SYSTOLIC AND DIASTOLIC BLOOD PRESSURE ESTIMATION, WITH SPECIAL REFERENCE TO THE AUDITORY METHOD.*

BY

J. A. MACWILLIAM, M.D.,

PROFESSOR OF PHYSIOLOGY, UNIVERSITY OF ABERDEEN;

AND

G. SPENCER MELVIN, M.D.,

LECTURER ON EXPERIMENTAL PHYSIOLOGY, UNIVERSITY OF ABERDEEN.

(From the Physiological Laboratory.)

It is being gradually recognized that systolic pressure estimation, though valuable, gives very insufficient information regarding circulatory conditions in health and disease, and that a knowledge of the range of pressure change during the whole cardiac cycle would be of great importance in various ways.

The auditory method, employed in a certain way, offers distinct advantages in the estimation of systolic pressure, but its greatest importance lies in its relation to the estimation of diastolic pressure.

SIGNIFICANCE OF DIASTOLIC PRESSURE.

The importance of a knowledge of diastolic pressure—the constant element in blood pressure, as Marey called it, in contradistinction to the variable systolic element—need hardly be enlarged upon. It is the load which the tissues of the arterial wall have to bear continuously during the life of the individual, the transitory systolic rises that constitute the pulse being superadded. The diastolic pressure is important not only with regard to the mechanical stress upon these tissues, but probably also with regard to the influence of an excessively high diastolic pressure upon their blood supply, especially in the vessels of the lower extremity, where, in the erect posture, the diastolic pressure is greatly augmented by the influence of gravity. The problem of the maintenance of an efficient capillary circulation in the walls of an elastic tube distended by a high internal pressure is an interesting one.

Diastolic pressure in the aorta is a measure of the strain which the aortic valve-flaps have to stand, and it is obvious that tear and wear resulting from this strain must be seriously augmented by a continued excess of pressure. Sir William Osler attaches much importance to the influence of high diastolic pressure, depending on excessive muscular exertion, in the causation of aortic incompetence in what is sometimes termed "athlete's heart."

Aortic diastolic pressure constitutes the resistance to be overcome in the forcing open of the aortic valves in the early part of the systole of the left ventricle.

Diastolic pressure estimation is valuable with reference to the gauging of the peripheral resistance. *Ceteris paribus*, an increase of this resistance involves a rise of diastolic pressure and vice versa. But it is essential to bear in mind that certain other factors have to be kept clearly in view and given due weight in the interpretation of the meaning of the diastolic pressure indications. Apart from changes in peripheral resistance, the diastolic pressure may vary markedly as a result of changes in the rate of the heart beat, a quickened cardiac action tending *per se* to raise the diastolic level, as there is less time for the pressure to fall between the systolic elevations—that is, less time for blood to pass out from the arterial tube into the capillaries.

Conversely an excessively slow ventricular rhythm (for example, in heart-block, etc.) will *per se* give long intervals for the arterial pressure to fall, thus tending to lower the level of diastolic pressure considerably. This is indicated diagrammatically by the dotted lines in Fig. 1. The tendency to a lowering of the diastolic pressure in this way may of course be compensated or over-compensated by other vascular adjustments, so that a quick pulse-rate may coexist with a normal or low diastolic pressure.

The effect of such alterations in the heart's action must naturally be allowed for in appraising the significance of a change in the diastolic pressure readings.

Fig. 1.—To illustrate the effect of slowing of the heart in lowering the diastolic pressure. If the heart-rate is halved the pressure has time to fall much further between the beats, as indicated by the dotted lines.

Again, a stiffening or loss of elasticity in the arterial system influences in an important way the actual height of the diastolic pressure and its relation to the height of the systolic pressure. The left ventricle pumping blood into the normally elastic arterial system of tubes produces lower systolic and higher diastolic pressures than would be present in a system of relatively inelastic or stiffened vessels. With an absolutely rigid system of tubes there would be a high systolic pressure at each pumping act, and a fall of pressure to zero between the pumping acts. It follows that the more the human arterial system approaches the condition of a rigid, as contrasted with an elastic, system of tubes the greater will be the tendency to a lowering of the diastolic pressure—with a concomitant heightening of the systolic pressure.

From these considerations it is evident that the tendency of a heightened peripheral resistance to raise the diastolic pressure may be opposed and more or less extensively modified by a stiffening of the arteries tending to lower the diastolic pressure, so that the presence of an increased peripheral resistance may be more or less completely masked, as far as a rise in diastolic pressure is concerned.

On the other hand, it is manifest that a high diastolic reading, obtained when the arterial system is stiffened and the heart-rate is not fast, must be of very great significance as an indication of increased peripheral resistance.

A change of 15 or 20 mm. in the diastolic pressure estimated under similar conditions (rest, posture, etc.) and unattended by any such alteration in the heart-rate as might in large measure account for the diastolic change, possesses a significance with regard to the behaviour of the peripheral resistance vastly greater than could be attached to a similar alteration in the reading of systolic pressure.

SIGNIFICANCE OF THE PULSE PRESSURE.

Many of the published estimates of the pulse pressure or range between the systolic and the diastolic level are no doubt vitiated by the erroneous values ascribed in a proportion of cases to the systolic pressure by taking the first readings of obliteration pressure, thus giving in certain instances a serious exaggeration of the actual systolic pressure. On the other hand, by the use of the maximum oscillation and some other methods too high estimates of diastolic pressure have often been made, while the taking of the lower limit of the sound in the auditory method as the diastolic index, as is a common practice at present, inevitably results in many instances in a wholly erroneous underestimate of the diastolic pressure.

It need hardly be said that most important information as to the state of the circulation, beyond what can be deduced from an estimation of the systolic or diastolic pressures singly, is to be obtained from a knowledge of the relation between these two—the pulse pressure. Obviously it is not merely the pressure of blood that is important, but also the velocity of the flow, determining the amount of blood which the organs receive per unit of time.

Assuming the competence of the aortic valves, it may be stated broadly that with the heart at a normal or moderate rate a defective range of pressure variation at systole and diastole—that is, a diminished pulse pressure—indicates a slowed flow of blood from the arteries into the capillaries. Thus there may be a good systolic pressure together with a lessened blood flow; this is indicated by

* Read at the Medico-Chirurgical Society of Aberdeen on December 4th, 1913.

the failure of the pressure to fall to the usual extent between the beats, the rate of the heart being of course kept in view as a factor. The converse of this rule only holds good within certain limits.

The formula that pulse pressure $\times$ pulse-rate is proportionate to the cardiac output and the velocity of the blood flow is not applicable in certain conditions (circulatory shock, etc.). Thus, in some pathological conditions there may be an extensive pulse pressure with a very defective mass movement of the blood.

The condition of aortic regurgitation, in which blood escapes from the arterial tube backwards as well as forwards, is, of course, a very special case that stands by itself.

Various observations have been made on the meaning and influence of alterations in pulse pressure.

In cases of haemorrhage it has been found by Wiggers that a progressively diminishing pulse pressure is suggestive of a continuance of the haemorrhage.

It has, of course, been long known that pulsation in the blood stream supplied to perfused organs has a very important beneficial influence upon the condition of the tissues and on the rate of perfusion.

Some ten years ago Erlanger and Hooker studied the relation of pulse pressure to renal activity; later the subject was pursued by Hooker and recently by Gesell. These investigations have produced important evidence; they concur in the finding that, as a rule, the amount of urine varies directly with the magnitude of the pulse pressure, also of the amount of urea, chlorides, etc., while in albuminuria the amount of albumin varies inversely as the magnitude of the pulse pressure. Gesell also suggests that the increased pulse pressure produced by digitalis and strophanthus may *per se* largely account for the diuresis caused by these drugs.

THE AUDITORY METHOD.

The auditory method, first suggested by Korotkoff of St. Petersburg in 1905, has so far been applied only on a very limited scale. In this country it has been recommended by Dr. George Oliver. It has been felt that there is no adequate basis of definite evidence as to the interpretation of the phenomena, at least in relation to diastolic pressure.

A prolonged investigation which we have carried out in recent years on both the experimental and clinical sides has yielded very definite results which enable us to predict for this method, applied and interpreted on lines that we have found to be reliable, a wide sphere of usefulness. From an exhaustive comparison with other methods we find that the auditory method can be made, with simple appliances and in very little time, to yield results that are unequalled, as regards range of information, precision, and reliability, by those derived from other methods, even when the latter involve time-consuming and relatively laborious procedures with more elaborate and cumbersome forms of apparatus.

The Apparatus Used.

After an extended trial of various apparatus, we use for routine examination an ordinary armlet (12 cm. broad) applied to the upper arm (not the forearm) and inflated by an ordinary ball filler, a mercury manometer (for example, Martin's form) to measure the armlet pressure, and an auditory tambour or phonendoscope (for example, Oliver's*) to auscultate the artery. This very sensitive tambour, strapped on the arm on the distal side of the armlet, has the great advantage, as compared with an ordinary binaural stethoscope or an ordinary phonendoscope, of leaving the hands of the observer free—an essential point in the application of the method as we employ it.† The tambour must be placed over the artery at the bend of the elbow close to the distal side of the armlet, and must be kept applied to the skin without exerting any appreciable pressure. It has, of course, long been a familiar fact that strong pressure applied to an artery by the end of a stethoscope causes production of sound in the vessel, the sound produced being commonly described as a murmur. Oliver remarks that it really has the character of a throb. We find that in the femoral a loud murmur is

usually produced; in an artery like the radial a sharp throb or thud; in the brachial a thud, tolerably pure or with a murmurish quality. Very considerable pressure with the tambour is needed to elicit sounds in this way. With any reasonable care in the application of the tambour there is no danger of fallacy from this cause in the use of the auditory method.

We have often used the Oliver screw compressor for inflating; it is very convenient for graduating the armlet pressure accurately by running it up and down a little near the critical point where the systolic or diastolic index is being obtained, the screw being easily turned a little forwards or backwards by one hand. The screw compressor is most conveniently used with an armlet bag of sufficiently small capacity to suit the capacity of the compressor, as is the case with the Oliver armlet, the bag going only part of the way round the limb. With a bag of larger capacity (like that of the ordinary armlet) embracing the limb completely, more than one fill of the compressor is needed, the tube to the armlet being pinched while the compressor is refilled; or, if so desired, a combination of ball filler and screw compressor may be used for rapid inflation and easy and accurate graduation of the pressure.‡ While the Oliver armlet gives good results upon the upper arm—care being taken that the bag is applied on the inner side over the brachial artery—we do not recommend it for application to the leg; we have found that the tactile indications obtained from the posterior tibial and dorsalis pedis arteries may sometimes be influenced by the position of the bag on the outer or inner sides of the leg. The presence of two bones with more than one large artery may evidently involve danger of fallacy when a compressing bag is used which goes only partially round the limb.

Where compactness and lightness are specially desired in the apparatus, the Oliver mercurial compressed air manometer is a convenient substitute for the ordinary mercury manometer; in a recent form the tube and scale are inclined at an angle suitable for easy reading. (The instrument should first be tested with a mercury manometer to make sure that the readings indicated on its scale are actually correct.) In its most compact and portable form the auditory apparatus may thus consist of armlet, ball filler, mercurial compressed air manometer, and auditory tambour; when the degree of compactness is not so essential, a mercury manometer (for example, Martin's) is to be preferred for measuring the armlet pressure.

APPLICATION OF THE AUDITORY METHOD.

In making an estimation (see Fig. 2), the armlet pressure is first raised well above systolic pressure, as indicated by

Fig. 2.

the disappearance of the pulse, tested by the ordinary tactile method. When this is done, no sound is heard over the brachial artery at the elbow. The armlet pressure is then gradually lowered, and as soon as this pressure fails to keep the artery obliterated and blood begins to force its way beneath the armlet at each heart beat, a sound is heard in the form of a distinct thud. The beginning of this sound serves as the index of systolic

* Supplied by Hawksley, 357, Oxford Street, London, W.

† We somewhat prefer the tambour attached to a separate band to the more recent form where it is held in position by a strap connected to the armlet.

‡ We have sometimes used, in conjunction with a ball filler alone, compression of the armlet by hand to vary the pressure up and down near the critical point.

pressure, affording a very sharp and precise indication. With a finger on the artery it is recognized that the beginning of this sound comes at least as early as the reappearance of the pulse tested by the tactile method; indeed, the former is usually a few millimetres above the latter—for example, 5 to 10 mm. The commencement of the sound is in no case below the tactile indication when the auditory method is working properly. The armlet pressure being gradually lowered, the sound becomes louder and may develop a murmurish quality, as Oliver describes it. At a lower level it diminishes in intensity, at one point rather suddenly becoming weaker, and at the same time changing in character from a clear to a duller sound. This change in intensity and character may (1) be very speedily followed by extinction of the sound, or may (2) on the other hand, be followed by persistence of the sound through a very considerable range of further lowering of the armlet pressure (for example, 20 to 30 mm., etc.). The weakening and dulling of the sound we regard as the index of diastolic pressure, for reasons to be stated later, in opposition to the view that extinction of the sound constitutes the diastolic index. The lower limit of the sound is an indication which seems to be at present very widely adopted as the basis of interpretation of diastolic readings and used in the calculation of pulse pressures, etc. Quiet surroundings are, of course, necessary for the precise recognition of sound persisting below the diastolic index. It is in young adults that marked persistence has, in our experience, been most frequently observed; in older persons, and in most cases examined in the wards of a general hospital, extinction of the sound has very speedily followed the occurrence of the change which constitutes the diastolic index.

The normal relation of the auditory and tactile systolic indices is of great importance; we wish to lay stress upon the concurrent estimation and comparison of these two indices as an essential part of the routine application of the auditory method of estimating systolic and diastolic blood pressures. The auditory reading should always be *at least as high* as the tactile reading; very often it is somewhat higher—a few millimetres, up to 10 mm., etc. An auditory reading lower in value than the tactile one at once impugns the accuracy of the auditory results, and shows that the conditions are such as to make the auditory indications, both systolic and diastolic, erroneous. Such conditions may be constituted by improper application of the auditory tambour over the artery, anatomical variation of the latter, etc., and may be remediable. If attention to the adjustment of the apparatus does not raise the auditory index to or above the level of the tactile index, the auditory method is to be regarded as inapplicable; we have rarely met with such a case. Abnormal lowering of the auditory as compared with the tactile index means that the former is erroneous, and there is no good ground for assuming that the alteration of the sound at a lower level of armlet pressure which constitutes the diastolic index should in these circumstances afford any valid evidence as to the height of the diastolic pressure.

By the use of the auditory method it is easy to estimate, with an accuracy not otherwise attainable, the influence of various agencies on the blood pressure—the slight variations associated with the normal respiratory movements, as well as slower periodic variations; the changes occurring in Müller's and Valsalva's experiments; the effects of voluntary muscular contraction in other limbs, the muscles of the limb embraced by the armlet being, of course, kept relaxed, etc.

Estimation of Systolic Pressure.

As far as systolic pressure is concerned, the chief advantage of the auditory method is that the sense of hearing is substituted for the somewhat more fallible tactile sense. The auditory index shows more precisely when the systolic jet of blood begins to arrive on the distal side of the armlet, being more accurate than the finger in detecting such beginning, and serving as a sharper indication of the point where the intra-arterial systolic pressure begins to overpass the external or armlet pressure. The use of the auditory method in this connexion is open to certain possibilities of fallacy that may affect the obliteration method used by the tactile plan—for example, the state of the arterial wall, regarding which investigations have been carried out by many workers in this country, by

Russell, Oliver, Herringham, Hill and his collaborators, and by ourselves; in America by Janeway and Park, etc. In a former investigation we reached the conclusion that the condition of the arterial wall plays no important part in the vast majority of blood pressure estimations, either in the healthy state or in diseased conditions, but that in a certain number of cases with resistant brachial arteries, exaggerated readings of systolic pressure may be obtained. In these cases the method of continued local compression, as already described, is found to be very valuable in minimizing the chance of error. We close the brachial artery by digital pressure (two fingers) about the middle of the arm for from two to three minutes, and then at once reapply the armlet and take another systolic reading. Resistance of the arterial wall, if present, is thus almost completely set aside, and a corrected reading of systolic blood pressure is obtained. When the artery feels resistant to palpation (it may be noted in passing that the condition of the radial artery is no sure guide to the condition of the brachial, the latter being very frequently in a worse state) we first make an obliteration reading in the usual way, then slip down the armlet sufficiently to enable digital pressure to be applied as above stated; the armlet is then put in position again and the second reading taken. In this way it is commonly possible to equalize readings which at first gave widely differing values in different arteries, the high readings from a resistant artery being reduced to the level found in a non-resistant one, but not below that level; further compression induces no further reduction. This method does not equalize the arm-leg readings in cases of aortic regurgitation.

Estimation of Diastolic Pressure.

Comparatively little attention is given at present to diastolic pressure, a fact that is not surprising in view of the very general conviction that no practicable and reliable method of estimating it is available. Some years ago Professor C. J. Martin expressed an emphatic opinion that the systolic pressure is the only one that can be estimated with any accuracy—a conclusion affirmed also by many other observers, and widely accepted at the present time.

In the study of diastolic pressure the methods that have been most frequently used are those based on the principle of maximum oscillation or pulsation—Marey's principle, namely, that when the intra-arterial pressure is counterbalanced by an equal extra-arterial pressure the artery will pulsate most largely, showing maximum volume oscillations at the pulse-beats. The application of this principle has been studied by Mosso, Roy and Adami, Hill and Barnard, Recklinghausen, Howell and Brush, Erlanger, Martin, and others. For a statement of the conflicting views that have been held as to the relation of the oscillation to the internal pressure—whether diastolic or mean pressure, etc.—we must refer to our paper in *Heart*, 1914, v, 153.

In the same paper we comment on some other methods (Strassburger, Masing, Sahli, and others), worked on a different plan, and depending on the recognition (by finger or sphygmograph), not of volume changes in the length of artery compressed by the armlet, but on changes in the artery distally to the armlet.

The Diastolic Index by the Auditory Method.

A circulatory schema was arranged so that the actual systolic and diastolic pressures within an excised surviving artery were measured by maximum and minimum manometers, graphic records of pulsation or volume oscillation being obtained and the concomitant auditory phenomena being examined while the artery, enclosed in a tube or miniature "armlet," was subjected to various degrees of compression.

We have correlated the results obtained from this experimental schema under precise conditions with those yielded by an extended series of observations made in normal and pathological conditions in man by one of us (G. S. M.) in conjunction with Mr. J. R. Murray, M.B., in which three methods were employed concurrently: (1) the auditory, (2) the ordinary tactile, and (3) the graphic method by the use of the Erlanger apparatus. (An account of this investigation will be published elsewhere.) We have also used the Pachon sphygmometer and found it to be by far the best of the forms of apparatus (yielding

visual indications) which we have employed. By an ingenious arrangement the aneroid capsule has an equality of pressures maintained on its outer and inner surfaces, and the middle movement indicating the range of oscillation is a very sensitive one. Of course, the spring manometer which shows the armlet pressure needs, as all such instruments do, to be checked by a mercury manometer from time to time. We frequently use the sphygmoscillometer in conjunction with an ordinary armlet applied to the arm, in preference to the narrower armlet applied round the wrist by Pachon. Unfortunately in some cases, as with the Erlanger apparatus, it is difficult to recognize a definite point of sudden and marked declension in the oscillation magnitude. But in many cases, where such declension was marked, the Pachon diastolic index represented by the level of armlet pressure immediately after the declension corresponded with remarkable exactness with the weakening and dulling of the sound which constitutes the auditory index; the oscillations of the needle and alteration in the sound varied together very strikingly. By using the data derived from these various sources we have been enabled to arrive at very definite conclusions as to the validity and the true interpretation of the results yielded by the auditory method.

We have stated as our index of diastolic pressure the weakening and dulling of the sound which occurs at a certain level in the process of lowering of the armlet pressure, in opposition to the widely accepted view that the extinction of the sound is to be taken as the diastolic index.

We find that the weakening and dulling coincides with the point at which the arterial tube just ceases to be flattened by the external pressure between the pulse beats. We ascertained, with the help of the experimental schema, that at this point the sound declines very markedly, the sharper sound evidently being produced by the sudden opening up by the systolic wave of the tube, which had been in some degree flattened by external pressure in the interval between the pulse beats; vibration associated with the sudden change in the shape of the tube is evidently responsible for the character of the sound. We have also had recourse to animal experiment for the verification of the auditory index.*

In Fig. 3 A the outer circle (dotted line) represents the

Fig. 3.

size of the artery when distended by diastolic pressure—that is, in what we term the diastolic position. (The further expansion normally occurring with each systolic wave is relatively slight, and is not indicated here.) The inner circle (broken line) represents the undistended vessel, empty, or filled with blood at zero pressure—what we call the zero position, the position assumed by the arterial tube (between the pulse-beats) when the internal diastolic pressure is counterbalanced by an equivalent amount of external (or armlet) pressure.

With a further addition (an excess) of external pressure the vessel ceases to undergo diminution in the circular form, but becomes more or less markedly flattened. By the term “half flattening” we mean a condition where the distortion has reached such a point that the shorter diameter of the flattened tube is approximately one half of the diameter of the undistended circular vessel in the zero position. (See Fig. 3 A, unbroken line.) In a normally elastic artery such an increase of external pressure as induces half flattening between the beats elicits maximum oscillation of the arterial volume at each pulse-beat, accompanied by a very loud sound, often murmurish in character. In a relatively inelastic artery a greater increase of external pressure, inducing a degree of flattening greater than half flattening, is needed to elicit the maximum oscillation.

The persistence of the sound below the level of diastolic pressure—below the point where the external pressure is sufficient to cause some distortion of the tube from the circular form between the beats—is obviously due to sound production under conditions that differ in respect of the fact that the arterial tube retains its circular form all the time, there being no flattening between the beats. The length of artery embraced by the armlet is constricted (not flattened) by the external pressure. The influence of the external pressure is to counterbalance an equivalent amount of internal pressure, and produce an effect such as would result from a similar reduction of the internal pressure in the length of artery in question—that is, the length of artery embraced by the armlet would be less distended by internal diastolic pressure than the parts proximal to and distal to the armlet, as indicated in Fig. 3 B. At each systole there is a sudden expansion of the constricted tube, a much more extensive movement than the very slight systolic expansion of the unconstricted portions of the artery not embraced by the armlet. Possibly the chief seats of sound production are in the regions where the constricted and unconstricted portions become continuous.

In aortic regurgitation where the artery is suddenly expanded by the very large systolic wave sound commonly persists to very low levels and often to zero armlet pressure, being easily audible without the application of any external pressure at all.

Normal Diastolic Pressure and Pulse Pressure.

In the arms of a series of healthy young adults (examined in the sitting position) the average diastolic pressure was found to be about 65 mm. (with a range from 50 to 80 mm.) by the auditory method; this average differed little from that obtained from Erlanger tracings as interpreted by an index (not the same as Erlanger's) which we have adopted on experimental evidence. These values are much lower than those commonly stated for diastolic pressure.

In pathological subjects, on the other hand, there is much divergence between the auditory and the Erlanger results; we accept the former as more reliable, on evidence derived from various sources.

The average pulse pressure in the series of normal adults above referred to was about 46 mm.

Recognition of Differences in Diastolic Pressure induced by Gravity.

We have often been able to estimate in similar fashion the diastolic pressure in the lower extremity, the armlet being placed upon the leg and the auditory tambour over the posterior tibial artery. The same procedure is followed in first comparing the auditory and tactile systolic indices and then ascertaining the auditory diastolic indication in the usual way. The diastolic reading, like the systolic, naturally varies according as the person is in the recumbent or in the erect position, or in the resting state. In the former case, in healthy individuals, with arm and leg at the same level, the diastolic index, like the systolic, is got at corresponding levels; the change in the sound over the posterior tibial artery is, as a rule, perfectly definite. In the standing or sitting positions, on the other hand, the diastolic pressure reading necessarily exceeds to a large extent that obtained from the arm, as also does the systolic reading.† Thus, in the sitting position, such diastolic readings as these were obtained—arm 75 mm., leg 125 mm. The vertical difference between the level of the two armlets was found to be 69 cm.; the leg pressure was necessarily augmented by the weight of a column of blood 69 cm. long. As this corresponds to a pressure 52 mm. Hg, it accounts for the difference in the arm-leg readings as compared with the equality (75 mm.) found in arm and leg in the recumbent position. These results are confirmatory of the accuracy of the auditory method for both systolic and diastolic pressures with considerable differences in the conditions present, with blood pressures at very different levels, etc. Correspondence of *tactile systolic* readings in arm and leg, hydrostatic difference being allowed for, was found some time ago by Hill and Flack, and verified in our own observations.

† The systolic auditory reading was 115 in the arm and 165 in the leg; the pressure difference between the systolic and diastolic levels (pulse pressure) was thus equal (40 mm.) in arm and leg.

* An account of these results will be published elsewhere.

Von Recklinghausen had postulated such correspondence. Similarly when the subject is lying down (in the horizontal position, or with the head lowered), and one leg is flexed at right angles to the trunk, the diastolic reading got from the lower part of the leg shows a reduction in accordance with the hydrostatic difference.

The influence of the altered conditions induced by local warming and cooling was also tested. Estimations were made before and after a limb had been kept immersed for some time in hot or cold water; the readings were compared with those made simultaneously on another limb. Sometimes one limb was warmed and another cooled, and a comparison made between the two. No appreciable difference was found in the readings under these different conditions.

We have also compared the auditory indications with those yielded by the oscillation method in (1) arm and leg at the same level, (2) arm and leg at different levels, and (3) leg at different levels, with results similar to those obtained in the arm.

The Auditory Method in Cases of Aortic Regurgitation.

The frequent presence in this disease of the well-known sounds (systolic thud or double murmur) audible without the application of any armlet pressure introduces new conditions. But the presence of such sound does not, as a rule, interfere with the recognition of the diastolic index, the sudden weakening and dulling being usually very well marked.

Comparison of Tactile and Auditory Systolic Indices as Means of Avoiding Certain Fallacies.

This comparison is essential in connexion with the estimation of both systolic and diastolic pressures. In regard to the former cases of difficulty occur, though rarely. An armlet pressure (for example, 300 mm.) very much above what is needed to obliterate the pulse, as tested by the tactile method (for example, 183 mm.), may fail to abolish the sound in the usual way, the sound being conducted past the obliterated area of artery, probably along the bone. Obviously the usual systolic index afforded by the upper limit of the sound is not applicable in such cases. While the armlet pressure is being lowered from a level far above the tactile systolic level a sudden increase in the intensity of the sound with the usual relation to the tactile index may occur and constitute, in all probability, the true systolic index in these instances. Such conditions have been noticed by one of us (G. S. M.), in conjunction with Mr. J. R. Murray, in a case of aortic regurgitation, and in one healthy student, a good athlete, in whom the sound at the elbow was found to persist at levels of armlet pressure far above what was necessary to obliterate the brachial artery as evidenced by the tactile method.

The estimation of diastolic pressure is not interfered with in such cases, the usual index being easily recognizable.

The comparison in question at once reveals inefficient working of the auditory method, due to an incorrect situation of the auditory tambour, stasis of blood in the limb from excessively and quite unnecessarily prolonged compression,* or the existence of an artery of insufficient size; both systolic and diastolic auditory indications may be vitiated by such conditions, though cases of unavoidable difficulty seem to be very rare. Danger of erroneous interpretation is readily obviated in the way stated. The applicability of the auditory method to the forearm has to be determined in this way; in some instances it fails, in others it gives quite satisfactory results.

The same test is essential in applying the method to the small arms of children; down to the age of 8 years we have obtained surprisingly good results in these.

Advantages of the Auditory Method.

The simplicity, ease, and rapidity of this method are strong points in its favour. It gives all the information that is to be obtained by more cumbersome and time-consuming methods, and that with greater precision, the index being a much sharper one than is present in other

methods; it also causes less disturbance to the patient than slower methods, which involve a longer compression with the armlet. In the cases where the Erlanger or the Pachon apparatus give dubious or unreadable indications, the auditory method has always in our experience given a definite verdict. It is greatly superior to the palpatory and sphygmographic methods that have been proposed. We are satisfied that all the evidence as to diastolic pressure gained by the other methods, and much more also, can be better obtained by the quick and simple auditory method. The diastolic estimation in this way is as easy as that of systolic pressure, and is relatively little, if at all, complicated by certain sources of fallacy (for example, state of arterial wall) which may come into question in systolic estimation.

This method, measuring the diastolic as well as the systolic pressure, has the great advantage, as compared with the ordinary tactile method, of giving the numerical range of pressure variation in the artery during the whole cycle of the pulse beat, that is, the pulse pressure range.

BIBLIOGRAPHY.

Erlanger and Hooker, *Johns Hopkins Hosp. Reports*, 1904, xii, 346. Gesell, *Amer. Journ. Physiol.*, 1913, xxxii, 70. Hooker, *Arch. of Intern. Medicine*, 1910, v, 491. Osler, *Principles and Practice of Medicine*, London, 1909, 797. Further references are to be found in *Heart*, 1913-14, iv, 317 and 408, and v, 153.

SYSTOLIC AND DIASTOLIC BLOOD PRESSURES IN AORTIC REGURGITATION.

BY

J. R. MURRAY, M.B.,

ASSISTANT IN PHYSIOLOGY IN THE UNIVERSITY OF ABERDEEN.

(From the Physiological Laboratory.)

THE arm-leg differences in the obliteration readings of systolic blood pressure observable in cases of aortic regurgitation when one armlet is applied to the upper arm and another to the calf of the leg are now very well known. Such discrepancy was first described by Hill, Flack and Holtzman,³ and later by Hare,² Hill and Rowlands,⁴ Rolleston,⁵ and others, the tactile method being employed to detect the disappearance and reappearance of the pulse. In view of the remarkable differences observed, sometimes amounting to as much as 100, 150 mm. Hg, or more, the question naturally arises as to what is the "blood-pressure,"* and whether the arm or leg reading is the better indication of the aortic systolic pressure. The conditions are strikingly in contrast with those obtaining in the normal subject, the systolic arm-leg readings in the latter, tested in the same way (in the recumbent position with arm and leg at the same level), being equal. It may be recalled that in presumably normal animals under experimental conditions Hürthle, using his spring manometer, recorded higher systolic pressures in the femoral than in the carotid artery and this was confirmed by Dawson working with valved manometers. But no evidence has been advanced to show the existence of such conditions in the normal human subject.

Nearly a year ago, when studying blood pressures in aortic cases, I observed some further differences of other kinds, and have repeated these observations many times, in 20 cases of aortic regurgitation. These differences affect both systolic and diastolic pressures in the different segments of the upper and lower limbs—quite a different matter from the arm-leg discrepancy in the tactile *systolic* readings from the upper arm and calf of the leg, above referred to.

METHODS.

In the present inquiry the systolic estimations were made by the auditory and tactile methods used in combination as already described by MacWilliam and Melvin⁷; the diastolic readings were obtained by the auditory method, using the sudden dulling and weakening of the sound as the diastolic index, after the application of the auditory method had been verified by comparing the auditory and tactile indices and finding the former to be at least as high as, or rather higher than, the latter. The

* The accuracy of the auditory indications may be seriously impaired from this cause if the compression be unduly prolonged.

⁵ Rolleston noted a difference of 210 mm. in one case and 195 mm. in another.