect of fatigue on the circulation is of special interest to the physician; for the temporary disturbance in the distribution of the blood, which it induces, is essentially the same as the pathological one so frequently obtained in the clinical field* (see p. 267-8).

6. *Rest—Sleep.*

As might be expected, rest—mental as well as physical—has a marked influence in lowering the blood-pressures (arterial and venous). This result is mainly due to a reduction in the output of the ventricle. In proportion to this reduction the maximum and mean

* Leonard Hill and Harold Barnard have shown, that when the resistance (or vaso-motor tone) in the splanchnic area is high or intact, the circulation will continue through the head, while an animal is placed in the vertical feet-down posture; but should that resistance be reduced to a minimum (as by section of the spinal cord at the level of the first dorsal vertebra) the hydrostatic pressure will distend the splanchnic area to such an extent, that the whole of the blood collects within the capacious venous reservoirs of the abdomen, and the current through the head ceases (*Journal of Physiology*, Cambridge and London, vol. xxi., p. 324).

arterial pressures are lowered; but, of the two, the former falls more than the latter. The peripheral vessels probably shrink, from diminution of the distensile pressure of the ventricle, and consequently the fall of the venous pressure is still more pronounced than that of the arterial pressures. Rest, therefore, specially conduces to the easing of the work of the pump, and must therefore favour the restoration of the tone to the cardiac muscle and to the vaso-motor mechanism.

The effect of sleep on the blood-pressure has not fallen within my observations. Leonard Hill has, however, shown that the arterial blood-pressure does not fall lower during sleep than in ordinary rest, and consequently he infers that the anæmic theory of sleep is untenable.* It is not improbable, that with the reduced activity of the circulatory forces, which obtains in sleep as in ordinary rest, there is a general passive shrinking of the arterial side of the circulation, and that the blood which fails to be distributed to the arteries collects on the venous side. If this be so, the reserve capacity of the veins may therefore be made available during periods of rest and sleep, as well as during those of exercise (see p. 168). Anæmia of the brain in sleep may thus be favoured; hence the earlier observations which suggested cerebral anæmia as the cause of sleep. The anæmia is, however, but the result of reduced activity of the arterial circulation, and should not be regarded as the cause of sleep. It

* *Lancet*, London, vol. i., 1898.

is probably a most important, if not a necessary, condition of sleep; and, so far my observations of the arterial pressure in insomnia support this view.

7. *Respiration; Forced Respiration; Effort.*

All forms of effort in man, by which the intra-thoracic pressure is increased, raises the mean arterial pressure as well as the venous pressure.—The influence of ordinary inspiration and expiration on the blood-pressure in man is not recognisable. It is quite otherwise, however, when the respiration is stimulated to increased activity, as in the execution of any effort which throws into action the thoracic and abdominal muscles. In all forms of effort the arterial and venous blood-pressures are very markedly raised, just as they are in muscular exercise of all kinds. Efforts, such as lifting weights, or pulling, &c., involve, however, something more than mere muscular action; they powerfully disturb the respiration. The glottis is partially or completely closed, and the intra-thoracic pressure is considerably raised. There are here, therefore, two important physiological causes of disturbance of the blood-pressure, namely, one respiratory and the other muscular. Muscular action is known to increase the arterial blood-pressure, but physiological experiment has shown that an increase of the intra-pulmonary pressure lowers that pressure. On the other hand, in man, observers have failed to detect this fall in the arterial pressure when the intra-thoracic pressure is raised by forcible respiration with closed mouth and nostrils (Valsalva's experiment). Lately some observations have been made to explain this discrepancy; for they tend to show that distension of the vena comites is sufficient to produce the sphygmographic evidence that has hitherto been regarded as pointing to a rise in the radial pressure.* It is quite obvious that Valsalva's experiment does raise the venous pressure very considerably; but observation has shown that it does not do so to the extent it was supposed before that pressure was determinable in man (see p. 123). It has been ascertained, for example, that it can rarely do more than double the venous pressure.

Quite recently Augustus Waller concludes from the evidence furnished by his lately devised digital sphygmograph, that in man the arterial blood-pressure is lowered in Valsalva's experiment.† It is not easy to determine the mean arterial pressure in Valsalva's experiment, for the progressive diminution of the pulsations produced by each attempt at prolonged expiration makes it difficult to obtain reliable readings at the acme of the effort; and it is consequently neces-

* See "The Effects of Venous Pressure on the Pulse," by Leonard Hill, H. Barnard, and J. H. Sequeira. *Journ. of Physiology*, Cambridge and London, vol. xxi., p. 147.

† See "A Digital Sphygmograph," by Augustus Waller, M.D., F.R.S. *Brit. Med. Journal*, 1900, vol. ii., pp. 840-842. According to Dr. Waller the finger sphygmograph affords direct information of the state of the pre-capillary arterioles, and records the blood-pressure in them, and is not a volume-recorder of the capillaries.

sary to repeat the observation several times before deciding as to whether the pressure remains unaltered, or is diminished or increased. While, however, giving due weight to this uncertainty, my observations have led me to conclude that the mean arterial pressure is raised, and is not lowered, by prolonged expiration with closed mouth and nostrils. In some of my observations a rise of 20 mm. Hg. was apparent. It therefore seems to me that the raising of the intra-thoracic tension by voluntary effort augments the mean arterial pressure — a result which does not accord with that derived from physiological experiment. This discrepancy may be accounted for by muscular action, which raises the blood-pressure (arterial and venous). In man the intra-thoracic tension cannot be increased without bringing into play all the abdominal and thoracic muscles; and this fact involves compression of the splanchnic reservoir, the unloading of which raises the arterial pressure (see p. 135). It is probable, therefore, that the energetic contraction of this extensive muscular area raises the arterial pressure so as to more than counterbalance the lowering influence resulting from the increase of the intra-thoracic tension. Observation shows that all muscular efforts with fixed thorax—the glottis being closed or not—raises the blood-pressure in the arteries as well as in the veins.

When vaso-motor tone is reduced, so that gravitation increases the splanchnic area and diminishes the systemic blood-pressure, forced

respiration rectifies the disturbance of the normal distribution of the blood.—During the past five years my observations have repeatedly shown that when in the vertical position of the body there is evidence of gravitation of blood into the splanchnic area from impairment of the tone of the arterioles, the downward drain may be arrested by respiratory exercises; the subject, in the recumbent posture, executing a series of full, deep, and sustained abdominal inspirations, followed by slow expirations obstructed by a pursed mouth, and accompanied by firm contraction of of the abdominal wall with pressure of the clasped hands.* Three years ago Leonard Hill and Harold Barnard demonstrated by experiment that the respiratory mechanism "forms a second line of defence (the first being the vaso-motor tone) against the influence of the force of gravity in conditions where the vaso-motor mechanism is weakened or paralysed."†

These clinical and experimental observations therefore coincide in supporting the same fact, namely, the counteracting influence of the respiratory pump over the effects of gravity when vaso-motor tone is lowered or is lost. In the respiratory exercises just referred to, the muscles of the chest and abdomen are brought

* In the Croonian Lectures, 1896, it was pointed out that respiratory exercises exert a corrective influence on vaso-motor inadequacy. Lately Harry Campbell has published an elaborate and instructive treatise on "Respiratory Exercises in the Treatment of Disease" to which the reader is referred.

† *Journ. of Physiology*, Cambridge and London, 1897, p. 324.

into active and prolonged contraction, by which the blood is pumped into the right heart from the venous system of the abdomen; the splanchnic area being effectually compressed by the firmly contracted abdominal wall, which expels the excess of blood from it, and in the erect position of the body reduces the undue onflow from the capillaries into the splanchnic veins. In this way the respiratory pump is made available for restoring the normal distribution of the blood when disturbed by the loss of vaso-motor tone. Frequent verification of this position has satisfied me that it is a fact. The same adjustment of the circulation takes place, however, as the result of any effort which throws into action the thoracic and abdominal muscles.

8. *Digestion.**

The mean arterial pressure and the venous pressure are raised by the mere intake of solids or liquids.—It was observed that, in the morning before breakfast, the taking of a glass of cold water may, within five minutes, raise the arterial pressure 10 mm., and the venous pressure 5 mm. Hg. The mere intake of anything appears to immediately stimulate the heart in a reflex manner, and to increase the output of the ventricle. This view is supported by the

* The observations on the physiological effects of digestion on the circulation were made while the subjects remained in the recumben posture.

observation that when the water is rendered more stimulant to the gastric mucous membrane, as when it contains a charge of carbonic acid or salt, the rise in the systemic blood-pressure is further increased. It is therefore quite conceivable that alcohol, ammonia, &c., have an immediate effect on the heart by reflex stimulation as well as by stimulation after absorption. The practical bearing of this position on the treatment of sudden cardiac failure is obvious; for even the mere swallowing of cold water may rouse the heart, and the most effectual draught will be one that is most stimulant to the gastric mucous surface. The marked increase of the arterial pressure so frequently observed in cases of irritative dyspepsia may be largely explained on the ground of reflex stimulation—especially in the cases in which direct mechanical pressure from flatus is not an obvious cause.

During the first stage of the digestive process (about half an hour) the arteries contract, and the mean arterial pressure continues to be raised, and the venous pressure falls.—The preliminary cardiac stimulation is followed by contraction of the arteries (indicated by the arteriometer) and arterioles, by a continuance of the rise in the mean arterial pressure, and by a fall in the venous pressure. This fact explains the sense of chilliness often experienced after a meal, which has suggested the old adage: "If you eat to be cold, you will live to be old."

The splanchnic area is greatly increased dur-

ing the first stage of the digestive process (about half an hour).—The method of gauging the splanchnic area by abdominal compression previously described (see p. 135), shows that during twenty or thirty minutes after the intake of a meal the splanchnic area increases enormously—the compression then raising the systemic blood-pressure to a much higher point than is observable at other times, whether before the meal or after the lapse of half an hour. This rapid and evanescent enlargement of the splanchnic area is doubtless due to the determination of blood to the abdominal organs resulting from the ingestion of food, and to the consequent dilatation of the arterioles which supply that area. The splanchnic overflow into the systemic area produced by abdominal compression before a meal may cause a rise in the mean arterial pressure varying from nil (before breakfast, when the tone of the arterioles is at its maximum) to 7 or 10 mm. Hg.; and that apparent at the acme of splanchnic fulness may induce an arterial rise of 17 or 20 mm. Hg.

After the lapse of twenty or thirty minutes the splanchnic area rapidly diminishes, and in about an hour settles down again.—From this fact it would seem that after the stage of the digestive process in which the secretions are copiously poured out the arterioles supplying the splanchnic area again contract.

When the splanchnic area diminishes the systemic arteries and arterioles dilate, the

mean arterial pressure falls, and the venous pressure rises.—It has been shown that when the splanchnic arterioles dilate the systemic arteries and arterioles contract. The next circulatory event that happens during the digestive process is the reverse of this; namely, a return of tonicity (contraction) to the splanchnic arterioles, when the systemic arteries and arterioles become relaxed and dilated. This alteration in the distribution of the blood is generally rapid—the contraction of the arteries quite quickly passing away with a feeling of warmth and flush all over the body, when it is found that the calibre of the arteries is increased, the mean arterial pressure is waning, and the venous pressure is raised.

The lowering effect on the arterial blood-pressure induced by the determination of the large volume of blood to the splanchnic area during the early stage of digestion is compensated for by vaso-motor contraction in the systemic area, which passes off when the tonicity of the splanchnic arterioles returns, and the blood diverted to the abdomen is restored to the somatic circulation.—There is no doubt that during the early stage of digestion the diversion of blood from the systemic to the abdominal area is so copious that, were it not compensated for by vaso-motor contraction in the somatic circulation, it would induce intense exhaustion and incapacity for a certain time after every meal; for it would probably lower the arterial pressure so much as to impair the cerebral circulation. Such an untoward result is obviated by an increase in the vaso-motor tone throughout the whole systemic circulation, by which the arterial blood-pressure is actually raised; and the adaptability of this self-adjusting mechanism is further shown by the rapid disappearance of the vaso-motor contraction when it is no longer required, when the volume of the systemic blood is restored by the subsidence of the splanchnic area.

Inasmuch as exercise, whether cerebral or muscular, diminishes the splanchnic area, it may, when taken immediately after a meal, prove injurious by counteracting the physiological enlargement of that area, which is necessary to normal digestion.—The effect of exercise, whether of the brain or of the muscles, on the splanchnic area is antagonistic to that of digestion; for it diverts blood from that area (see pp. 163, 170-1) while digestion determines a flow of blood to it. This radical difference in the distribution of the blood induced by exercise and by digestion indicates that rest is the most fitting physiological condition for half an hour or so after a meal, and that active exercise should then be avoided.

9. *Beverages.*

The beverages, alcohol, tea, coffee, raise the mean arterial pressure; but they do not produce this result by acting in the same way on the circulatory mechanism.—Some observations —which, however, can only be regarded as preliminary—on the effects of the beverages, alcohol, tea, coffee, on the blood-pressure point to the conclusion that, though they all raise the mean arterial pressure, they do not exert the same influence on the different parts of the circulatory organs. It would seem that alcohol and coffee, for example, more particularly stimulate the heart and increase its output, and that tea should be regarded mainly as a vaso-motor tonic. Alcohol and coffee raise the maximum and mean arterial pressure, whereas tea, while augumenting the mean arterial pressure, lowers the venous pressure, and does not materially affect the maximum arterial pressure.

Tea contracts the arterioles, whereas coffee does not.—Observation has shown that the arterioles supplying the splanchnic area are contracted by tea, but remain uninfluenced by coffee. The following data support this conclusion; for they indicate that tea arrests the splanchnic overflow into the systemic area induced by abdominal compression, whereas coffee does not.

Effect of Tea on the Splanchnic Overflow.

		Subject A.	Subject B.
Mean Arterial Pressure.	After walking 1 hour, 30 minutes .	115	105
	,, abdominal compression by weight 28 lb.	135	117
	Difference	20	12
	After tea	130	117
	,, abdominal compression by weight 28 lb.	130	117
	Difference	0	0

Effect of Coffee on the Splanchnic Overflow.

		Subject A.	Subject B.
Mean Arterial Pressure.	After walking 1 hour, 15 minutes .	125	105
	,, abdominal compression by weight 28 lb.	137	117
	Difference	12	12
	After black coffee	135	115
	,, abdominal compression by weight 28 lb.	147	127
	Difference	12	12

It has not as yet been ascertained whether the alkaloids theine, derived from tea, and caffeine, derived from coffee, though believed to be chemically identical, are physiologically different in their effects on the circulation, or whether the vaso-contracting property of tea is due to the large proportion of tannin which it contains. But whatever the source of this vaso-tonic influence, the restorative action of tea largely depends on it. We know that all forms of work reduce vaso-motor tone; the worked parts, if exhausted, remaining passively congested until restored by rest. This passive congestion is probably one of the main conditions of fatigue; though there are doubtless others, such as the accumulation of the products of chemical change and infiltration into the tissues. Tea quickly stimulates the peripheral vessels and the splanchnic arterioles to contraction, and in this way restores vascular tone, raises the arterial blood-pressure, and alleviates or removes the sense of fatigue. This vaso-tonic property of tea may account for the remarkably progressive ascendency of this beverage in public favour year by year by the side of the fluctuating demand for other beverages; and it likewise provides the *raison d'être* of the now prevailing custom of tea-drinking in the afternoon—a period of the day when in fact observation shows that vaso-motor tone begins to be lowered (see p. 192). Then again, the injurious effects of tea-drinking, as observed in the gouty and neurotic, in whom vaso-contraction is a prominent pathological feature (see p. 257), may to a large extent spring from this peripheral influence of tea. It may aggravate the increased distal resistance of chronic goutiness, especially in women. It may also be inferred that a combination of tea with a cardiac stimulant should prove more efficacious in raising the arterial blood-pressure than one or the other alone; and this supposition may explain the pronounced cardio-vascular restorative power of a small quantity of alcohol—such as a tea-spoonful or so of brandy—when administered in a cup of tea in quickly dispelling the effects of fatigue.

10. *Temperature; Climate.*

Temperature alters the distribution of the blood and the blood-pressure.—Temperature plays an important part in modifying the blood-pressure. This fact is well illustrated by the effects of hot, warm, and cold baths of various kinds on that pressure (see pp. 222-4). The temperature of the atmosphere, when it rises above, or falls below, a certain average range, likewise affects the arterial and venous pressures and the distribution of the blood to the splanchnic and systemic areas; higher temperatures lowering the arterial and raising the venous pressure and increasing the splanchnic area: and lower temperatures raising the arterial and lowering the venous pressure and also increasing the splanchnic reservoir. But, as has been pointed out (see p. 144), these general results of high and low temperatures on the arterial blood-pressure are qualified by the output of the ventricle; for, when in a warm medium the heart contracts more frequently, the lowering effect of heat on the arterial blood-pressure is counteracted by a larger output, and when in a cold medium the heart slows down, the rise in the arterial pressure is modified by the reduced output. In this way the disturbing influence of the varying temperature of the atmosphere on the arterial blood-pressure is checked and controlled, and consequently the normal arterial pressure, as a rule, remains but little affected by it. Though this is so in regard to the ordinary or minor changes, it has been observed in the course of physiological and clinical observation, that the more pronounced variations of temperature do produce measurable alterations in the arterial and venous pressures; a spell of hot weather, for example, lowering somewhat high readings of the arterial pressure and raising comparatively low readings of the venous pressure, and cold weather increasing the former and reducing the latter—in a word warmth diminishing the indications of increased peripheral resistance and cold emphasizing them. Different individuals seem to vary much in their susceptibility to the effects of change of temperature on the blood-pressure; the more nervous subjects, and especially women, being particularly sensitive in this respect.

The blood-pressure may furnish indications for selecting climate.—Temperature forming the most prominent feature in climate, observation of the blood-pressure (arterial and venous) may provide useful hints for the selection of the most suitable climate in individual cases; the indications of an obstructed periphery, for example, pointing to the choice of an equable and warm climate, and the signs of a relaxed periphery suggesting a more variable, cool and bracing climate. It has been observed that the same mean arterial pressure may acquire an average rise of

10 mm. Hg. in high altitudes (see p. 202), and an average fall of about the same extent in the warm equable climate of Egypt.

11. *Pulse-rate.*

In the normal state of the circulation a moderate increase in the pulse-rate does not appreciably raise the mean arterial pressure.—It is doubtful when the periphery of the circulation possesses the normal capacity of onflow from the arteries to the veins, whether a moderate acceleration of the heart's action appreciably increases the mean arterial pressure. Stewart has, however, shown that the output of the ventricle per second is increased by a moderate rise of frequency, though "in general when the pulse-rate increases considerably the output per heart beat diminishes while the output per second may or may not alter, but is usually diminished too, although not in the same proportion as the output per beat." *

An increase in the pulse-rate does raise the mean arterial pressure when the peripheral resistance is increased.—The mean arterial pressure is, however, raised by an increase of the pulse-rate when the onflow of the blood from the arteries to the veins is obstructed; as when the terminal arteries and arterioles become contracted, for example,

* *Journal of Physiology*, vol. xxii., 1897, p. 172.

under the influence of nervousness and fear—the rise being then due to an increase of the output of the ventricle and the diminished onflow into the veins. In the clinical field a more rapid pulse-rate is certainly much more effective in raising the mean arterial pressure when the peripheral resistance is increased, either by vaso-constriction, or by organic changes, than when that resistance is normal, or when it is lowered, as in the febrile state. It therefore follows that in clinical observation the frequency of the pulse should not be ignored when the mean arterial pressure is estimated; for it may be important to take it into account in certain cases. As a rule, for example, a slight or moderate rise of the arterial pressure is of much greater significance when the pulse-rate is infrequent than when it is normal; and a high arterial pressure becomes of somewhat less clinical import in proportion to the rapidity of the pulse.

12. *Diurnal Variation of the Blood-pressure.*

Vaso-motor tone is at its maximum in the morning and at its minimum at night; and as it diminishes the arterial blood-pressure is maintained by the increased output of the heart.—Observation of the blood-pressure throughout the day shows, that the venous pressure is lower absolutely and relatively to the mean arterial pressure in the morning and in the earlier half of the day than in the subsequent hours and in the evening; and that the arterial pressure—and especially the maximum pressure—increases as the day advances, and attains its highest point in the evening. Inasmuch as the increase of the venous pressure indicates a more open state of the arterioles, and the rise of the maximum arterial pressure a more forcible contraction, and therefore a more complete emptying of the ventricle, it may be inferred that the vaso-motor tone attains its maximum on awaking in the morning, and gradually waning during the day, reaches its lowest degree at night; and that *pari passu* with this loss of tonicity in the vessels the energy of the ventricular contractions and the output of the ventricle increase. The evidence afforded by the compression of the splanchnic area likewise indicates that vaso-motor tone is greatest in the morning, for before breakfast there is a minimum splanchnic overflow; and is less as the day advances, the overflow being more pronounced in the evening. Rest and sleep restore vaso-motor tone, which is lowered by work. As the day advances the maintenance of the arterial blood-pressure therefore depends more and more on the cardiac muscle—the diminution of pressure, which would have resulted from the uncompensated waning of vaso-motor tone, being more than counter-balanced by the gain induced by the more powerful and more frequent ventricular contraction increasing the output of the heart. In the clinical field there is abundant evidence of the same fact; for example, those in whom the vaso-motor tone is low and the splanchnic area is large become more exhausted towards evening, and those in whom the mean arterial pressure is raised from augmented peripheral resistance, are more heavy and depressed from the circulatory obstruction in the earlier hours of the day, and become brighter and more comfortable in the after part of the day.

III. The Venous Pressure and the Reserve Capacity of the Veins (Systemic and Splanchnic).

1. *The Variations in the Venous Pressure.*

The characteristic features of the venous pressure are its lowness, its great and rapid variability, and the wide range of its variations.—Whereas the mean arterial pressure rarely exceeds the normal taken at rest by 40 per cent., and falls but slightly below it, the venous pressure may exceed an average mean by at least 100 per cent., and may fall below it quite 75 per cent. The large capacity of the veins provides for this enormous range of variation, and is a necessity in order to meet all the physiological exigencies of the circulation.

The venous pressure is increased by whatever relaxes the arterioles, stimulates the heart, or increases the intra-thoracic pressure.—The venous pressure rises from one or more of the following causes :—

(*a*). Relaxation of the terminal arteries and arterioles, as when the body is exposed to warmth; then, for example, the venous pressure may be doubled, while the mean arterial pressure will fall (see p. 225).

(*b*). Stimulation of the heart's action, as in emotional excitement. Observation has repeatedly shown that the venous as well as the arterial pressure may be raised in a marked degree when the ventricle contracts with increased frequency and energy from some passing emotion—this effect being produced quite independently of physical exertion. The distensile power of the intensified ventricular push suffices to open up the whole periphery and to raise the venous pressure at least 100 per cent.—even though the muscles are quiescent, and are therefore not contributing to the dilatation of the distal circulation. Repeated observation points undoubtedly to the conclusion, that of the two great causes of variation in the venous pressure, the centric and peripheral, the former is at least equally powerful, and is apparently capable of distending the peripheral vessels, and of immediately raising the venous pressure. Under ordinary physiological conditions, the venous pressure is closely associated with the arterial, and bears a certain relation to it. In the recumbent posture, with the arm extended on a level with the back, it varies as a rule from one-tenth to one-fifth of the normal mean arterial pressure. While the subject remains in the same position, it is found that when the arterial pressure is raised by whatever cause, as in the following observation on the effects of coffee, the venous pressure is likewise increased, and the venous rise is much the same as the arterial :—

	Vrnous Pressure, mm. Hg.	Arterial Presure, mm. Hg.		Pulse Rate.
		Mean.	Maximum.	
Before Coffee - - -	10	95	160	72
20 minutes after coffee -	18	105	170	72
35 " " -	20	105	170	72
40 " " -	12	97	160	72

(*c*). Increased intra-thoracic pressure, as in all forms of effort, is another cause of the rise of venous pressure. It may double that pressure. Hence the heightened venous pressure observed clinically when the breathing is oppressed and the return of blood to the right heart is obstructed.

The venous pressure is lowered by whatever contracts the arterioles, reduces the ventricular output, and increases the splanchnic drain. —The venous pressure falls :—

(*a*). When the arterioles contract as in exposure to cold, and as the effect of fear. The low venous pressure observed in some nervous affections is due to arteriolar constriction.

(*b*). When the heart's action slackens and the ventricular output is reduced ; hence the lowest attainable venous pressure observed in recumbent rest.

(*c*). When the splanchnic area increases from loss of vaso-motor tone; hence the rapid reduction of the venous pressure which results from the downward splanchnic drain in fatigue (see p. 169), and from the enlargement of the splanchnic area from heat (see p. 227).

2. *The Reserve Capacity of the Veins.*

The large capacity of the veins (systemic and abdominal) enables the blood to be temporarily stored in them during periods of physiological work and rest.—The large calibre of the veins (systemic and abdominal), far in excess of the average volume of blood circulating through them, serves an important physiological purpose, namely, to provide for the temporary storage of blood during periods of work and rest. During exercise the systemic veins become loaded with blood (see p. 168) and their large reserve capacity enables them to temporarily retain such portions of the blood as the heart cannot for the moment send forward into the arteries. In the intervals of rest during the day the blood employed in systemic work reverts to the capacious splanchnic reservoir, where it remains until again withdrawn by the physiological activities of the system. In this fact is to be found the *raison d'etre* of the large capacity of the splanchnic veins; for this is necessary in order to provide a reserve of blood from which the supplies required for systemic work may be drawn, and to which they may be returned during periods of inaction and rest. It has been shown, for example, how the brain incited to activity draws on the blood-supply of the abdomen, and how consequently the systemic blood-pressure (arterial and venous) is raised by mental work and emotional disturbance (see p. 170). The same fact is illustrated by exercise which diverts a large volume of splanchnic blood to the muscles (see p. 163). The spacious splanchnic veins, therefore, form an adjunct to the systemic circulation, serving as a reservoir for the supply of blood necessary to the performance of work, and as an overflow chamber in times of rest.

In health a definite degree of functional interchange is maintained between the two systems (splanchnic and systemic), so that the "give" and "take" of each fall within certain limits; but in disease this normal balance is apt to be greatly disturbed—the splanchnic reservoir becoming surcharged, and the systemic "draw" being lessened (see pp. 265-70).

IV. The Normal Readings of the Blood-Pressure (Arterial and Venous).

The Physiological Standard of the mean Arterial and the Venous Blood-Pressure.

The standard should embrace the limits of physiological variation in the majority of healthy subjects.—Although it has been shown that the blood-pressure is liable to considerable physiological variation, it is nevertheless remarkably constant in the same individual in a state of repose; and the agreement between the blood-pressures of different healthy subjects is sufficiently close for the setting up of a fairly reliable normal standard. All physiological standards, however, require to be formulated with a certain margin of elasticity, so as to include individual variations consistent with perfect health; and the standard of blood-pressure is no exception to this rule.

A large number of observations have led me to accept 100 c.mm. Hg. as the nearest approximation to the average mean arterial pressure taken from the radial or ulnar artery in healthy subjects placed in the horizontal position with the arm extended on the plane on which the back rests. To this average for the recumbent posture should be added about 10 c.mm. Hg., above and below it, to embrace the majority of healthy subjects and the average physiological variation. For the sitting position, with the wrist on a level with the epigastrium, about 10 c.mm. Hg. should be further added to the recumbent pressure.

The average venous pressure in recumbency (the wrist being level with the back) varies from 10 to 20 c.mm. Hg.; and in the sitting posture (the wrist being level with the epigastrium) from 20 to 40 c.mm. Hg.

The mean arterial pressure is modified by

the age, weight, and build of the subject.—The arterial pressure is much the same in women as in men; but it is somewhat less in children. Observations point to an increase of it after the age of 45 or 50. But this is a matter somewhat difficult to decide with accuracy; for after 50 years of age there is, as a rule, less or more uncertainty as to whether the pathological may or may not be encroaching on the physiological state of the organism. And, besides this, it is not at all an uncommon observation to find healthy subjects of 50, 60, or even 70 affording the low arterial pressure common at 20 or 30; a fact which often suggests a doubt on the physiological rise of the arterial pressure as age advances. Such cases, however, are probably exceptional instances of the postponement of the peripheral changes incidental to age; and this view is somewhat supported by the fact, that very frequently enquiry elicits a history of pronounced longevity in the ancestors of those presenting exceptionally low readings of the arterial pressure after 50 or 60 years of age. Observation undoubtedly shows that there are far greater differences in the normal arterial pressure in persons over 50 years of age than at earlier periods of life—differences which may in fact extend from the lower limit of 90 or 95 c.mm. Hg. to 10 c.mm. Hg. above the upper limit of 110 c.mm. Hg. (recumbent posture).

Increase of weight above the average for height is generally associated with a rise in the arterial pressure; and in obesity the rise may become very considerable, and of pathological significance (see p. 261).

The build of the subject likewise modifies the arterial pressure; for, as a rule, it is higher in broad built men and women, and is lower in small and thin subjects and in the tall and slim.

The physiological causes of variation of the arterial pressure raise that pressure, except rest and sleep; and they do not disturb clinical observation.—From the foregoing survey of the physiological causes of variation of the blood-pressure, it is obvious that all the conditions of life, except those of rest and sleep, raise the arterial pressure. They all imply physiological work of one kind or another; therefore, physiological work has as its invariable concomitant an increase in the arterial blood-pressure. Though the extent of this increase is but limited and the duration of it temporary, it should be excluded from clinical observation as much as possible by recording the blood-pressure in a state of physiological rest—free from the influence of the exercise of brain or muscle, or of the first stage of the digestive process, and under strictly uniform gravity conditions (see p. 150).

CHAPTER VI.

THE CIRCULATION: CLINICAL VARIATIONS.

INASMUCH as altitude, resisted exercises, massage, and baths are employed as important physiological modes of treatment, I will adduce some data bearing on their effects on the circulation before touching on some of the practical aspects of hæmodynamometry which have come under my observation.

Altitude.

Observation shows that altitude may raise the mean arterial pressure for a time.—Twenty-four consecutive observations, made daily in the early morning, on the blood-pressure in two subjects (aged 23 and 57) at Arosa (5800 ft.) suggest that altitude for a time raises the mean arterial pressure. Fig. 44 is the record afforded by subject æt. 23; it is quite similar to that of subject æt. 57. During 14 days after arrival the mean arterial pressure was raised on 12 days above the highest point recorded at home, and on two occasions only did it fall to that point; but on the subsequent days it was comparable with the pressure observed just before leaving England.

Altitude probably increases the output of the ventricle.—The maximum arterial pressure was

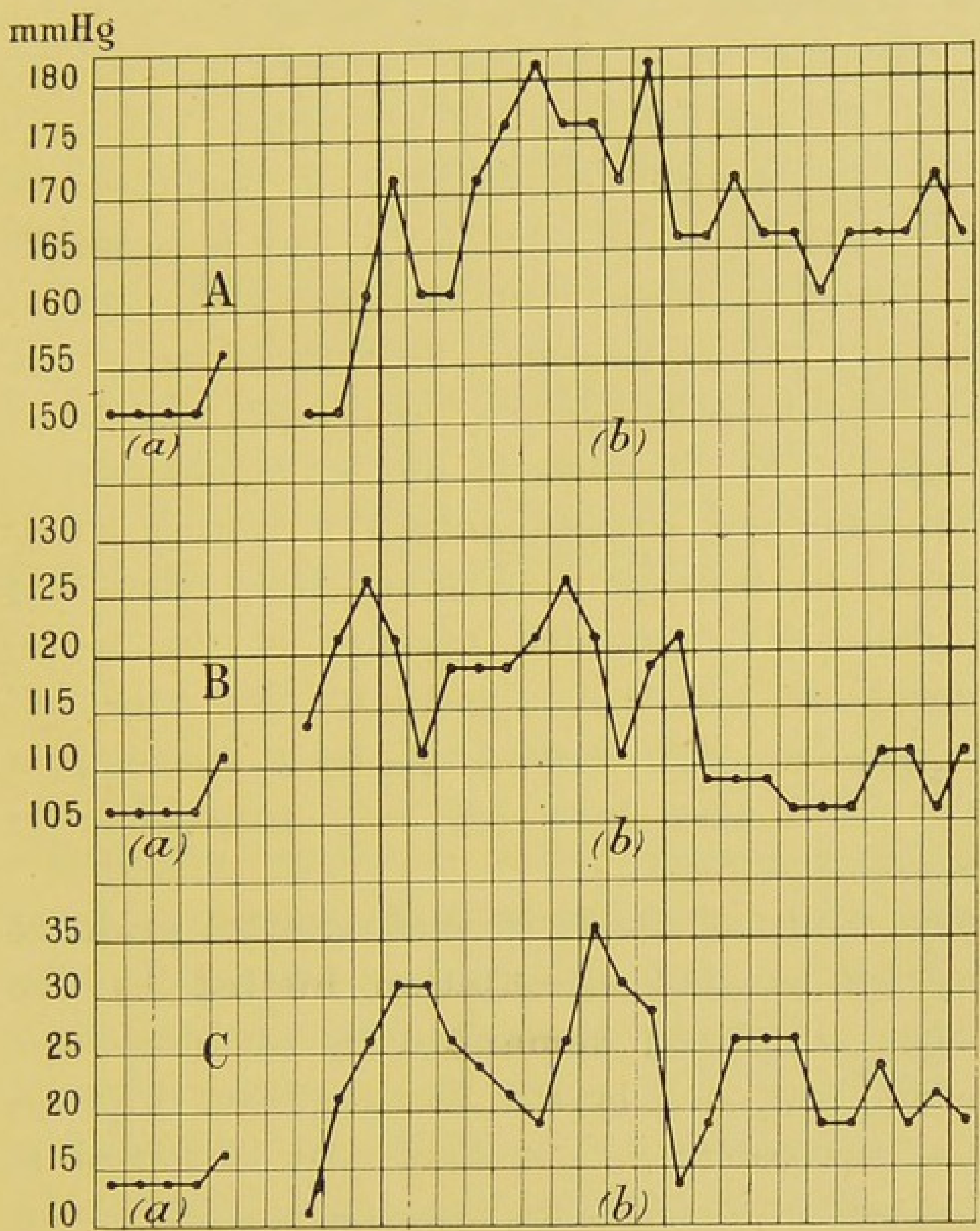


FIG. 44.—The blood-pressure (*a*) before, and (*b*) during the visit to Arosa (5,800 feet). A. Maximum arterial pressure. B. Mean arterial pressure. C. Venous pressure.

raised throughout the whole visit; and this fact suggests that altitude exerts a stimulant action on the heart.

It is doubtful if the rise in the mean arterial pressure should be ascribed to cold contracting the arterioles.—Unfortunately during the first half of the visit, when the mean arterial pressure was raised, the temperature of the atmosphere was much lower than during the second half of it; and therefore, as cold contracts the arterioles it may be suspected that the lower temperature may have contributed to raise the arterial pressure. Precautions were, however, taken to exclude as much as possible this source of fallacy; for the room in which the observations were made was warmed—though it is true, it was difficult to maintain a uniform temperature day by day. Moreover, the readings of the venous pressure do not lend support to this suspicion; for they are high, instead of being lowered, as they would have been had cold constricted the arterioles.

The cause of the increased arterial pressure may be cardiac stimulation incited by the deeper breathing demanded by altitude.—The teaching suggested by the foregoing data does not seem improbable; for the heart may be incited to increased action and to the discharge of a larger output through the demand made by altitude on the respiration, and in this way the arterial pressure may be raised, at any rate for a time, until in fact the heart and lungs and the periphery of the circulation become adjusted to the new conditions. Moreover, if this be so, some light is thrown on the clinical experience showing the unsuitability of altitude to cases of chronic Bright's disease and heart disease.

It is possible that altitude may be made available as a cardiac tonic in certain cases.—Although it is undesirable, as a rule, that cardiac cases should proceed at once to considerable altitudes—such as 4000 or 6000 ft.—it does not follow that the resort to such altitudes in progressive stages, judiciously arranged in regard to each grade and the time of sojourn at each, may prove to be equally inadvisable; for it is indeed probable that such a graduated course of ascent may prove to be beneficial as a cardiac tonic of considerable value in suitable cases.

Resisted Exercises.

Resisted exercises were employed in the treatment of heart disease nearly fifty years ago.—Nearly fifty years ago Saetherberg of Stockholm applied the method of resisted exercises known as the Swedish system to the treatment of heart disease, and reported his results some fifteen years later* ; and following him other observers showed the value of this form of exercise in cardiac disease. The patients were prescribed a series of exercises, which were executed under various degrees of resistance imposed by the operator. In more recent times this simple method of

* "Hygiea," 1862, quoted by Dr. Hermann Nebel of Frankfort, *Lancet*, 1896, vol. i.

treatment has been improved by the physicians at Bad-Nauheim—the brothers, August and Theodor Schott, and others—who modulated the resistance, and greatly reduced the rate of the movements. This system of resisted exercises thus carefully modified, and now somewhat extensively employed in the treatment of dilatation of the heart, produces in a marked degree the peripheral effect of voluntary exercise, while it fails to induce the centric effect—excitation of the heart—which invariably attends all degrees of active exertion.

The peripheral vessels become dilated and contain an increased charge of blood as in active exercise.—This fact is indicated by the increase in the volume of a limb as determined by the method of fluid displacement (fig. 50); and by a very pronounced rise in the venous pressure. Edgecombe and Bain have shown that the venous pressure may even be raised threefold by resisted exercises (see Table II., Resistance Exercises).*

The mean arterial blood-pressure is lowered.—In healthy subjects resisted exercises invariably diminish the calibre of the arteries after inducing a slight and transitory enlargement (fig. 45), the calibre in this instance being determined by the arterial blood-pressure.† It may therefore be concluded with Lauder Brunton and Tunnicliffe,‡ that reduction of

* *Op. cit.*

† See *Lancet*, 1896, vol. i.

‡ *Brit. Med. Journ.*, 1897, vol. ii.

the arterial pressure following an insignificant initial rise is the prominent effect of resisted exercises; and this fact has, moreover, been independently ob-

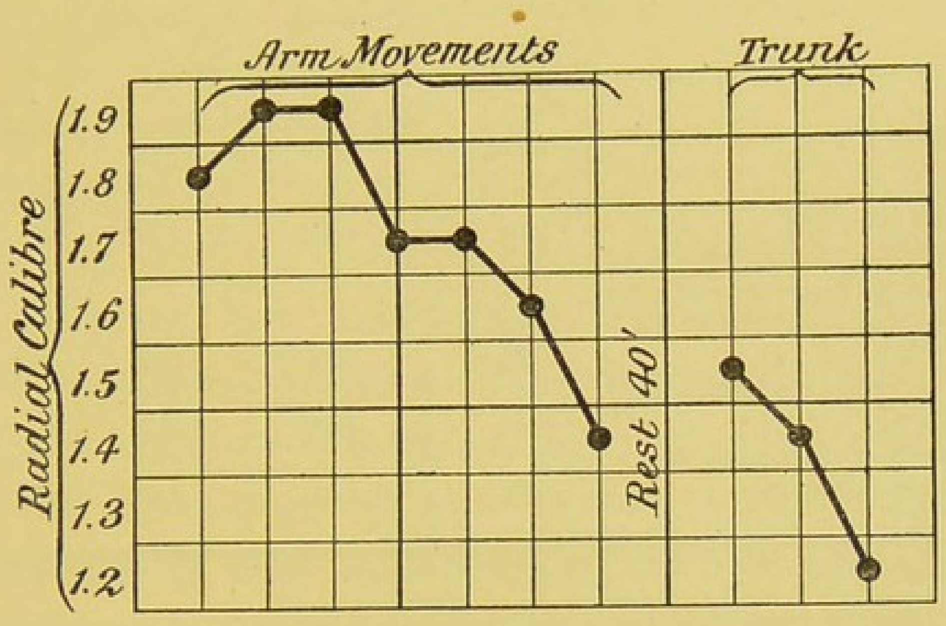


FIG. 45.—Radial calibre before and during resisted exercises.

served by Edgecombe and Bain, whose results I here quote :—

I. RESISTANCE EXERCISES (GENTLE).

	PULSE RATE.	ARTERIAL PRESSURE. mm. Hg. Maximum.	ARTERIAL PRESSURE. mm. Hg. Mean.	VENOUS PRESSURE. mm. Hg.
Before (sitting)	74	175	130	10
After five minutes' exercise (sitting)	74	175	130	10
After twenty minutes' exercise (sitting)	68	165	120	20
Ten minutes afterwards (sitting)	68	160	115	20
Twenty minutes afterwards (sitting)	68	175	130	10

II. Resistance Exercises (More Severe).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before (sitting) - -	84	165	125	7
After fifteen minutes strong resistance exercises respiration increased (sitting) - - - -	94	175	110	22
Fifteen minutes afterwards (sitting) - - -	84	165	105	17
Thirty-five minutes afterwards (sitting) - -	84	165	120	10

"With resistance movements performed gently without causing a rise in the pulse-rate, we obtained results corroborative of those of Brunton and Tunnicliffe—viz., an initial rise (or delayed fall as in the example given) in mean and maximum arterial pressure, followed by a fall during continuance of movement, with a further fall subsequently and a gradual rise to normal, the venous pressure rising as the arterial pressure falls (Exercise I.). Where, however, the resistance was made stronger and the exercise became such as to increase the frequency of the pulse and respiration a rise in maximum pressure resulted, with a fall in mean pressure and a trebling of venous pressure (Exercise II.)."*

Resisted exercises, as a rule, do not incite the ventricle to increased or more frequent action.—

* *Op. cit.*

When the exercises are gentle and carefully graduated, they diminish the frequency and the force of the ventricular contractions (see Table I., Resistance Exercises). They, therefore, lengthen the diastolic interval, and exert a sedative effect on the heart. In a word, they rest the heart muscle, by prolonging the recuperating moment, and by moderating the expending moment; hence it may be inferred, that in dilatation of the heart, when they diminish the intra-ventricular distensile pressure by diverting the blood to the periphery, they should favour the nutrition of the cardiac muscle.

The lowering of the mean arterial blood-pressure is due to widening of the peripheral bed in the muscles.—It has been observed that the mean arterial pressure may be lowered very considerably, though the pulse-rate, or the maximum arterial pressure (which is roughly proportionate to the ventricular effort) remains unaltered, or is actually increased (see Exercise II.); it may, therefore, be inferred, that the reduction of the pulse-rate, or the diminution of the force of ventricular contraction ordinarily induced by properly modulated resisted exercises, does not play an important rôle in reducing the mean arterial pressure. Vaso-dilatation is the prominent physiological effect of these exercises, and that condition is well known to effectually diminish the mean arterial pressure; it may, therefore, be concluded that the broadening of the bed of the blood-stream through the muscles is the main cause of the fall in that pressure.

The blood diverted to the systemic periphery of the circulation in the muscles is drawn from the splanchnic veins and the heart.—It has been shown that in normal subjects the great splanchnic venous reservoir is the source of the blood diverted by exercise to the muscles (see pp. 162-5); and in cases of dilatation of the heart the cardiac chambers as well as the visceral venous system will yield some of their surplus charge of blood.

Properly modulated resisted exercises, therefore, (1) transfer a certain not inconsiderable volume of blood from the visceral to the systemic circulation without stimulating the heart, and (2) widen the bed of the blood-stream through the muscles, so as to ease and render more effective the systemic circulation—as indicated by the lowering of the arterial and the raising of the venous blood-pressure. These physiological effects certainly fulfil the clinical indications afforded by (1) a loaded and embarrassed heart—the distended ventricle not being capable of delivering its extra load of blood; and by (2) the consequently overcharged condition of the visceral circulation.

In this way resisted exercises tend to restore the normal balance between the visceral and systemic areas of the circulation disturbed by the overloaded and ineffective condition of the heart muscle. Moreover they counteract the increased peripheral systemic resistance which so commonly determines the cardiac distension and inefficiency (see pp. 249-254); for they facilitate the flow out of the systemic arteries into the veins.

Tension exercises.—I have observed, that when the muscles of the arms and legs are repeatedly thrown into a prolonged and continuous state of contraction for definite periods, alternating with relaxation of similar duration, the arterial calibre is increased, the mean arterial pressure is lowered and the venous pressure is raised. The physiological effect of this simple variety of muscular exercise on the circulation is, therefore, identical with that of the resisted form. The procedure that has been usually adopted is as follows:—The subject assumes the recumbent position, and throws the muscles of the arms into a state of tension, which is equably maintained for one minute by the watch, after which he relaxes the muscles for the same period; he then contracts the muscles of the legs for one minute, and finally rests them; the alternating intervals of muscular contraction and repose are repeated once, twice, or three times. The following is an example of the effects produced on the systemic circulation by a series of tension exercises extending over 10 minutes.

	Radial Calibre.	Mean Arterial Pressure.	Venous Pressure.	Pulse Rate.
Before tension exercises	1·4 mm.	125 mm. Hg.	5 mm. Hg.	72
After ,, ,,	2·1 mm.	110 mm. Hg.	10 ,,	72

It is evident that the lowering of the arterial pressure and the raising of the venous pressure result from the widening of the arterial and arteriolar bed. This result can only be obtained by the sustained contraction being confined to the muscles of the limbs; for, when the whole muscular system (including the abdominal muscles) is thrown into a state of alternate tension and repose, after the arterial pressure has been lowered and the venous pressure raised by tension exercises of the arms and legs, the arterial pressure rises again, even though the pulse-rate is not altered, as in the following example:—

	Radial Calibre.	Mean Arterial Pressure.	Venous Pressure.	Pulse Rate.
After tension exercises of arms and legs - -	2·1 mm.	110 mm. Hg.	10 mm. Hg.	72
After general tension exercises - - -	2·1 mm.	130 ,,	10 ,,	72

The explanation of this difference in the effect on the arterial pressure of general tension exercises and of tension exercises limited to the limbs is doubtless to be found in the fact, that when the whole muscular system is contracted, the splanchnic area is compressed by the abdominal muscles, and a portion of blood is thus dispersed from the abdomen into the general circulation, and the arterial pressure is raised. When this has happened, tension exercises of the limbs, while the subject remains recumbent, no longer lower the arterial pressure, for they cannot further dilate the distal circulation; moreover, the dislodged splanchnic blood continues in general circulation for some time (see pp. 149-50), but after the assumption of the erect posture, it quickly drains again into the splanchnic area, and then, when the subject resumes the recumbent posture, the arterial pressure is found to have fallen.

	Mean Arterial Pressure.	Pulse Rate.
After general tension exercises	130	72
After tension exercises of limbs	130	72
After standing up one minute	120	72

The practical inference to be drawn from these facts is, that tension exercises, when resorted to for the purpose of widening the bed of the distal circulation and lowering the arterial pressure, should be confined to the limbs.

Massage.

The general effect of massage is to accelerate and increase the circulation of blood and to lower the blood-pressure.—It is agreed by all authorities on massage that the circulation of blood through the manipulated tissues is accelerated and increased. This fact has, moreover, been clearly demonstrated experimentally on dogs and cats by Lauder Brunton and Tunnicliffe, who determined the amount of blood which issued from the efferent vein derived from the group of muscles manipulated, the observation having been made immediately before, during, and at various intervals after the application of the massage. These observers established the following conclusions:—" 1. During the massage of muscles the flow of blood through them is increased. 2. Immediately after the cessation of massage an accumulation of blood occurs in the massaged muscles; this is rapidly followed by an increased flow through the muscles. 3. The massage of a considerable muscular area causes first a slight rise in the general blood-pressure; this is followed by a fall which in some cases amounts to one-fifth of the initial blood-pressure."*

The results of my observations in man coincide with these conclusions when the massage, in the form of pétrissage, is confined to the limbs and trunk—the abdomen being excluded.

The effects of general massage on the blood-pressure vary with the form in which it is applied, and with the inclusion or not of the abdomen in the process. Observations with the arteriometer and hæmodyna-

* "On the Effects of the Kneading of Muscles upon the Circulation, Local and General. By Sir T. Lauder Brunton, M.D. Edin., F.R.S., and F. W. Tunnicliffe, M.D. Lond. *Journal of Physiology*, vol. xvii., 1894, Klein also showed that kneading of the muscles of a rabbit's leg produced a fall of the blood-pressure.—Skandinay, *Archiv. für Physiologie*, Band i., p. 247, 1887. These observations have recently been confirmed by Reid Hunt, *Journal of Physiology*, vol. xviii., 1895, p. 389.

mometer show that in massage the arterial calibre is determined by the blood-pressure.

The blood-pressure may be differently influenced by the kind of massage employed.— Figures 46 and 47 show that the lighter and superficial

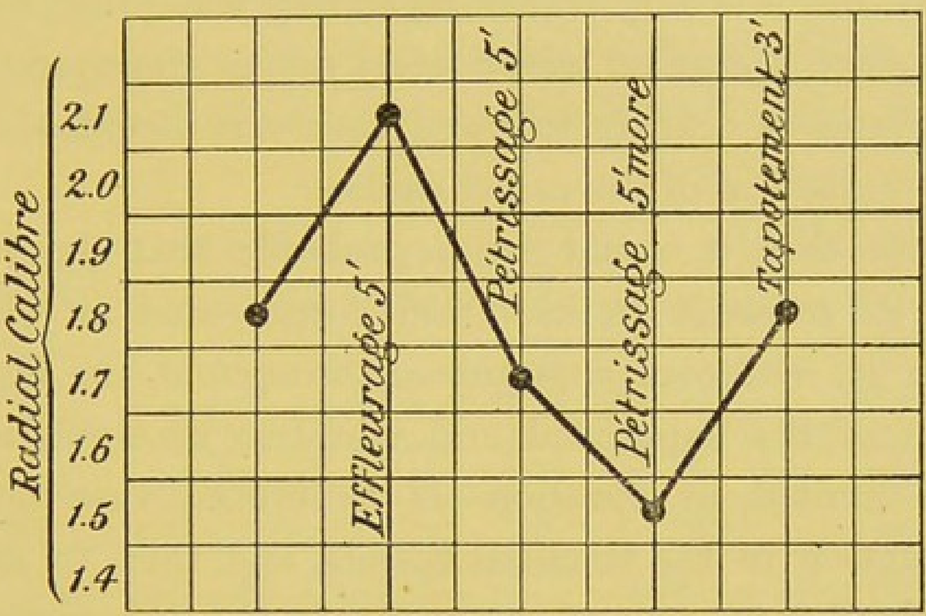


FIG. 46.—Effects of different forms of massage on the radial calibre.

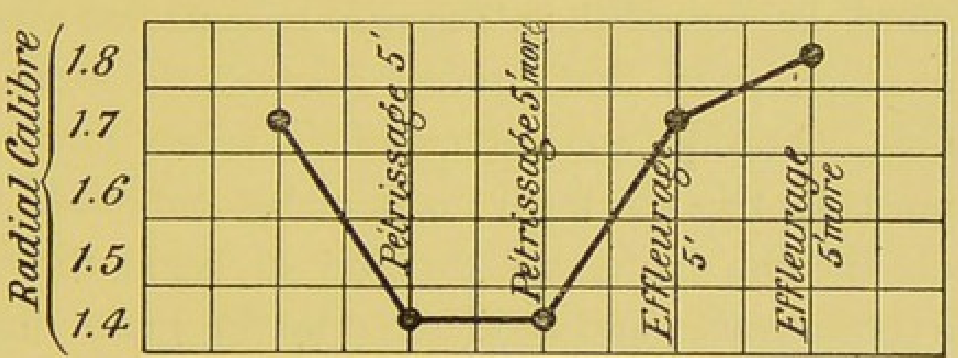


FIG. 47.—Effects of different forms of massage on the radial calibre.

manipulations (such as stroking, effleurage) and vibratory movements or percussion (such as what is known as hacking, punctation, slapping, &c.) raise the radial blood-pressure and calibre, and that the intermittent rolling and squeezing of the muscular tissue (pétrissage) reduce them. The immediate effect of all the forms of massage is to raise the blood-pressure and to enlarge the calibre of the artery. This preliminary stage is maintained for some time while the more superficial and vibratory manipulations are being employed, but it is very transitory indeed when that form of massage is applied which freely moves the muscular tissue and is quickly followed by a very decided and sharp reduction of the radial calibre.

From this it would seem probable that the first effect of massage in its various forms—and an effect which is, moreover, maintained throughout the application of the superficial and vibratory manipulations when limited in duration—is to induce vaso-motor contraction in the terminal vessels, and thus to raise the blood-pressure and the calibre in the intermediate arterial tubing between them and the heart. This may, therefore, be regarded as the vaso-motor tonic aspect of massage, when that process assumes the forms of stroking, vibration, and percussion.* When, however, the muscular tissue is freely manipulated and rolled, the vessels therein dilate, and the flow of blood through them is increased and accelerated by the rapid mani-

* Dr. W. Balfour eighty years ago wrote:—"Percussion, instead of repelling, creates an afflux of nervous energy and sanguineous fluid to the part. Vessels in a state of atony are thereby roused to action and circulation is promoted."—"Illustrations of the Power of Compression and Percussion in the Cure of Rheumatism, Gout, and Debility of the Extremities, and in Promoting Health and Longevity," by W. Balfour, M.D. Edin., 1816.

pulations acting in the manner of a supplementary heart, and the blood-pressure and calibre of the radial and other systemic arteries fall. This is the vaso-motor relaxant effect of massage which reduces arterial tone and lowers the arterial blood-pressure.

Systemic massage (pétrissage) lowers the mean arterial and the venous blood-pressure.—It has been invariably observed than when vigorous

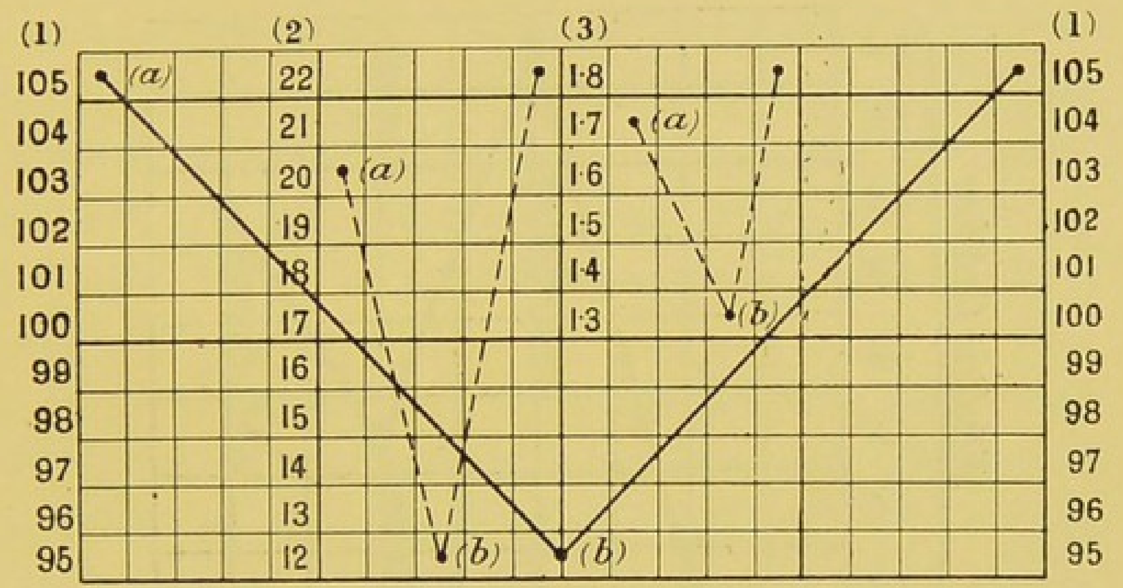


FIG. 48.—The blood-pressure (arterial and venous) and the radial calibre before and after systemic massage *(a)*, followed by abdominal massage *(b)*. (1.) Mean arterial pressure. (2). Venous pressure. (3). Radial calibre.

massage is applied to the limbs and trunk (save the abdomen) for thirty or forty minutes, the radial calibre diminishes, and the arterial and venous blood-pressure falls (fig. 48, *a*, *a*, *a*).

Abdominal massage (kneading and compression) raises the mean arterial and the venous blood-pressure.—When systemic massage is followed by deep abdominal massage, the radial calibre and the blood-pressure (arterial and venous) are restored, or are actually raised above the original degrees (fig. 48, *b*, *b*, *b*). It has likewise been observed, that when the arterial calibre and the blood-pressure have been increased by kneading and compression of the abdomen, they may be again reduced by systemic massage, and then once more may be increased by abdominal massage (fig. 49).

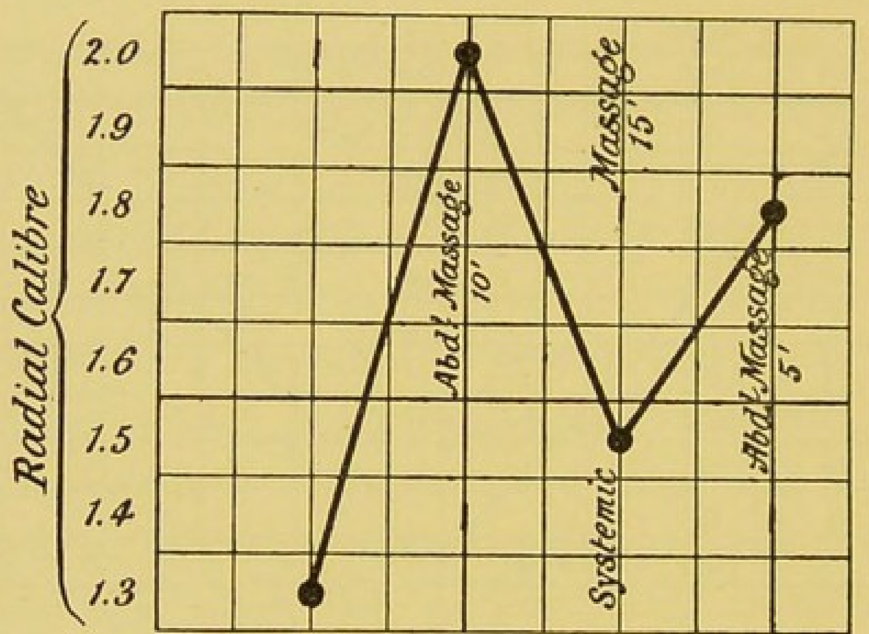


FIG. 49. Radial calibre before and after abdominal massage followed by systemic massage and a second abdominal massage.

Blood may be transferred by massage from the systemic to the abdominal circulation and *vice versâ*.—The foregoing facts point to the removal of a certain volume of blood from the somatic to the abdominal areas of the circulation by systemic massage, and from the abdomen to the skeletal portions of the body by abdominal massage.

That such a dispersion of blood from the splanchnic to the systemic circulation, with a rise in the arterial blood-pressure, may be effected by manipulating the abdomen is, moreover, rendered highly probable by Glovetzky, who made a large number of experiments on men and dogs to show the effects of abdominal massage on the general circulation. This observer found that the upper half of the body increased in weight after the *séance*, as shown by Mosso's balance, and plethysmographic measurements proved that during the sitting both the upper and lower extremities increased in volume, but returned to their normal size after the massage. The blood tension and the intracranial pressure invariably rose during the massage and the elevation lasted for a certain period afterwards.*

Moreover, it has been demonstrated that abdominal compression produced by applying a well distributed weight (*e.g.*, 28 lb.) to the abdominal wall of a subject in the recumbent position at once raises the systemic blood-pressure (see pp. 135-6).

The evidence, therefore, points to the position that massage of the abdomen raises the arterial blood-pressure by dispersing blood from the splanchnic veins to the heart and thence to the arteries, and that systemic massage lowers that pressure by causing some of the blood in general circulation to overflow into the capacious splanchnic reservoir.

Massage favours the flow of blood and lymph

* See "A Treatise on Massage," by D. Graham, M.D., New York, 1890.

from the tissues.—This fact is shown by the reduction of the volume of a limb effected by massage. Figure 50 shows that, when the volume is increased by resisted exercises, the increment may be quickly and effectually removed by it. In this respect, therefore, massage differs from voluntary exercise and from resisted exercises.

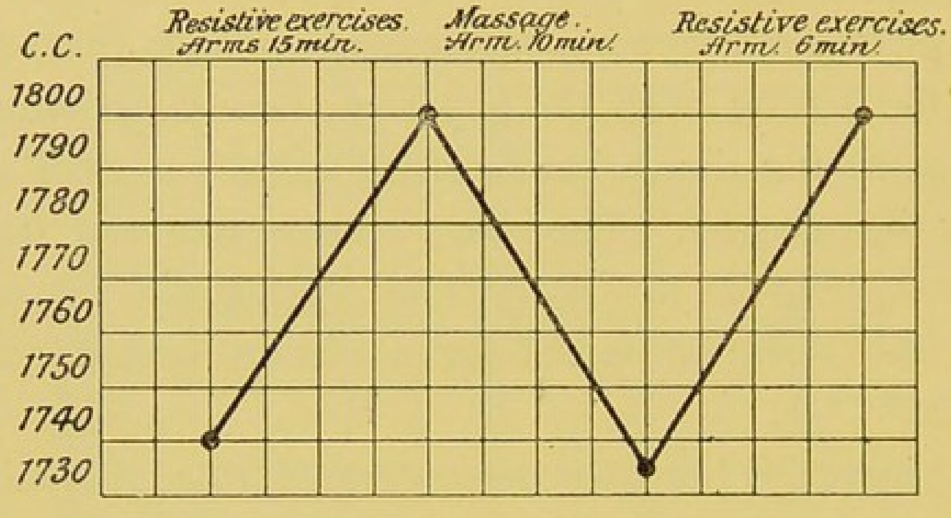


FIG. 50.—Resistive movements and massage; contrary effects on arm-volume.

A few practical inferences suggested by these observations.—It is obvious that massage should not be prescribed and performed in a mere perfunctory routine fashion, as is to be feared it too often is, but like other therapeutic measures, should be applied with due discrimination. The leading features of the circulation—the blood-pressure and vaso-motor tone—are the best indications for the selection of the kind of manipulations to be adopted, for the limitation of the time of their application, and for the distribution of them—whether merely to the abdominal region, or to the systemic muscles. When, for example, the vaso-tonic effects are sought for, the manipulations should be lightly applied and partake chiefly of the nature of vibration or percussion; and, when muscle-kneading is resorted to, percussion should terminate the process, and in all cases the abdomen should receive special attention at the close of the *séance*. When, on the other hand, the aim is to reduce the arterial blood-pressure, and to relieve the ventricular effort or cardiac strain, the deep rolling movements should be preferred throughout, and should be applied only to the limbs, back, &c., and the abdomen should not be manipulated at all.

It has been shown that abdominal massage disperses blood from the splanchnic veins to the systemic circulation, and in this way raises the arterial blood-pressure. This form of massage should, therefore, prove particularly useful when the splanchnic area is increased from diminution of tone in the arterioles which supply it. But inasmuch as the blood thus transferred is driven from the abdomen to the heart, and not drawn from the splanchnic veins as when the resisted exercises are resorted to, abdominal massage should be employed with caution when the heart wall is dilated and inefficient.

Baths.

A large number of observations with the hæmodynamometer have been made on the physiological effects of baths on the circulation by Edgecombe and Bain,* and by myself.† In selecting the data to illustrate these effects, I will quote as freely as possible the observations made independently by Edgecombe and Bain, which in the main coincide with my own.

The blood-pressures (arterial and venous) were taken just before and after a bath under exactly the same condition of gravity—the subject being recumbent with the arm extended on a level with the back.

(A). **Cold baths.**—Immersion in cold water raises the arterial pressures (maximum and mean) and diminishes the venous pressure; the rise of the former, however, being quickly followed by a fall, and by a slight relative increase in the venous pressure.

COLD BATH.

Two minutes at 13° C. (54° F.). (Edgecombe and Bain).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before - - -	70	190	130	25
After - - - -	72	210	150	10
Ten minutes after -	70	185	125	25

* *Op. cit.*

† *The Journal of Balneology and Climatology*, 1899.

These data indicate that a short exposure to cold water induces peripheral constriction, with stimulation of the heart, which is rapidly replaced by peripheral relaxation (reaction) and a slight lowering of the arterial pressure.

(B). **Warm baths.**—Immersion of the body in a heated medium—whether it be water, or air, or steam-charged air—invariably lowers the arterial blood-pressures (maximum and mean), and this effect is in a general way proportionate to the rise of temperature. The following examples were observed by Edgecombe and Bain :—

WARM IMMERSION BATHS.

BATH TEMPERATURE. Duration.	WHEN OBSERVATION MADE.	PULSE RATE.	ARTERIAL PRESSURE. mm. Hg. Maximum.	ARTERIAL PRESSURE. mm. Hg. Mean.	VENOUS PRESSURE. mm. Hg.
HOT BATH. 43° C. (109° F.) Ten minutes.	Before - -	62	185	130	20
	After - -	64	170	117	15
WARM BATH. 38° C. (101° F.) Fifteen min.	Before - -	60	190	135	17
	After - -	60	180	130	15
SULPHUR BATH (Natural) 37° C. (98° F.) Twenty min.	Before - -	72	175	125	22
	After - -	68	140	85	20

Warm Air Baths.

Bath Temperature. Duration.	Time of Observation.	Pulse Rate.	Arterial Pressure. mm. Hg. Maximum.	Arterial Pressure. mm. Hg. Mean.	Venous Pressure. mm. Hg.
Turkish Bath. Hottest room 99° C. (210° F.)	Before - -	70	200	135	25
	After seven minutes in hottest room	120	155	100	20
	In cooling room	74	170	115	20
Russian Bath. Needle douche cooled to 30° C. (86° F.)	Before - -	72	175	130	25
	After - -	70	160	115	25

Air superheated by electricity (as in the Greville or Dowsing bath), whether applied merely to a limb or to the whole body, save the head, likewise reduces the arterial pressure, as in the following examples :—

Partial Non-radiant Electro-thermic Bath (Greville) Arm Enclosed.*

	Pulse Rate.	Mean Arterial Pressure.	Temperature of Air.
Before - - -	84	95 mm. Hg.	
After twenty minutes -	84	87 ,,	C. (264° F.)
After thirty minutes -	84	82 ,,	C. (264° F.)
After forty minutes -	80	80 ,,	C. (270° F.)

* These observations were made while the subjects were in the bath.

General Non-radiant Electro-thermic Bath (Greville) the whole body enclosed save the head.*

	Pulse Rate.	Mean Arterial Pressure.	Venous Pressure.	Temp. of Bath.
Before - - -	88	97 mm. Hg.	30 mm. Hg.	
After twelve minutes -	104	92 ,,	40 ,,	C. (264° F.)
After twenty-two min.	112	85 ,,	50 ,,	C. (275° F.)
After thirty minutes -	120	77 ,,	60 ,,	C. (270° F.)

General Radiant Electro-Thermic Bath, the whole body enclosed save the head.†

	Pulse Rate.	Arterial Pressure.		Venous Pressure.	Temp.
		Maximum.	Mean.		
Before - -	68	175	105	17	
After 15 min.	92	160	90-95	35	71° C (160° F)

Edgecombe and Bain found that warm running Sitz baths also lower the arterial pressure.

* These observations were made while the subjects were in the bath.

† I am indebted to Dr. Page May for opportunities of testing the effects of this bath in the now well equipped bathing establishment at Hellouan, near Cairo. It is a neatly arranged cabinet bath containing 48 incandescent lamps of 32 candle power, and lined with reflectors. It is also designed for local treatment by luminous heat. While making these observations, I was much struck with the fact, that active perspiration appeared at quite low temperatures, in fact before the thermometer registered 37° C. (98° F.), as if the light rays incited the sweat glands before the air of the bath is warmed up to the temperature of the body.

Sitz Bath, running.

10 Minutes at 37° C. (98° F.), cooled at finish to 30° C. (86° F.).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before - -	66	160	125	17
After - -	64	135	85	12

We know that heat is a relaxant. Therefore it may be presumed that the fall in the mean arterial pressure is mainly attributable to dilatation of the arterioles and arteries. The relaxation of the arteriolar region of the circulation will favour a rise in the venous pressure, which is the primary effect of heat on that pressure during the immersion and for a short time afterwards. But it has been repeatedly observed that this rise may be very quickly converted into a fall; as for example, when the *vis a tergo* slackens below a certain point, diminishing the output of the ventricle, or when the blood drains unduly into the splanchnic veins in consequence of relaxation of the arterioles supplying them —then it may be presumed that the blood flows sluggishly through the dilated peripheral vessels into the veins, or the fullness of the systemic circulation is relieved by the afflux of blood to the splanchnic area.* This condition of reduced venous pressure is apt to supervene on withdrawing from a warm bath. In this case the venous pressure does not afford, therefore, a gauge of the dilatation of the peripheral vessels; for other important factors play then their part in reducing that pressure, such as the lowered tone of the ventricular contractions, and the recession of blood to the splanchnic veins.

The following observations show that warm baths, by relaxing the arterioles supplying the splanchnic area, increase that area, and impair the integrity of the adjustive function of the splanchnic vaso-motor mechanism for gravity. The splanchnic overflow into the systemic circulation produced by the application of an equably distributed weight over the abdomen of the recumbent subject is greatly increased by a warm bath; as in the following example:—

MEAN ARTERIAL PRESSURE.	Before hot bath, temperature 42·6° C. (108° F.) 13 minutes	102
	After abdominal compression by weight (28 lb.)	107
	Difference	5
	After hot bath	95
	After abdominal compression by weight (28 lb.)	112
	Difference	17

The following observation shows that warm baths impair the postural variation of the radial calibre and of the mean arterial pressure, and therefore weaken the protective vaso-motor mechanism for gravity.

* The observations of Edgecombe and Bain, supporting their conclusion that heat reduces the venous pressure, are probably in this way accounted for.

	Radial Calibre.	Mean Arterial Pressure.
Before bath, temperature 43° C. (109° F.)		
Sitting	1·9 mm.	105 mm. Hg.
Recumbent	1·4 "	95 "
After bath.		
Sitting	1·4 "	95 "
Recumbent	1·9 "	105 "

The firm application of pressure to the abdomen by means of traction on a bandage, however, completely restores the arterial calibre and pressure.

	Radial Calibre.	Mean Arterial Pressure.
Sitting posture—		
Before traction on bandage	1·4	95 mm. Hg.
After " "	2·0	110 "

Exposure to heat, therefore, whether in the form of warm water baths, or in that of hot air baths, lowers the arterial blood-pressure, and primarily raises and secondarily diminishes the venous pressure; and, by relaxing the splanchnic arterioles, increases the splanchnic area and impairs the protective vaso-motor mechanism for gravity. These effects of heat on the circulation are the natural consequences of relaxation of the musculature of the arteries and arterioles, and of the heart. In a word, heat reduces the cardiac and vaso-motor tone.

(C). **Percussive Baths—Massage Baths.** The leading effects of temperature *per se* on the circulation, when applied in the form of baths, have been indicated in the preceding paragraphs. It is now necessary to enquire—What is the influence of percussion and mas-

sage when combined with that of temperature, as in the various forms of douche and needle baths?

Percussive baths.—When the general application of cold water is conjoined with percussion, as in the form of the needle bath, the rise of the arterial pressure is much more decided, and the fall of the venous pressure is less marked, than when the bath is merely cold and still.

Strong Needle Bath.

Begun at 37° C. (98° F.) and rapidly cooled down to 16° C. (60° F.); time, 2 min. (Edgecombe and Bain).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before	64	115	85	15
After	72	150	115	10

The less pronounced diminution of the venous pressure in this case does not, however, indicate that such a cold percussive bath fails to produce as great a peripheral constriction as the still cold bath; for the enormous increase in the maximum pressure (35 mm. Hg.) and the more frequent pulse-rate (62 raised to 72) from stimulation of the ventricle, will suffice to increase the ventricular output, and to propel more blood through vessels equally or more contracted into the veins.

When a needle bath is warm (percussion being thus combined with warmth) the arterial pressure rises, and does not fall as when the body is simply immersed in warm water.

Warm Needle Bath.

Temp. 38° C. (101° F.); time, 3 min. (Edgecombe and Bain).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before - -	72	140	115	15
After - - -	72	145	120	20

It may therefore be inferred that percussion may overbalance the lowering effect of warmth on the arterial pressure and on the heart.

In the needle bath of alternating temperature (from warm to cold) the arterial blood-pressure also rises.

Alternating Needle Bath.

Temp. from 37° C. (98° F.) to 27° C. (80° F.); time, 6 min. (Edgecombe and Bain).

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before - -	60	175	130	25
After - - -	66	190	145	22

The toning effect of percussive bathing on the muscular coat of the arteries and arterioles is well illustrated by the use of the needle bath of alternating temperature after warm baths of various kinds; as in the following examples :—

1. EFFECTS OF A NEEDLE BATH REDUCED TO 10° C. (50° F.) AFTER A WARM SULPHUR BATH.

	FREQUENCY OF PULSE.	MEAN ARTERIAL PRESSURE. mm. Hg.	VENOUS PRESSURE. mm. Hg.
Before needle bath	64	90	40
After ,, ,,	64	135	15

2. EFFECTS OF A NEEDLE BATH AFTER A CABINET HOT AIR BATH.

	FREQUENCY OF PULSE.	MEAN ARTERIAL PRESSURE. mm. Hg.	VENOUS PRESSURE. mm. Hg.
Before needle bath	84	95	35
After ,, ,,	78	102	22

The needle bath doubly alternating in temperature (*i.e.*, falling from warm to cool, then rising to warm, and again falling to cool), with a hot descending spinal douche, has the most powerful effect in raising the arterial pressure; as in the following example :—

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before needle needle and spinal douche	56	97	25
After ditto	60	135	20

There is no doubt that the effect of the percussion of water on the peripheral vessels is greatly intensified by varying the temperature, and especially by allowing it to dip to low ranges. Apart from percussion, the mere alteration of temperature when considerable, has a remarkable effect on the blood-pressure. The following is the most striking example I have met with. It is the effect of a plunge into cool water after the subject had been exposed to a temperature of 102° C. (270° F.) in Greville's general electro-thermal bath for thirty minutes.

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before the plunge	120	77	60
After " "	88	105	30

In this case the electro-thermal bath reduced the mean arterial pressure from 97 to 77 mm. Hg. and doubled the venous pressure (raising 30 to 60 mm. Hg.) ; and the plunge raised the arterial pressure 30 mm. Hg. (adding 10 mm. to the normal arterial pressure which existed before the thermal bath), and reduced the excessive venous pressure of 60 to 30 mm.

In the case of the abdominal douche, the alteration of the blood-pressure is greater than that induced by the needle bath, and other forms of percussive bathing, and is quite pronounced, even though the temperature of the douche be quite warm, as in the following example:—

ABDOMINAL DOUCHE.

Temp. 37° C. (98° F.) following the Needle Bath.

	FREQUENCY OF PULSE.	MEAN ARTERIAL PRESSURE. mm. Hg.	VENOUS PRESSURE. mm. Hg.
Before needle bath	60	87	25
After " "	58	95	35
After abdominal douche - -	58	105	45

In this case the venous pressure was raised as well as the arterial. It is perhaps not difficult to understand how this result was brought about; for the abdominal douche induces powerful contraction of the abdominal wall, and this contraction must compress the spacious splanchnic veins, so that any excess of blood collected in these veins is driven onward to the heart, and is thereby transferred from the splanchnic to the systemic circulation. Such an effect as this is much greater, of course, when there is diminution or loss of tone in the splanchnic vaso-motor nervous system permitting the force of gravitation to come into play; for then the blood gathers in the abdominal veins, and a large portion of it remains there withdrawn from the systemic circulation.

Percussion constricts the terminal arteries and arterioles reflexly by stimulating the cutaneous nerves; when that stimulation is carried further than obtains in the needle bath and douche by the application of a counter-irritant, the arterial blood-pressure is raised to a still more pronounced degree. The following is an example of this fact as the result of a mustard liver pack :—

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before the pack	60	105	30
During smarting	76	135	30
Smarting subsiding	60	125	30
Later	56	115	35

In this case the rise of the mean arterial pressure was probably not entirely due to vaso-motor constriction, but was also attributable to cardiac excitation—for the venous pressure was maintained.

The massage baths are represented by the Aix-les-Bains and the Vichy douches. The massage is applied in both forms of bathing; in the former the subject being in the sitting, in the latter in the recumbent posture; and in the Vichy bath the procedure is preceded by exposure to hot air in a box arrangement. Though these baths are somewhat similar, the net result on the circulation which each produces is somewhat different.

In the Aix douche my observations show that the douching alone, without the massage, raises the arterial pressure; whereas the massage alone, without the douching, lowers it. But the general net result of the Aix douche is to lower the mean arterial pressure and to raise the venous pressure.

On the other hand, the general net effect of the horizontal massage and douching of the Vichy bath is to raise the mean arterial and the venous pressure. The following observations are examples of this difference:—

1. Aix-les-Bains Douche (without Needle Bath).

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before - - -	84	95	25
After - - -	84	85	35

2. Vichy Bath (without Needle Bath).

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before - - -	72	95	20
After hot air - -	72	85	30
After massage and douche - -	72	105	40

The obvious explanation of this difference would seem to be that in the horizontal massage of the Vichy bath the splanchnic area is more thoroughly manipulated than it can be in the sitting posture in the Aix douche, and consequently the blood cleared from the splanchnic veins becomes available in the systemic circulation.

In normal subjects, however, when these forms of massage bathing are followed by the needle bath of alternating temperature, the arterial pressure is raised, with a relative fall in the venous pressure.

1. Aix Douche, followed by Needle Bath of alternating temperature.

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before needle bath	84	85	35
After ,, ,,	80	125	25

2. Vichy Bath, followed by Needle Bath of alternating temperature.

	Frequency of Pulse.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before needle bath	72	105	40
After ,, ,,	72	115	25

These data, therefore, show that percussion and massage modify considerably the effects of cold and warm baths on the circulation; intensifying the vaso-cardiac tonic properties of the former, and either qualifying or entirely obviating the vaso-cardiac relaxant effects of warm baths. When properly combined they enable the physician to secure the derivative influence of heat on the systemic circulation without impairing the cardiac tone or relaxing the splanchnic arterioles.

(*D*). **Saline and carbonic acid baths.**—My observations on the effects of artificial Nauheim baths (still and aerated) on the circulation agree with those of Edgecombe and Bain which are here quoted:—

Bath Temperature. Duration.	When observation made.	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
			Maximum.	Mean.	
Nauheim bath* (still)	Before - -	54	190	115	5
34° C. (93° F.)	After - -	60	140	95	10
20 minutes.	20′ after -	60	155	110	7
Nauheim bath (aerated)	Before - -	88	165	125	12
34° C. (93° F.)	After - -	84	140	97	15
20 minutes.	30′ after -	84	145	105	20

These baths, therefore, facilitate the peripheral circulation, and thereby unload the embarrassed ventricle, just as effectually as baths of a much higher tempera-

* 3·2 kilos NaCl and 85 grammes $CaCl_2$ to 136 litres of water.

ture, which tend to lower and exhaust the action of the heart (see p. 228).

A few practical inferences suggested by the foregoing data.—It is obvious from these observations, that baths—including as they do the employment of temperature, mineralization, percussion and massage—are agents of considerable therapeutic power, even when viewed merely from their effects on the circulation, and apart from their influence on metabolism and the excretion of residual products. By their agency we can modify the action of the heart (the output and the force of contraction) and the distribution of the blood to the systemic and the splanchnic areas. The data furnished by them are in general accord with the results of clinical experience; such as the vaso-cardiac tonic effects of the lower ranges of temperature, and of percussion, the relaxant influence of heat on all parts of the circulatory apparatus, and the therapeutic gain so frequently secured by judiciously combining percussion and massage with warmth, and by the employment of alternating temperatures. But though there is a general agreement between these physiological results and clinical experience, observation has shown that it is not always safe to infer what will happen in the abnormal from what we know does take place in the normal. For example, the fact has frequently been observed that, when the arterial pressure exceeds the normal in consequence of increased peripheral resistance, the Aix douche bath followed by the needle bath of alternating temperature—which in normal subjects raises the arterial pressure—produces a marked fall in that pressure.

AIX DOUCHE, FOLLOWED BY NEEDLE BATH, REDUCING A MODERATE INCREASE OF ARTERIAL PRESSURE.

	FREQUENCY OF PULSE.	MEAN ARTERIAL PRESSURE. mm. Hg.	VENOUS PRESSURE. mm. Hg.
Before bath - -	68	145	35
After - - -	64	115	45
Twenty min. later -	64	110	25

A fact analogous to this has been referred to in the more pronounced lowering effect of exercise on the mean arterial pressure, in subjects in whom it is higher than usual; in such cases the effort distends the peripheral vessels, which offer an increased obstruction to the onflow, and these becoming dilated, the mean arterial pressure falls relatively lower than it does in normal subjects (see p. 162). Observation, therefore, shows that the stimulant and tonic forms of bathing, which raise the arterial pressure in those in whom it is normally low, actually lower it in cases in which that pressure is raised from increased peripheral resistance; and clinical experience, derived from the records of the blood-pressure taken during a course of such baths, amply confirms this conclusion. The following are a few examples in support of this position taken from my notes.

ILLUSTRATIONS OF THE EFFECTS OF A SERIES OF AIX DOUCHES FOLLOWED BY NEEDLE BATHS OF ALTERNATING TEMPERATURE ON THE RADIAL CALIBRE, AND ON THE MEAN ARTERIAL AND VENOUS PRESSURES.*

CASE I.

	Radial Calibre. mm.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before baths - - -	1·7	155	12
After three baths - - -	2·1	145	22
After thirteen baths - -	2·3	115	28

CASE II.

Before baths - - -	1·4	120	18
After three baths - - -	1·7	105	18
After fourteen baths - -	2·0	100	28

CASE III.

Before baths - - -	0·8	152	8
After four baths - - -	1·4	135	20
After eight baths - - -	1·6	115	30

* The observations were made in the sitting posture, and at intervals during the course, apart from the immediate effects of the baths.

CASE IV.

	Radial Calibre. mm.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before baths - - -	1·5	145	25
After three baths - -	2·0	130	40
After twelve baths - -	2·2	112	45

CASE V.

Before baths - - -	0·9	145	20
After three baths - -	1·3	130	25
After twelve baths - -	1·8	97	25

CASE VI.

Before baths - - -	1·2	135	10
After five baths - - -	2·1	105	15
After fourteen baths - -	2·3	95	25

CASE VII.

Before baths - - -	1·5	135	10
After three baths - -	2·3	115	20
After ten baths - - -	2·7	95	20

CASE VIII.

Before baths - - -	1·3	135	10
After three baths - -	2·0	115	35
After eight baths - -	2·3	105	30

CASE IX.

	Radial Calibre. mm.	Mean Arterial Pressure. mm. Hg.	Venous Pressure. mm. Hg.
Before baths - - -	1·7	135	10
After three baths - -	2·1	120	18
After eleven baths - -	2·3	105	40

CASE X.

Before baths - - -	1·5	150	20
After six baths - - -	1·8	105	40

It will be observed that the effects of the baths in each course were cumulative, and that in every instance the calibre of the radial artery progressively increased *pari passu* with the fall in the mean arterial pressure; in other words that the bed of the systemic circulation was widened, and consequently the mean blood-pressure was diminished. The net gain resulting from the course of baths was, therefore, an easy normal flow of a larger volume of blood through the somatic area than was before possible through the narrowed arteries, and a corresponding diminution of the splanchnic blood—for it has been found that when the arteries are lessened in calibre, the blood excluded from the systemic area recedes to the abdomen.

Edgecombe and Bain have likewise shown, that a series of Aix douches lowers considerably the arterial pressure and raises the venous pressure (see p. 258).

Clinical observation has demonstrated that when the normal balance between the systemic and splanchnic areas of the circulation is disturbed, it is more effectually corrected by a balneological course, which combines massage and percussion with warmth, or with alternating temperatures, than by a series of warm still baths. It is true the experimental evidence demonstrates that the immediate effect of heat is to widen the systemic bed of the circulation ; but it likewise indicates that warmth alone is apt to leave the circulation sluggish and so toneless, that in the erect postures an excess of blood gravitates into the veins of the abdomen, and of the lower portions of the body, and is thus withdrawn from general circulation.

These relaxant effects are apt to rapidly accumulate during a course of warm immersion baths. The fact that such a course disposes to the development of an attack of gout is instructive in this connection ; especially when the comparative rarity of such an event in the course of warm massage and percussive bathing is borne in mind.

It would seem as if the stagnating effect of heat on the systemic periphery of the circulation is counteracted by massage, which accelerates the onflow of blood (see pp. 213 and 219), and by percussion and alternating temperature, which stimulate and tone the vaso-motor nerves.

Warm immersion baths, and especially short superheated immersion baths, as well as superheated douches, are of much service in the early stage of the balneological course of treatment of cases in which the systemic area is diminished by arterial and arteriolar constriction.

The aim of all balneological procedures should be to secure a good reaction when the patient is resting after the bath ; and the refreshing glow should be favoured as much as possible in the after management by enveloping him in a warm towel through which he should be shampooed. The more complete the reaction the better is the effect on the systemic circulation, and the more prolonged is that effect.

The clinical relation of the arterial blood-pressure to the calibre of the arteries.

Physiological variations of the calibre of the arteries generally coincide with those of the arterial blood-pressure.—It has been shown that in the normal subject the variations of the blood-pressure produce, as a rule, corresponding differences in the calibre of the arteries—the latter being passively determined by the former. The vaso-motor disturbances induced by digestion, however, afford a marked exception to this rule (see pp. 182-4).

The clinical relation between the arterial blood-pressure, when increased above the normal range, and the calibre is generally the reverse of the physiological.—In clinical observation, when the arterial blood-pressure falls within the normal limits, the calibre is, as a rule, in agreement ;

but when that pressure rises above these limits it is generally diminished. Examples of this fact have been already given (see pp. 240-42). Now and then, however, it is increased; and this fact has been observed more especially when the arterial pressure is excessively high—as in the following examples:—

	Radial Calibre. mm.	Mean Arterial Pressure. mm. Hg.
Case I.	3·0 2·5	185 145
Case II.	2·7 2·5 2 2	155 130 125
Case III.	3·2 2·8	175 145
Case IV.	2·6 2 2	175 135
Case V.	3·0 2 8	150 145
Case VI.	3·0 2·7	185 145
Case VII.	3·2 2·2	170 145
Case VIII.	2·8 2 2	155 115

In these instances it will be observed that the radial calibre was large when the blood-pressure was very high, and diminished as the pressure fell. In cases of this type the resistance caused by constriction in the arteriolar region is doubtless so great that the arterial pressure is raised to such a height as to master the tone of the arteries, which consequently become passively dilated. The best illustrations of this fact I have observed in chronic Bright's disease, and in chronic goutiness in the full-blooded.

In neurotic subjects very high arterial pressures (*e.g.*, 160 or 180 mm. Hg.) are not unfrequently met with, and in spite of such excessive blood-pressures, the radial calibre remains diminished—often greatly diminished. In such cases it would seem that the tonic muscular constriction is so great as to resist the expanding force of the high blood-pressure.

The clinical relation of increased arterial blood-pressure to the heart. Simple dilatation of the heart. The peripheral origin of heart disease.

Increased arterial blood-pressure may lead to distension of the left ventricle.—It has been observed that in certain cases the arteries become dilated when the arterial blood-pressure is so excessive as to over-power the vaso-motor tone. This dilating influence of a high blood pressure is not, however, confined to the arteries; for clinical observation has shown that it may extend to the heart itself—the left ventricle becoming distended far beyond its normal limits, while the arterial pressure remains excessive, and, either diminishing or returning even to its former dimensions, when that pressure is reduced. But how does a high arterial pressure induce dilatation of the ventricle? It is true that in health there is no evidence obtainable to show that the internal capacity of the ventricle varies with the physiological alterations continually taking place in the arterial blood-pressure. But this is not surprising, for any such response, if it does take place, will be too small for direct observation, as the normal variations in the arterial pressure are comprised within comparatively narrow limits, and are very temporary; moreover, the tone of the ventricle will doubtless suffice to meet them effectually. Experimentation on animals, however, affords an explanation of the clinical observation of the ventricle becoming distended under the stress of a persistently high arterial blood-pressure. The late Prof. Roy and Prof. Adami showed that "the ventricles normally do not become completely emptied at the end of systole. If the pressure in the aorta fall without any change in the force of the contractions of the ventricular wall, the ventricle empties itself more completely at each beat, and there is less residual blood. If, on the other hand, the aortic pressure rise, let us say from 80 to 160 mm. of Hg., the resistance offered to each contraction will be doubled. The increased aortic pressure will necessarily produce the same effect on the ventricular wall, which would result from doubling the weight on a parallel-fibred voluntary muscle, which is being stimulated to a series of maximal contractions by single induction shocks, care being taken to prevent the muscle being stretched by the weight when in a relaxed condition. In both cases the shortening in full contraction will be diminished. . . . . With *increase of aortic pressure there is, other things being equal, an increase in the amount of the residual blood.* . . . . The increase of residual blood is of course always increased, also, whenever the aortic pressure remaining constant the force of the ventricular contractions is reduced from malnutrition or other cause."* Therefore when the arterial blood-pressure is considerably raised—and moreover raised persistently—it is not improbable that the increased resistance *a fronte* may prevent a ventricle failing in tone from delivering its contents as completely into the aorta as when the blood-pressure was normal; and in such case the ordinary residuum of blood may gradually increase to unwonted proportions, which with the circulating blood will distend the chamber. Three factors, therefore, contribute to the overloading and dilatation of the ventricle, namely:—(1) a high blood-pressure ahead, (2) an increasing residuum within the ventricle, and (3) diminished expulsive power of the ventricular wall; and of these factors the first (the protracted increase of the arterial blood-pressure) is the dominant cause of the dilatation of the ventricle. Furthermore, inasmuch as the raised arterial pressure is but the result of peripheral obstruction,

* *Philosoph. Trans. of Roy. Soc. of London*, vol. 183 (1892), pp. 212 and 213.

it should be concluded that the cardiac dilatation is due primarily to that obstruction.

Simple dilatation of the heart.—A large number of observations made during the past few years on the relation between the arterial blood-pressure and the condition of the heart wall have led me to conclude that the heart, without affording any evidence of valvular disease, may become quite temporarily dilated, so long as the arterial blood-pressure remains excessive—this being the invariable clinical concomitant of the cardiac dilatation; but may quickly regain its normal condition as soon as the arterial pressure is reduced by relieving the peripheral resistance, which maintained the high pressure. The facts have, therefore, led to the conclusion, that there is a causal relation between the increased peripheral resistance and the cardiac dilatation—the latter resulting from the former through the intervention of the rise in the arterial blood-pressure. This temporary and recoverable condition is one of simple dilatation—there being no indications of organic changes either in the heart or in the blood vessels; the apparent cause being tonic constriction of the arteries and arterioles, which may disappear under treatment, when the heart may resume its former dimensions. It is much more common in women—though it is far from uncommon in men; and this fact is probably accounted for by the greater liability of women to vaso-motor disturbances, and to a lower tone and diminished resistance in their muscular tissue—so that the arteries and arterioles are disposed to constrict more and the ventricular wall to resist less than in men. It is also most frequently met with between the ages of 25 to 50; and in the neurotic and anæmic—but it is not unfrequently met with in subjects neither neurotic nor anæmic, so long as the arterial blood-pressure is raised persistently.

There is, as a rule, some dyspnœa on exertion, and especially on walking upstairs, or on rising ground; and a feeling of precordial weight and tension is common. Percussion shows the enlarged area of the heart; but I have not relied entirely on percussion for the demonstration of the dilatation, because it does not appeal to all with equal force as a convincing method of proof. It seemed to me that everyone could, however, appreciate the exact position of the maximum spot of the apex beat in relation to a fixed point (such as the nipple when not pendulous) as a more reliable and a more definite sign than any other to demonstrate the condition of the ventricle; I therefore trusted mainly to the site of the apex beat, and preferred to confine my observations to the cases in which it was well defined. The displacement of the apex to the left varied of course in different cases; but, according to my observation in this recoverable form of cardiac dilatation it may extend even so far as one inch outside the nipple line. Figure 51 illustrates a typical case. It shows the calibre of the radial artery, the mean arterial pressure and the venous pressure, and relative position of the apex beat to the nipple before and after treatment.

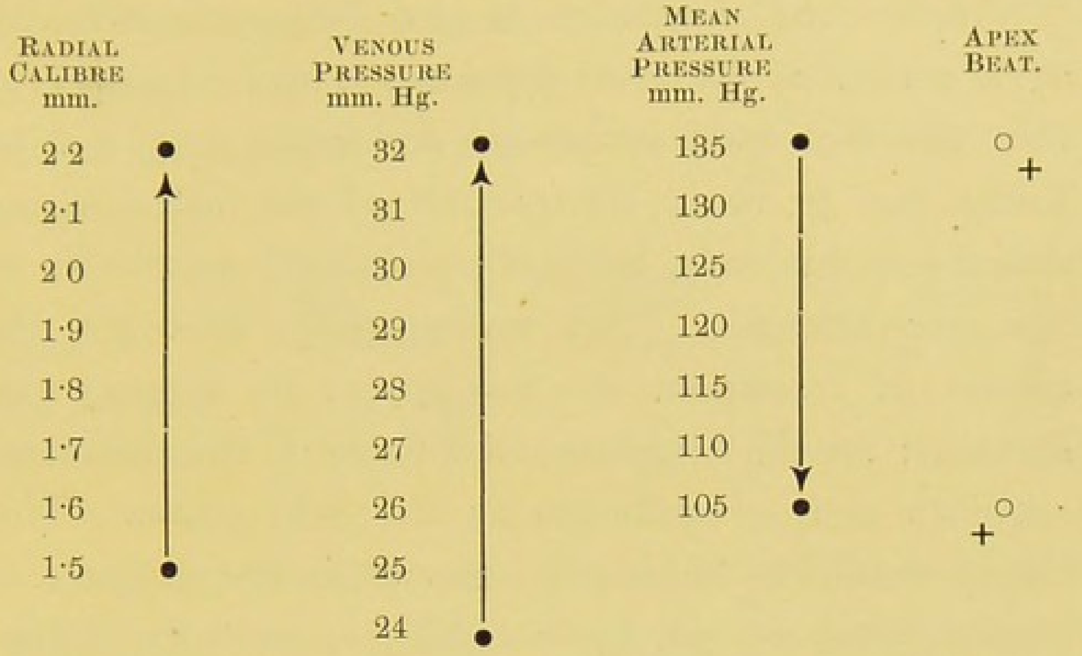


FIG. 51.—Effects of treatment in a case of simple dilatation of the heart on the radial calibre, the venous pressure, the mean arterial pressure, and on the position of the apex beat.

The reduction of the peripheral resistance is indicated by the increment of the radial calibre (from 1·5 to 2·2 mm.), and of the venous pressure (from 24 to 32 mm. Hg.), the fall of the mean arterial pressure (from 135 to 105 mm. Hg.), and the restoration of the apex beat to its normal site. The following data show the progressive stages of improvement effected in one case by a course of massage and percussive baths as expressed in the radial calibre, the arterial pressure and the position of the apex beat.

	Position of Apex Beat.	Radial Calibre.	Mean Arterial Pressure.
Before baths	○ +	.. 1·1 mm. ..	135 mm. Hg.
After four baths	○ +	.. 1·2 ,, ..	125 ,,
After nine baths	○ +	.. 1·4 ,, ..	115 ,,
After twelve baths	○ +	.. 1·6 ,, ..	105 ,,

Simple cardiac dilation is also frequently met with at a period of life (over 50) when it may be suspected that the increased peripheral resistance may not be solely due to tonic contraction of the arteries and arterioles, but may be partly or wholly ascribable to vascular changes. Not unfrequently, however, the results of treatment do not appear to support this surmise; for the complete subsidence of the dilatation suggests mere contraction as the sole cause. This happy result is frequently observed in the subjects of chronic gout (see pp. 240-2 and 256); as in the following example, æt. 54 :—

	Position of Apex Beat.	Radial Calibre.	Mean Arterial Pressure.
Before baths	○ +	1·5 mm.	145 mm. Hg.
After twelve baths.. ..	○ +	2·0 ,,	105 ,,

The baths employed in this case were Aix douches followed by needle baths of alternating temperatures.

It more generally happens in this class of case (over 50) that the cardiac dilatation is only lessened by the treatment which reduces the arterial pressure; as in the subjoined instance, æt. 64, in which Aix douches and needle baths were resorted to :—

	Position of Apex Beat.	Radial Calibre.	Mean Arterial Pressure.
Before baths	○ +	0·9 mm.	145 mm. Hg.
After three baths	○ +	1·3 ,,	130 ,,
After twelve baths ..	○ +	1·8 ,,	105 ,,

Sometimes in such cases the heart's action is intermittent or irregular, when relief to the flow through the periphery of the systemic circulation not merely lowers the arterial pressure, but causes the irregular action of the heart to cease, as in the following case, æt 56 :—

	Position of Apex Beat.	Radial Calibre.		Mean Arterial Pressure.
Before baths ...	○ Irregular +	1·3 mm.	..	140 mm. Hg.
After three baths	○ Less irregular +	2·1 ,,	..	105 ,,
After twelve baths	○ Regular +	2·2 ,,	..	95 ,,

An extremely common, if not invariable, concomitant of cardiac irregularity is increased peripheral resistance, as expressed in the mean arterial pressure being raised, and in the venous pressure being relatively or absolutely lowered.

According to my observation the most effectual means of treating cases of simple cardiac dilatation due to increased peripheral resistance is to resort to a course of warm massage baths (the massage being applied while the subject is either immersed in warm water or is douched by it) followed by alternating warm and cool needle baths, which develop a good reaction. Nauheim baths are also useful, but certainly not more so than these stimulating forms of bathing, which open up the constricted arterioles, and at the same time tone up the nervous system and the heart muscle. By the judicious employment of lower temperatures and of percussion the course should be ultimately rendered more and more tonic. Still warm immersion baths are better avoided.; or they should be resorted to only in the early stage of treatment, and then should be immediately followed by some form of percussive bathing. After the systemic periphery has been liberated by the more active treatment of warmth with massage and percussion and alternating temperature, Nauheim baths and resisted exercises prove useful; and later, tension exercise (see p. 211) or Sandow's graduated dumb-bell or elastic cord exercises, and strong tepid salt baths twice a week, and a warm equable climate (such as that of Egypt) in winter, will favour the maintenance of the improvement initiated by the course of baths. These cases also require a careful regulation of rest and exercise; and the more sensitive and nervous should be inspired with hopefulness as to the issue, for hope is a powerful relaxant of the arterioles constricted by the chronic fear which is so apt to be generated by ailments of the nervous system and the heart.

The peripheral origin of heart disease.— The foregoing facts suggest the important rôle which a narrowing of the systemic periphery may play in the production of heart disease in the later decades of life. Additional evidence of this view is likewise apparent in the high arterial pressure generally observable in cases of cardiac dilatation associated with valvular disease after 50 years of age; and in the relief of that pressure and of that dilatation afforded by the physiological modes of treatment which have of late years acquired a leading position in the remedial management of heart disease, such as Nauheim baths and resisted exercises, and those balneological procedures (massage and percussion baths of alternating temperatures) which observation has shown to be useful in widening the bed of the distal circulation, and in thus easing the work of the ventricle.

Some diseases in which the arterial blood-pressure is raised.

According to my observation the arterial pressure is, as a rule, increased in:—(1) some nervous disorders; (2) chronic goutiness; (3) renal disease; (4) heart disease of peripheral origin; (5) irritable skin affections; (6) anæmia; (7) obesity, and (8) the forms of endarteritis.

1. **Some neuroses.**—Tonic constriction of the arteries and arterioles is common in hysterical and neurasthenic subjects, in whom the radial calibre is, as a rule, reduced, the mean arterial pressure raised, and the venous pressure markedly lowered; and furthermore the left ventricle may in such cases be dilated if the increase in the arterial pressure has been persistently maintained for sometime, and the tone of the heart muscle is diminished. The evidence of the arterial and arteriolar constriction may be equally apparent in all the postures; but it frequently passes away in recumbency, so that in that posture the radial calibre increases, instead of diminishing as in normal subjects (see p. 152) and the mean arterial pressure falls while the venous pressure rises. When in such cases the recumbent posture is assumed, the arterial pressure, in spite of the widening of the arterial bed from

the subsidence of the constriction, may however, rise, but only for a time from the liberation of blood into the systemic circulation from the splanchnic veins, in which it was imprisoned by gravity in the erect postures (see pp. 265-72).

In Raynaud's disease the radial calibre is as a rule reduced, but certainly not always; it may therefore be inferred that the constriction invades primarily the terminal arteries and the arterioles, and may in some cases only extend to the large arteries. The arterial pressure is not always raised; therefore it may be concluded that in such cases the constriction is quite local.

In attacks of migraine the arteries are constricted and the arterial pressure is raised.

2. **Chronic goutiness.**—Extended observation with the arteriometer and the hæmodynamometer in those suffering from chronic goutiness has amply shown that this morbid state produces marked departures from the normal state of the circulation. The arterial blood-pressure is generally persistently raised 20, 30, or 40 mm. Hg. above the normal range. The radial calibre is as a rule diminished; but now and then it exceeds the average size—the artery being distended by a high blood-pressure, as it is in many cases of chronic Bright's disease. Another feature of the circulation in chronic goutiness is, that the radial calibre as a rule does not vary with change of posture—being the same in recumbency as in the sitting position; and generally the normal postural variations in the arterial pressure are

also absent. Sometimes, however, the calibre and the blood-pressure will rise for a short time after the patient assumes the recumbent posture—the increment being due to splanchnic blood freed from the control of gravity (see pp. 268 and 269).

The narrowing of the arteries in chronic goutiness is an interesting feature of the disease. It is not an unalterable condition however; for it is quite a common experience to observe the opening up of the diminished calibre, and the consequent lowering of the arterial blood-pressure under the influence of a course of baths. Several instances of this beneficial effect on the arterial calibre and pressure in the gouty have already been quoted (see pp. 240-2).

These facts, therefore, suggest that the diminution of the calibre of the arteries in chronic goutiness may be largely due to tonic contraction, and not entirely to organic changes in the arterial wall. If so, it is perhaps not improbable that this widespread contraction throughout the arterial system may be the *direct* effect of the presence of residuary products in the blood.

3. **Renal disease.**—According to my observation a rise—and indeed a very marked rise—in the arterial pressure is a prominent clinical feature in chronic Bright's disease, and in acute nephritis; but in functional (or cyclical) albuminuria and in the lardaceous kidney it is not generally apparent. It would therefore seem as if the increase of the arterial pressure were associated with the retention of renal products

in the blood inciting tonic constriction of the arterioles and terminal arteries. It has been shown that in chronic goutiness the tonic contraction of the arteries and arterioles may be reduced with a consequent fall in the arterial pressure by a course of warm massage baths (see pp. 240-2). Observation has likewise demonstrated, that in chronic Bright's disease the same balneological course may induce a similar dilating effect on the vessels and a corresponding reduction of the blood-pressure; as in the following cases:—

	Position of Apex Beat.	Radial Calibre.	Mean Arterial Pressure.
Before baths	O +	1·3 mm.	160 mm. Hg.
After nine baths	O +	1·6 ,,	132 ,,
After fourteen baths	O +	1·8 ,,	115 ,,

Series of Aix Douches.

Temperature 37° to 38° C. (97° to 101° F.).*

	Pulse Rate.	Arterial Pressure. mm. Hg.		Venous Pressure. mm. Hg.
		Maximum.	Mean.	
Before (sitting)	100	240	155	15
After four baths (sitting)	96	215	130	25
After twelve baths (sitting)	86	180	110	30

These facts suggest that there is a similar state of

* These observations were made by Edgecombe and Bain. *Op. cit.*

the vascular wall in chronic Bright's disease as in chronic gout, namely, tonic contraction, and a contraction presumably induced by a similar cause, namely, the presence of deleterious excretory material in the blood. But, inasmuch as the vascular system in chronic Bright's disease is less easily influenced by the balneological treatment than that in chronic gout, it may be inferred that the vessels are more involved in organic change (arterio-sclerosis) than in goutiness uncomplicated by renal disease.

My observations with the arteriometer and hæmodynamometer in these two morbid states afford some support to the acknowledged pathological kinship between them; for both reduce the calibre of the arteries and arterioles, and thus raise the arterial pressure; both abolish the postural variation of the radial calibre, and both may lead to cerebral hæmorrhage and to heart disease. Bright's disease (especially in the form of the contracting kidney) is, however, more decisive than simple goutiness in its effects on the circulation; it has, for example, afforded me some of the highest readings of the mean arterial pressure, such as 200, 210 and even 220 mm. Hg. Hence the great liability in Bright's disease to passive distension of the arterial wall (the radial calibre then being increased) and to dilatation of the left ventricle—the features of the renal disease becoming ultimately masked by those of cardiac disease; a clinical transformation, which is perhaps the best illustration that can be adduced, as to how a high peripheral resistance may at last over-master the heart muscle and disorganize the heart.

4. **Heart disease of peripheral origin.**—The presence of a high arterial pressure in cases of heart disease points to increased peripheral resistance as the cause, and as a condition that must further embarrass the action of the heart. It therefore follows, that treatment which opens up the contracted state of the systemic circulation, and consequently reduces the resistance ahead, will favour an increased output of the heart, and will enable the distended ventricle to unload itself into the arteries, and will render the work of the heart more easy and more efficient. Experience has confirmed this position in the beneficial results achieved in cardiac dilatation by the adoption of the physiological modes of treatment, represented by Nauheim baths, warm massage baths, and resisted exercises, which widen the bed of the systemic circulation.

5. **Irritable skin affections.**—In chronic eczema there is very commonly a rise in the arterial pressure, and frequently a marked contraction of the arteries. The condition of the circulation in eczema is, as a rule, identical with that found in chronic goutiness, even when the eczema is slight. This fact has sometimes afforded a suggestion as to the balneological treatment of intractable cases; for, having observed the beneficial effects of massage baths in the gouty, these baths have been prescribed in such cases, whenever the state of the skin would allow, with, as a rule,

most satisfactory results. The arterial pressure is raised in all pruriginous affections of the skin; as if the irritable state of the cutaneous nerves incites tonic constriction in the arterioles. It has been shown that cutaneous irritation raises the blood-pressure (see p. 234).

6. **Anæmia.**—In chlorosis and anæmia the mean arterial pressure is, as a rule, raised; but the rise is generally but moderate in degree. It is, however, sufficient to determine the dilatation of the ventricle as frequently observed in anæmia—the toneless state of the ventricular wall being favourable to dilatation from a comparatively slight increase in the arterial blood-pressure.

7. **Obesity.**—The mean arterial pressure is generally raised in the obese; and frequently the increase is very considerable. This fact suggests a probable pathogenic relationship between obesity and heart disease.

8. **The forms of endarteritis: atheroma; arterio-sclerosis; arteritis syphilitica.**—Atheroma may be regarded as the physiological form of thickening of the arterial wall, and arterio-sclerosis the pathological. Observation shows that, as a rule, atheroma diminishes the calibre of the arteries, and raises the arterial blood-pressure. It may diminish the radial calibre to within 1 mm.; but it does not always increase the arterial pressure. There may, for example, be extensive thickening of the arteries—radial, brachial, temporal, &c.—and yet the blood-

pressure may not exceed the normal limits. From this it may be inferred that the organic change may be limited to some of the larger arteries, and so long as the terminal arteries and arterioles are not involved, the arterial pressure may not be appreciably raised; on the other hand, cases are met with in which that pressure is considerably increased when the arteries accessible to observation are obviously atheromatous. Therefore, it would seem, that the hæmodynamometer may enable the observer to distinguish between cases in which atheroma is confined merely to some of the larger arteries, and those in which it invades also the small arteries and arterioles.

In many cases of chronic goutiness and of chronic interstitial nephritis the calibre and the blood-pressure resist entirely or partially the influence of the balneological procedures which produces a markedly beneficial effect in others; hence, it may be inferred that in such cases the arteries and arterioles are the seat of organic changes of the nature of arterio-fibrosis (arterio-capillary fibrosis).

Several cases have been met with in which, from the persistence of an unaccountably high arterial pressure and the general clinical features, there seemed to be some probability of the existence of the pre-albuminuric stage of chronic interstitial nephritis due to a general arterio-fibrosis of the small arteries and arterioles.

Syphilitic endarteritis.—Observation with the arteriometer in over 150 undoubted cases of acquired syphilis has shown that the radial calibre is commonly reduced with loss of postural variation. The reduction of calibre is sometimes very marked; especially so after the lapse of several years from the date of infection, and especially too when the disease is producing its secondary and tertiary manifestations. According to trustworthy observers, syphilis "may be regarded as one of the most frequent causes of arteritis and its effects."* My observations, however, not only confirm this conclusion, but suggest a wider one; for they point to a general arteritis as the ordinary effect of the syphilitic infection, the intima of the whole arterial tract being involved. The textural change in the arterial wall in all cases may be so slight as to elude detection by the finger; but in certain cases in the course of time it may become palpable as arterio-sclerosis and aneurism. The data contained in the following table provide some illustrations of the reducing effect of acquired syphilis on the radial calibre, and of the beneficial influence of mercury and baths in enlarging the diminished calibre.

The mean arterial pressure is, as a rule, increased in syphilis, but according to my observation it is not quite as commonly so as in chronic goutiness, and in renal disease.

* "Outlines of the Pathology and Treatment of Syphilis," by Hermann Von Zeissl, M.D., 1889, p. 274.

CASES OF SYPHILIS TREATED BY MERCURY.

Treatment	Age.	Leading Manifestation.	Infecting Chancre Years Ago.	Radial Calibre. Before Treatment.	Radial Calibre. After Treatment.	Radial Calibre. Difference.	Duration of Treatment.
Mercurial Inunctions and Sulphur Baths.	47	Syphilide	1	1·3	2·0	+ 0·7	28 daily inunctions and baths.
	30	Ulceration of Nose (Rupia)	5	1·3	1·7	+ 0·4	21 daily inunctions and baths.
	45	Incipient Locomotor Ataxy	7	1·1	2·2	+ 1·1	21 daily inunctions and baths. Then twice a week for 9 months.
	40	Obstinate Neuralgia . .	8	1·3	1·8	+ 0·5	21 daily inunctions and baths.
	46	Ulcer on Tongue . .	20	1·4	2·1	+ 0·7	31 daily inunctions and baths.
	45	Neurasthenia obscure nervous symptoms . .	23	1·2	1·9	+ 0·7	Inunctions followed by Pil. Hydrarg.
Pil. Hydrarg. gr. j. o. n.	33	Neurasthenia . . .	11	1·3	1·7	+ 0·4	11 days every night.
	42	Incipient Locomotor Ataxy	23	1·4	2·2	+ 0·8	Every night for alternate fortnights during 5 months.
	56	Vertigo	27	1·1	1·6	+ 0·5	21 days.
	42	Alopecia	27	1·3	1·7	+ 0·4	21 days.

Overloading of the splanchnic reservoir, or splanchnic stasis; splanchnic inadequacy, or vaso-motor ataxia.

The volume of blood in the splanchnic veins may be greatly increased by pathological causes.—It has been shown that in the normal state of the circulation, a certain ratio is maintained between the volume of blood present in the splanchnic area and that circulating through the systemic area—the diminution of the volume in one district of the circulation being accompanied by a corresponding increase in that of the other.* The limits of this normal interchange in the distribution of the blood between the abdominal and the somatic portions of the circulation are, however, apt to be greatly disturbed by pathological causes: the deviation met with being a

* The clinical significance of this complementary relation between the abdominal and skeletal circulations was recently insisted on by Sir Willoughby Wade, who says, "The splanchnic and somatic (or skeletal) circulations are complementary, the one to the other . . . if we repress the blood from the other parts of the body it takes refuge in the abdominal organs and vice versa. Or, if we attract it to skin and muscles, we withdraw it *pro ratâ* from the abdominal organs and vice versa. Herein, it may be said in passing, is the chief, if not the sole and adequate explanation of the benefits obtained by the Schott system. The baths attract the blood to the skin, and the resisted exercises to the muscles, and, by emptying the splanchnic circulation relieve the stasis therein." "On the Treatment of Abdominal Palpitation," by Sir Willoughby Wade, M.D., F.R.C.P., Florence. *Brit. Med. Jour.*, vol. i., 1899, p. 145.

less or more continuous surcharge of blood in the splanchnic veins. This fact is shown by the abnormal rise apparent at all times in the systemic blood-pressure produced by applying an equally distributed weight to the abdomen (see p. 135), when the mean arterial pressure may mount 20 or even 30 mm. Hg.

The causes of a surcharge of blood in the splanchnic reservoir are narrowing of the systemic arteries and diminished tone of the splanchnic arterioles.—Observation has shown that abdominal compression is apt to produce an abnormal rise in the systemic blood-pressure where the calibre of the arteries is diminished, and when the tone of the arterioles of the splanchnic circulation is lowered.

Excess of splanchnic blood from narrowing of the arteries is commonly met with in chronic goutiness and in various neuroses which induce contraction of the arterial bed of the circulation.—It has been observed that, when the arteriometer has indicated a diminution of the calibre of the arteries—whether from organic changes in the wall, or from contraction of the musculature of the arteries—evidence of loading of the splanchnic veins is apparent. From this it may be inferred that the blood excluded from the systemic circulation gradually accumulates in the spacious splanchnic reservoir.

Over-loading of the splanchnic veins, from diminution or loss of tone in the arterioles which feed them, is a common, if not an invariable, fact in all forms of debility.—The maintenance of vaso-motor tone in the splanchnic arterioles is necessitated by the assumption of the erect posture in man, in order to obviate the downward drainage of blood into the spacious splanchnic veins by the agency of gravity. The acquirement of this tone is doubtless one of the recent developments in the evolution of man, and this late acquisition is invariably the first to become impaired or lost, when the organism is exhausted or debilitated from any cause. This corrective mechanism for gravity is generally weakened by whatever reduces the vaso-motor tone—such as arduous or prolonged exercise (see p. 165), exposure to heat (see p. 227), nervous exhaustion (neurasthenia), anæmia and other forms of impoverished nutrition. This condition when persistent may be designated splanchnic inadequacy, or vaso-motor ataxia.

In splanchnic stasis the normal postural variation of the radial calibre is reversed.—The arteriometer throughout this enquiry has indicated that in all forms of diminished vaso-motor tone, the radial calibre is smaller in the erect than in the recumbent posture, and this fact has lately been observed by others (see J. Henton White, *Birmingham Medical Review*, Oct. 1900). When the recumbent posture is maintained, it has been found, however, that the rise of the calibre gradually subsides after a shorter or longer interval.

The reduction of the radial calibre in the erect position of the body may be merely pas-

sive (the artery shrinking with the diminution of pressure caused by the splanchnic drain), or it may be due to contraction of the arterial wall, which, compensating for the lowering effect of the drain on the blood-pressure, may even raise it.—The conjoint employment of the arteriometer and of the hæmodynamometer has shown, that when splanchnic stasis is physiologically produced, as by exposure to heat (see p. 228), the blood-pressure passively determines the arterial calibre—both being less in the erect than in the recumbent position. But in the pathological field this coincidence between the arterial calibre and the blood-pressure commonly fails—the calibre in the erect posture being diminished by contraction of the arterial wall, while the mean arterial pressure rises somewhat. This contraction which serves to compensate for the lowering effect of the splanchnic drain on the mean arterial pressure in the erect posture, passes away and the arteries dilate in recumbency, when, in spite of the afflux of blood no longer directed by gravity to the splanchnic veins, the mean arterial pressure, as a rule, falls; as in the following example:—

Posture.	Radial Calibre.	Mean Artérial Pressure.
Sitting - - - - - -	1·2 mm.	135 mm. Hg.
Recumbent - - - - -	2·0 ,,	125 ,,

When the splanchnic drain is large (indicated by the excessive splanchnic overflow into the systemic circulation produced by the application of a weight to the abdomen) the blood-pressure in recumbency may at first equal, or even exceed, that in the erect posture; and then will gradually subside below it.

When the arteries are contracted in the active postures, as in neurasthenic states, it may be that the splanchnic surcharge is rather the result of the systemic constriction than of the diminished tone of the splanchnic arterioles—it being in fact the overflow into the splanchnic veins of blood excluded from the somatic area of the circulation.

Splanchnic drain frequently produces a pale and quasi anæmic appearance.—According to my observation a large proportion of the subjects—and especially of the younger subjects—affording evidence of loading of the splanchnic veins, present a pallor of skin and mucous membrane suggestive of the existence of anæmia; and such cases had frequently been subjected to long courses of iron without any appreciable benefit. Moreover, examination of the blood does not, as a rule, in these cases support the theory of anæmia; for the proportions of the hæmoglobin and of the red discs fall well within the normal limits of variation. The pallid appearance is due not to an impaired quality, but to a reduced amount of the blood in the vessels—these being either contracted or imperfectly filled.

Persistent loading of the splanchnic veins favours hepatic derangement and chronic gastro-intestinal catarrh.—Observation has shown that congestion of the liver and chronic catarrh of the stomach and bowels are common accompaniments of a surcharged state of the splanchnic circulation. Frequently the liver is enlarged with a tender margin, and the urine contains an excess of bile salts.* An aggravated and persistent form of mental depression, which is frequently a prominent feature in cases of overloading of the splanchnic veins, may depend on these derangements of the abdominal viscera; at the same time, it is not improbable that this symptom may in some measure proceed from an impoverished condition of the brain tissue, resulting from the lowered state of the cerebral circulation induced by a continuous splanchnic drain.

The aim of the treatment of splanchnic stasis is to widen the bed of the skeletal arteries, to unload the splanchnic veins, and to tone the splanchnic arterioles.—The first indication is to increase the volume of blood in the systemic circulation, by the adoption of such measures as will enlarge the calibre of the arteries, without relaxing the splanchnic arterioles. If the diminished tone of the patient will admit of a resort to voluntary exercise, it should be limited in duration and degree, and that form of exercise should be selected, which maintains for the longest period the fulness of the skeletal circulation, and throws the least strain on the splanchnic

* The test, which my observation has proved to be most useful and reliable for clinically estimating bile-salts in the urine, is an acidified and clarified solution of commercial peptone described in "Bedside Urine-Testing," London, 1889.

vaso-motor system, such as cycling. Every effort should be followed by a period of absolute rest (recumbent). Systematic resort to resisted and tension exercises is always beneficial. It has been shown (p. 218) that ordinary massage limited to the skeletal muscles diminishes the area of the somatic, and increases that of the splanchnic circulation; it is, therefore, ill-adapted to the treatment of splanchnic stasis, unless perhaps when followed by abdominal kneading and compression. On the other hand, it has been demonstrated that massage, when conjoined with the percussion and the warmth and the alternating temperature of douching, incites an accession of blood to the systemic circulation (see pp. 240-2); therefore massage and percussion baths are particularly valuable in the treatment of all cases in which the splanchnic veins are surcharged.

The second indication for treatment—namely, the unloading of the splanchnic veins—is best met, according to my observation, by the application of a weight (such as a bag containing from ten to fifteen pounds of shot) to the abdomen for stated intervals during the day; *e.g.*, for half an hour after the completion of the active determination of blood to the abdominal viscera which takes place for thirty minutes following a meal. It is a beneficial rule to prescribe recumbency for an hour after each meal and the application of the bag of shot, or other similar weight, during the second half of this period. General tension exercises have been shown to widen the arteries and arterioles and to diminish the splanchnic area (see p. 212); and observation has demonstrated that when systematically resorted to they are useful in restoring the normal distribution of blood between the systemic and splanchnic regions of the circulation. Respiratory exercises also form another physiological means of reducing splanchnic stasis (see pp. 180-1). The blood lodged unduly in the splanchnic reservoir, when thus dispersed into the general circulation, should become available for improved nutrition and general well-being; and the results of observation confirm this belief.

The third indication for treatment—the toning of the splanchnic arterioles—is fulfilled by the adoption of general restorative measures and tonic medication. Abdominal massage and the percussion of the abdominal douche are useful adjuncts. Lately, observation has shown that a daily suppository, containing gr. i.-ij. dried supra-renal gland, inserted after the morning evacuation, is likewise beneficial in restoring the impaired splanchnic vaso-motor tone.*

* The remarkable vaso-tonic property of the supra-renal gland was demonstrated by Professor Schäfer and myself (see *Journal of Physiology*, London and Cambridge, 1894 and 1895). This fact has likewise been amply confirmed by the topical use of supra-renal extract; for many observers have shown that it promptly and powerfully contracts blood-vessels (as in the removal of congestion of the mucous membrane of the nose and eye) and arrests hæmorrhage (*e.g.*, from the nose, stomach, rectum). Observation has led me to regard the rectal mode of administering the gland as preferable to the oral, in splanchnic inadequacy; and perhaps this mode of introduction might be adopted with advantage also in the treatment of Addison's disease.

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