Remarks

ON

THE DETERMINATION OF ARTERIAL BLOOD PRESSURE IN CLINICAL PRACTICE.

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THE importance of determining arterial blood pressure for the clinician need hardly be emphasized, for such knowledge is essential to the interpretation of circulatory conditions in health and disease. Indeed, I imagine such information to be in many cases as important as any obtained by listening to the sounds of the heart or feeling the pulse. I conclude that the reason why blood-pressure determinations are not more generally made by English physicians is entirely owing to the fact that they have found the apparatus available unhandy or unreliable.

I am aware that many physicians have been, and perhaps still are, of opinion that they are capable of gauging arterial pressure with sufficient accuracy by means of their fingers. With the acquisition of technical skill it is possible to do much by this means, but the method is only qualitative and liable to considerable fallacy. In estimating by the finger the force necessary to compress an artery one relies upon muscular sense. A perfectly educated muscular sense would give one a good indication of the force applied—but only of the force applied, and not necessarily of the pressure in the artery, for the force necessary to compress an artery under such circumstances varies not only with the pressure distending it but also with the area compressed—that is, with the size of the vessel.

Fig 1.

One easily compresses with the fingers the small carotid artery of a rabbit, but that of a large dog requires a much greater expenditure of force; nevertheless the pressure in the former may be, and often is, greater than in the latter.

METHODS WHICH HAVE BEEN EMPLOYED FOR PRESSURE DETERMINATIONS.

These all depend on balancing the pressure on the inside of the vessel by an external pressure and interpreting the former in terms of the latter.

As the pressure inside an artery is periodically varying by some 30 to 50 mm. of mercury it is necessary to decide at which stage in the variation one is to attempt to determine it; whether at the moment of systole or at what period during diastole.

The simplest and easiest point to ascertain is the systolic

pressure, and this is, I believe, the only determination which can be made with accuracy without opening the vessel; and for practical purposes I think the observation of the maximum systolic pressure is of as much value to the physician as that at any other period of the cardiac cycle.

A prime consideration in any method of determining internal pressures in a tube by balancing them by an external pressure is the part played by the wall of the tube itself.

Fig 2.

If the wall possesses any considerable amount of elasticity or resistance to being collapsed or expanded, this will obviously have to be added to or deducted from the external pressure. For instance, an attempt to estimate the pressure in a piece of rubber tubing by measuring the external pressure required to be applied around it in order to obliterate all flow, would lead to considerable error, for in this case a pressure greatly in excess of the internal must be applied externally, owing to the resistance which even a thin rubber tube exercises against complete collapse at the corners.

Fig 3.

An artery, however, is a very special kind of tube, and von Basch¹ found that until it is stretched beyond the limits of pressure which it may be subjected to under physiological conditions it offers a quite negligible resistance to either collapsing or expanding, namely, $\frac{1}{2}$ to 2 mm. for a healthy and 5 mm. for an artery from a case of arterio-sclerosis.

This very striking fact can be easily demonstrated by a simple experiment illustrated in Fig. 1.

A is a piece of glass tube about $\frac{1}{4}$ in. in diameter, into the ends of which two rubber corks are inserted. The corks are pierced by two glass tubes, on to the ends of which the piece of artery is secured. One of the glass tubes is a T-piece communicating with the reservoir R containing water at some feet above the level of A, and also with a mercury manometer, M. When the pinch-cock, P, is opened, a small stream passes through the artery, and the manometer M records the internal pressure. The glass tube at the outlet is drawn to a fine point so as to offer considerable resistance. A is filled with water and is in connexion with manometer M' and reservoir R'. The latter can be elevated at will by a pulley and winch.

To measure the elastic resistance opposed by the walls of the artery when collapsed by a pressure from outside, P is opened and water flows through the apparatus: R' is now raised until the flow just ceases.

The difference in height between the mercury columns in the two manometers registers the pressure required to collapse the arterial walls.

With a normal artery—for example, carotid of man, horse, or large dog—this pressure was in my experiments only 2 mm. of mercury, and in an advanced case of arterio-sclerosis it was 7 mm.

One may therefore conclude that a determination of the external pressure necessary to obliterate an artery is a valid indication of the internal pressure in health within 2 mm., and that in extreme cases of sclerosis about 7 mm. must be deducted from the observed external pressure.

A considerable number of pieces of apparatus have been introduced from time to time with the object of estimating blood pressure in man, by raising the pressure on the outside of an artery until it equals that inside and at the same time measuring the pressure exerted.

These fall into two distinct groups:

(a) In which the pressure is applied only over a superficial artery and its immediate surroundings: Vierordt,² von Basch,³ Hill and Barnard⁴ (small instrument), Oliver.⁵

Fig. 4.

(b) In which the pressure is applied by a bag completely surrounding the limb or finger, or enclosing fingers, or the whole hand and fore-arm (plethysmograph): Riva Rocci,⁶ Hill and Barnard⁷ (large instrument), Gärtner,⁸ Mosso,⁹ Marey.¹⁰

I have used nearly all these various forms of apparatus, and I will now state my experience of the various methods.

A. The type in which a superficial artery is compressed by a small rubber bag over it is exemplified by Hill and Barnard's pocket sphygmomanometer and Oliver's haemodynamometer, as well as by the older instrument of von Basch.

In using the instruments of Hill and Barnard and Oliver one is recommended to take the pressure at which the maximum oscillation occurs, and to regard this as representing the mean pressure in the vessel. Von Basch's instrument is used to compress the artery, and the pressure in the bag at which pulsation in the parts beyond disappears is regarded as the criterion of the blood pressure.

These small instruments I have not found very reliable, and they nearly always indicate pressures considerably in excess of those shown by the second type mentioned above. The inflation of a bag encircling the arm until the pulse beyond vanishes cannot mislead one in the direction of too low a reading, so that the fault must rest with the smaller instruments, which are pressed down upon a superficial artery.

To ascertain the reason why this form of manometer generally records too high a pressure I dissected out a good length of the carotid artery in dogs, and connected the

Fig. 5.

Fig. 6.

external carotid to a mercury manometer registering the pressure. The long piece of common carotid was laid upon a solid block of smooth wood, and the sphygmomanometer or haemodynamometer pressed down upon it until:

- (a) The maximum oscillations occurred, and
- (b) The pulse vanished from the manometer record.

Used in this way both instruments recorded pressures upon condition (a) at or about the mean pressure shown by the mercury manometer, and under condition (b) at or about the systolic pressures, and were always consistent. Therefore, used under these circumstances I have nothing to find fault with in them, assuming that the point of maximum oscillation can be taken as a good indication of blood pressure. The nearest approach to these ideal conditions is when the instrument is applied over the temporal or superficialis volae artery.

I next tried placing the artery upon a smooth surface, but in a slight groove, and found at once that considerably higher pressures, 20 to 30 mm. mercury, had to be exerted to obliterate the pulse or produce the maximum oscillation.

It is, I think, easy to see why this should be so. Supposing one pushes down the rubber bag over an artery lying on a flat surface until the flow is obliterated, the pressures per unit area in the bag and upon the artery will be approximately the same, or at any rate the instrument can be graduated so that it shall correctly record under these conditions.

If, however, the artery is lying between two more or less rigid structures, as the radial lies between the flexor carpi radialis tendon and the slope of the radius, directly pressure is brought upon the vessel it will recede, and in order that the bag may follow and compress it, some amount of aneurysmal dilatation must occur. Under these conditions the pressure recorded in the interior of the bag by the manometer or anaëroid is greater than the pressure exerted by the outside of the aneurysmal dilatation upon the artery, owing to the extra pressure required to produce this distortion of the rubber membrane, and the readings will be too high.

In the usual mode of employment on the human subject, the conditions are more nearly comparable to the second experiment.

Another very common fault, but not one of principle, is due to the fact that the fluid in the pads of Oliver's haemodynamometer evaporates and leaves the upper and lower surfaces concave instead of convex. Under these conditions they at once read too high. This can be remedied by injecting glycerine with a fine hypodermic needle passed obliquely through the rubber.

I do not, however, dispute for a moment the results brought forward by the inventors of these instruments, nor do I doubt that in their hands they may give consistent results. I can

only say that in my hands in the laboratory and at the hospital they have proved very unsatisfactory and misleading, and have given readings almost invariably too high. I may mention that I find that my experience is not unique.

B. Methods in which the pressure is applied by a bag enclosing or completely surrounding a limb.

The method in which a limb is enclosed in a chamber (plethysmographic) was introduced by Marey¹¹ and elaborated by Mosso.¹² Although the apparatus of both of these physiologists possess much importance historically, they are not well adapted for use outside the laboratory, and I do not propose to further discuss them.

In 1897 a very simple and efficacious method of estimating the maximum systolic pressure in the brachial artery was introduced by Riva-Rocci.¹³

The original Riva-Rocci instrument consisted of a rubber cuff, not unlike a small piece of the inner tube of a bicycle tyre. Rather more than one-half of the circumference (the outside) of the tube forming the cuff was covered with a supporting layer of canvas. The interior was connected by a T-piece with a pump and a manometer. The cuff was slipped over the upper arm and blown up until the radial pulse disappeared. This point was read off on the manometer and regarded as the blood pressure in the brachial artery.

Riva-Rocci tested his apparatus upon animals in which the blood pressure was recorded by a manometer connected with the interior of an artery, and found it accurate.

This method has been extensively employed in clinical practice on the Continent and in America, and with a few modifications, to be discussed directly, has been found entirely practicable and reliable.

A year later Hill and Barnard¹⁴ introduced an instrument founded on a similar principle. In their instrument, the interior of which is connected with a manometer and a pump, a piece of thin-walled rubber tube is wrapped around the upper arm and supported on the outside by means of a strip of leather broader than the rubber tube and secured by straps. The manometer is of anaëroid form. Their apparatus can be used in the same way as Riva-Rocci's to determine the maximum systolic pressure, but they prefer to inflate the tube until the point at which the maximum oscillations of pressure as shown by the manometer occur. This point they regard as equal to the mean arterial pressure, and on experimenting with their apparatus on a dog, in which the arterial pressure was simultaneously observed by connecting the interior of an artery with a mercury manometer, they found this to be the case.

Notwithstanding the fact—and it is a fact—that the instruments of Riva-Rocci and Hill showed the true arterial pressure when tried upon the limbs or neck of a dog, both these instruments as originally introduced—as was pointed out by

Fig. 7.

v. Recklinghausen¹⁵—indicate pressures which are considerably higher than the actual arterial pressure. V. Recklinghausen showed that this was due to the rubber tubes used to encircle the arm being too narrow.

The following series of observations of simultaneous pressures in the brachial arteries of the two sides with bags of different widths shows that v. Recklinghausen's criticism is well founded:

Width of Bag.	J. B. Obliterating Pressure.	C. J. Obliterating Pressure.
3 in. ...	116 114	112 108
3½ in. ...	112 110	108 106
4 in. ...	106 104	100 100
4½ in. ...	94 96	96 100
5 in. ...	94 96	96 102

On another occasion I experimented upon two different individuals with even narrower bags, and obtained the following pressures simultaneously:

	4 cm. bag. (1.6 in.)	5 cm. bag. (2.0 in.)	10 cm. bag. (3.9 in.)	12 cm. bag. (4.7 in.)
C. J. ...	123	110	93	94
G. H. ...	135	119	106	105

A bag of at least 4 in. broad is required for an average arm. There is a relation between the breadth of bag necessary to give the minimum reading and the size of the limb (C. F. Gumprecht¹⁶ and Hensen¹⁷). So broad a bag is not required with the small limbs of children or animals, which explains why the narrow armband of the original Riva-Rocci gave correct readings upon dogs.

Another precaution must be mentioned. It is essential that the two free ends of the bag overlap. If the two ends fail to meet readings in excess of the true pressure will be obtained.

Provided these conditions are fulfilled any instrument upon the Riva-Rocci principle is reliable for determining the maximum pressure in the brachial artery with an error of less than 4 per cent., and this magnitude of the error is dependent upon the accuracy with which the individual can determine the presence or absence of pulsation in the radial.*

* Mummery has recently repeated the experimental observations of Riva-Rocci and Gumprecht (*Proc. Physiol. Soc.*, February 25th, 1905) and compared on the dog readings from a Riva-Rocci instrument with blood pressures directly recorded by a mercury manometer and found agreement.

A simple and inexpensive form which I have been in the habit of using in the Physiological Laboratory at Melbourne for the last five years consists of a bag of thin rubber $\frac{1}{8}$ of an inch in thickness, 14 in. long and 5 in. broad, connected with a four-way piece of glass by stout-walled rubber tube. In using this apparatus the thin rubber bag was wrapped round the arm, supported by a wider piece of thin sheet lead and secured by straps. The other three limbs of the four-way piece were connected with (a) a U limb mercury manometer fitted with a paper millimetre scale, (b) a small bicycle pump, (c) a piece of rubber tube with a screw clamp upon it which is used to relax the pressure.

To fulfil the requirements of the physician, this arrangement of pieces of laboratory apparatus can be modified without increasing its complexity and without greatly increasing the expense. The following description refers to an arrangement which has been used during the last two years by many of my clinical friends, and which has undergone minor modifications at their suggestion, with a view to increasing its convenience. The form of bag described was shown me by Dr. Mummery at a recent meeting of the Physiological Society, and is the best I have seen. This form does away with the inconvenience of the supporting lead or leather.

The apparatus consists of a flat bag 14 in. long and 4½ in. broad (b, Fig. 2), one side of which is composed of thin rubber $\frac{1}{8}$ in. in thickness and the other side of a mixture of rubber and canvas, from the centre of which a short length of tubing projects.

The interior of the bag communicates by flexible rubber tube with a four-way piece of brass (t). This junction is in communication on the one hand with a mercury manometer (m), and on the other with a rubber ball (p). The tube connecting with the ball contains a valve (v). The fourth way of the junction is closed by a screw and leather washer, by loosening which the air in the system may be allowed to leak out.

The manometer is of the ordinary U-tube variety, 11½ in. in length; the internal diameter of the tube is $\frac{1}{8}$ in. One limb is provided with a scale in millimetres. The glass tube is fixed to an upright piece of wood fitted into a wooden base, which, when in use, can be clamped to the table for greater security. The upright piece of wood with attached manometer is removable from the base for convenience of packing in a box.

The manometer can be carried in any position, provided the ends be secured with rubber caps. The whole apparatus is fitted into a box 13 in. by 4 in. by 2½ in. in such a way that there is no danger of damaging the glass tube.*

In using the instrument the bag is wrapped evenly round the right upper arm of the patient, either next to the skin or over soft clothing, so that the ends overlap. It is secured in position with two broad pieces of webbing. With children the bag can be placed round the thigh.

The arm and hand of the patient must rest upon a table at the level of the heart. The fingers of the observer's left hand

* The apparatus in this form and fitted in a neat walnut box is made for me by my late assistant, Mr. E. Burgess, Summer Road, East Molesey, Surrey, and costs 25s. complete. New rubber bags can be supplied, 5s. each.

Fig. 8.

being kept upon the pulse, the pressure of the bag is slowly raised by squeezing the ball with the right hand until the pulse can no longer be felt.* At this point the depression of the mercury in one limb of the manometer is read on the scale, and this doubled (the mercury having risen correspondingly in the other limb) is a measure of the maximum systolic pressure at the time.

On raising the pressure very gradually towards the end an intermittent disappearance of pulsation in the radial may often be observed. This is due to the rise and fall of arterial pressure consequent upon respiration.

The patient must be kept quite quiet, as the slightest effort or excitement (for example, talking) raises the pressure. The mental disturbance caused by the idea of having a blood-pressure determination made may in a new patient send up the pressure 40 mm. of mercury! It is well to take a second reading later in the interview. This rise occurs when there may be no visible expression of excitement whatever.

Modifications of the manometer with the view of diminishing its length have been introduced by Sahli,¹⁸ who has suggested both a single U limb jointed manometer (Fig. 3, *a*), made in two sections, and also a double U limb manometer (Fig. 3, *b*) in which, of course, the total difference of level of the mercury is distributed over the two limbs. The length of the manometer is thereby reduced to one-half. These modifications, however, increase the cost and fragility of the instrument, and I doubt whether the advantage gained is adequate.

Gärtner's ring sphygmometer is in principle the same as Riva-Rocci's, but on a very much smaller scale, adapted for use upon a finger. It consists of a metal supporting ring about 1 cm. broad, on the inside of which is a thin-walled hollow rubber ring, the interior of which communicates with a pump and a manometer. The ring is passed on to the middle phalanx of the finger, and the distal portion rendered bloodless by a special thick-walled rubber fingerstall, or a stout umbrella ring rolled slowly along the finger will do. Having blanched the peripheral portion, the small rubber ring of the instrument is pumped up so as to stop the circulation, and the fingerstall or umbrella ring removed. The pressure in the rubber ring is now allowed to slowly fall until the colour commences to return in the blanched portion, when the pressure in the manometer is read off. The return of colour indicates that the pressure in the bag is less than the systolic pressure. Gärtner's instrument possesses the advantage of being small and compact, and not requiring the removal of any clothing. It is not so accurate as the Riva-Rocci, because it is not so easy to determine slight changes in colour as to say when the pulse disappears, or, to use a chemical term, the end-point is not so delicate.

According to v. Recklinghausen¹⁹ the ring is too narrow, and often gives too high readings in consequence. The

* The disappearance of pulsations in the manometer must not be taken as an indication that the artery is obliterated (see later).

pressure in the digital arteries is about 8 mm. less than in the brachial.

THE POINT OF MAXIMUM OSCILLATIONS AS THE CRITERION IN DETERMINATIONS OF BLOOD PRESSURE.

Throughout this article I have displayed a bias in favour of using the determination of the maximum systolic pressure, rather than taking the point at which maximum oscillations in pressure occur, for indication.

I am strongly of opinion that the maximum systolic pressure is the only point in the varying pressures of the cardiac cycle which can be determined with any degree of accuracy without opening an artery, for the following reasons:

1. The maximum oscillations are not infrequently spread over a very considerable range of pressure, so that it is difficult to determine when the oscillations are maximal, as they tail off gradually on each side, the only safe method being to raise the pressure until one is certain that they diminish and record this point, then to lower the pressure until undoubted diminution again occurs, and take the mean.

2. Exactly at what phase in the varying pressures of the cardiac cycle the maximal oscillation occurs is the subject of a difference of opinion. Tschlenoff²⁰ says this occurs at the systolic, Sahli²¹ at the diastolic, Hill²² at the mean pressure, and Roy and Adams²³ at a point just above the minimum intravascular pressure.

As to what is the relation of pressure in an external compressing bag applied to the arm to that in the brachial artery when maximum oscillations occur in the former is not a problem very easy to solve.

As a first instalment towards its solution I put an artery inside a glass cylinder, as in Fig. 1, but, instead of it being connected to a head of pressure in a reservoir, a stream of water was pumped through it by an intermittent pump in order to imitate the circulatory conditions. The oscillations of pressure in this artificial circuit and those of the fluid in the tube surrounding the artery were recorded by manometers supplied with writing floats and arranged to record upon a travelling surface.

The pressure of the water outside the artery was slowly raised and lowered by raising the small reservoir (*a*, Fig. 1), thus imitating some of the conditions obtaining when blowing up the bag of a Riva-Rocci armlet.

Figs. 4 and 5 are records of experiments with the arteries of a horse and a man respectively, and show that in these experiments the maximum oscillations occurred when the mean pressure outside was about halfway between the systolic and lowest diastolic pressures.

On the other hand, Fig. 6, which represents an experiment made with the same human carotid as Fig. 4, but less stretched, gave maximum pulsations in the external pressures which are distinctly subdiastolic. In fact, by varying the stretch of the artery I could modify the position of the maximum oscillations at will.

I then sought to obtain some light on the question by taking

a large number of graphic records of the oscillations of pressure in a Riva-Rocci armlet during the time that the pressure was gradually raised, as in using the instrument. To this end I inflated the bag with warm water instead of air, as otherwise the inertia of the mercury in the manometer would be too great to record satisfactorily. A float and style with writing point were attached to the open limb of the manometer and the pressure recorded upon a travelling smoked surface. In these experiments (200) the pressure at which the pulse was obliterated was also indicated by stopping the electrically-controlled time record by means of a key operated with the foot. The time-recording line also indicates the zero of pressure in these tracings. The raising and lowering of pressure was managed by means of a two-way cock, through which either water under pressure could be slowly driven into the bag, or what was already therein allowed to escape. I have a large number of such tracings from normal individuals and patients with a variety of circulatory disturbances from which I have chosen two types to illustrate this paper. It will be seen that the pulse is signalled as having disappeared from the radial whilst the oscillations are still marked, and with high pressures often nearly maximal. This is due to the transference to the upper edge of the bag of the exaggerated pulsation of the portion of the brachial and its branches above the point where it is obliterated. This introduces an important source of error when the point of maximum oscillation is taken to indicate mean arterial pressure.

Fig. 7 shows a record from a healthy young adult, and Fig. 8 from another healthy adult. The obliterating pressure in both instances is practically identical, but the relation of the pressure at which maximum oscillations occur to the systolic pressure is quite different, although the pulse-rate is the same (63).

From other considerations in these two cases, I believe the variations in pressure during the cardiac cycle were greater in the individual from which the tracing recorded in Fig. 7 was taken, so that the mean pressure would be lower.

Fig. 9 is from an old man with considerable arterial sclerosis and failing heart and a high pressure (200 mm.). In this tracing the maximum oscillations occur at the systolic pressure with rising pressure in the instrument, and considerably below with falling pressure. This variation in the position of the greatest oscillations with the conditions under which the record is taken not infrequently occurs, and is a serious indictment against the employment of maximum oscillations as an indication of blood pressure.

From the analysis of 90 records under all manner of circulatory conditions, taken for me by my friend Dr. Embley, I find that the average ratio of pressure at which maximum oscillations occur to obliterating pressure is very nearly 0.8, but the variation from this average is very considerable, 0.96 to 0.6.

The higher figures for this ratio were always obtained in cases exhibiting big pressures, and the lowest in cases of marked incompetence of the aortic valves. I think, therefore, there is no doubt that the maximum oscillations of pressure in the Riva-Rocci instrument usually occur about the mean

Fig. 9.

pressure as maintained by Hill,²¹ but that there are conditions peculiar to the method which influence the position of the maximum oscillations, and make this observation less valuable as an indication of arterial pressure than the methods in which the obliteration of the pulse is employed as the criterion of the systolic pressure.

The observation of Hill that maximum oscillations do occur at or about the mean pressure shown by a mercury manometer connected with the artery of an animal when a rubber bag is used to compress the limb, I have been able to confirm; but I think that as employed in man this is less constantly the result than one is led to believe from his experiments and my own.

In conclusion, I wish to express my indebtedness to Dr. Embley for much valuable assistance in experiments in the taking of a large number of records upon which the conclusions recorded above are based.

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THE SPITTING NUISANCE AT DAVOS.—By an ordinance recently issued by the local authorities at Davos every consumptive patient is required to carry a pocket spittoon, and is forbidden to spit on the floors, on the streets, pavements, and footpaths, and also on the snow. The penalty for breach of the regulation is a fine not exceeding 50 francs (£2). It is to be hoped that, in the interest of the place as well as of the inhabitants and visitors, the ordinance will be rigorously enforced.