Measurement of blood pressure—a routine test in need of standardization

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Summary

Some of the different factors that can influence the measurement of blood pressure are discussed. It is essential that those engaged in the care of patients with high blood pressure should standardize the measurement of blood pressure so that the established routine is followed at each attendance. This is especially important today because so many people perform blood pressure checks.

It is important to use the correct cuff and manometer. When considering costs, one should remember that the measurement of blood pressure is an inexpensive examination, but that poor equipment will prove costly both for the patient and for the community medical programme.

THE measurement of blood pressure has been one of our most common and most important routine diagnostic tests for many decades. Often this measurement constitutes the only study upon which long-term treatment is based. Thus, for the patient, the blood pressure estimation may have far-reaching medical and social consequences. It is therefore essential that the blood pressure is measured correctly.

From the point of view of cost, the measurement of blood pressure is inexpensive. A mercury manometer equipped with a blood-pressure cuff (Riva-Rocci sphygmomanometer) costs less than £23. An aneroid manometer with a blood-pressure cuff costs about £7, whereas a blood-pressure cuff alone costs less than £2. At the Department of Internal Medicine at the University Hospital of Lund, about 1500 blood-pressure measurements are made in each consultation room annually. If the lifetime of a mercury manometer is 10 years, and three cuffs are worn out during this period, the price for each blood pressure determination will be about 0.2 p. For comparison, the erythrocyte sedimentation rate (Westergren

method), which is routinely checked in as many patients, costs between 10 and 20 p depending upon whether a disposable syringe or the Vacutainer® technique is employed. The material expense for checking the ESR is thus 50 to 100 times greater than that of the blood pressure.

For many, the points of view now presented are truisms, but because blood pressure measurements are, to an ever increasing degree, conducted in surveys and clinics by nurses, it is pertinent to survey this important routine test.

A historical glimpse

The first quantitative measurement of blood pressure was performed in 1733 by an English clergyman, the Rev. Stephen Hales (Geddes, 1970). He measured the blood pressure of a horse. This first measurement of blood pressure was effected by introducing a brass tube into the femoral artery to which a 9-ft-long glass tube was connected: the blood column rose to 8 ft and 3 in (Fig. 1). Hales observed that the blood column in the glass tube rose and sank in time with the pulse. In a later experiment with a gelding, Hales was able to get the blood column to rise to even higher levels by making it more difficult for the horse to breathe.

In 1828, Poiseuille introduced a method of measuring the blood pressure in millimetres of mercury (Hg). He employed a U-tube with the mercury connected to a blood vessel of a dog, and could in this way reduce the length of the apparatus by a factor of 27.2 (2×13.6). It was difficult at times to read the maximum and minimum blood pressures correctly in the oscillating mercury column.

To eliminate the observer's error in reading the oscillations of the mercury column in the U-tube, Carl Ludwig in 1847 added a graphic recording of the blood pressure. He equipped the U-tube with a writing point, which inscribed the variations of the blood pressure on smoked paper attached to a rotating drum—the 'smoked-drum kymograph'.

Thus, the first measurements of blood pressure

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FIG. 1. Rev. Stephen Hales' third experiment measuring the blood pressure in a horse. Here, in the year 1733, the blood pressure is being measured in the carotid artery. Rev. Hales commented: 'The Blood rose in the Tube in the same manner as in the Case of the two former Horses, till it reached to nine Feet six Inches Height'. (Photo through the courtesy of Statham Medical Instruments, Oxnard, California.)

were made by the 'direct method'. The first published investigations of blood pressure measurements by the 'indirect method' are from the latter part of the last century and the beginning of the present century (von Basch, 1876; Riva-Rocci, 1896; Potain, 1902; Brunton, 1909). In brief, the indirect method, as described by Brunton, was performed by palpating the radial artery with three fingers: with the finger nearest to the wrist, the recurrent pulse from the palmar arch was obliterated; with the middle finger, the pulse was felt; and with the finger nearest to the heart, the artery was compressed until the middle finger no longer could feel any pulsations. The blood pressure was then estimated on the basis of the finger pressure that was required to occlude the pulse.

One of the first attempts quantitatively to estimate the blood pressure indirectly was made by placing weights over a superficial artery and recording the weight that was required to 'shut off the vessel'.

Our present-day, indirect measurement of the systolic and diastolic blood pressures is based on the

characteristic opening and closing sounds—described by Korotkoff (1905)—arising from the artery. With cuff pressures exceeding the systolic blood pressure, the lumen of the artery is fully occluded; with pressures between the systolic and the diastolic pressures, the lumen is intermittently open and closed; and at pressures below the diastolic pressure the arterial lumen is fully open. The turbulence in the vessel in phase with the pulse generates the sounds.

Indirect measurement of blood pressure

The systolic blood pressure corresponds to the maximum pressure in the aorta during the injection period of left ventricular systole. The diastolic blood pressure corresponds to the lowest pressure in the aorta immediately before the next systole. The difference between systolic and diastolic blood pressure is known as the pulse pressure. The average blood pressure (mean arterial blood pressure) is also a relevant concept. This varies with the waveform of the arterial pulse and can only be determined by direct measurement. For practical purposes, the following approximation for the mean arterial blood pressure (BP) is employed:

$$\text{diastolic BP} + \frac{\text{systolic BP} - \text{diastolic BP}}{3}$$

(Rashmer, 1961).

Comparative investigations between the direct and indirect measuring techniques have demonstrated that the appearance of the first pulsation sounds (Phase I of Korotkoff) over the brachial artery during decreasing cuff pressure agrees well with the level of the systolic blood pressure. The indirectly measured systolic pressure does not differ significantly from the pressure obtained during intra-arterial measurement (Karlefors, Nilsén and Westling, 1966). Agreement is less good between indirectly and directly measured diastolic pressures. The results depend upon the choice of reading. If the attenuation of the pulsation sounds are chosen—immediately before they entirely disappear (Phase IV of Korotkoff)—an overestimate of the diastolic blood pressure (5–9 mmHg) is obtained.

There seems to be a consensus that correspondence with the intra-arterial diastolic blood pressure is best in Phase V of Korotkoff; that is, the recording of blood pressure at the point when the sounds disappear completely. However, Phase V of Korotkoff may also occasionally lead to overestimation of the diastolic blood pressure when compared with intra-arterial recordings (Karlefors *et al.*, 1966). Sometimes turbulence may occur in the artery even without compression. This turbulence may be due to increased velocity of blood flow or to high stroke volume, which can occur *inter alia* during work,

in aortic insufficiency, in pregnancy and in thyrotoxicosis. Local irregularities in the wall of the vessel can also give rise to turbulence. In these cases it may be difficult to measure the diastolic blood pressure adequately by auscultation. It becomes obligatory, then, to choose Phase IV of Korotkoff, that is, when the sounds are decreasing in strength, as the measured value for the diastolic blood pressure.

Standardized conditions for measurement are necessary

In most individuals the blood pressure displays large variations during a 24-hr period. The blood pressure increases during physical exertion, in stress, and with fright. Smoking tobacco evokes a rise in blood pressure, and exposure to cold causes the vessels to contract, resulting in an increase in blood pressure. Peace and tranquillity and rest and warmth tend to lower the blood pressure. Consequently, the milieu in which the blood pressure is being measured is important. Whether or not the patient is used to having his or her blood pressure measured and whether the patient knows the examiner are also important factors.

Standardization of the measurement of blood pressure is important. The manometer should preferably be a mercury manometer, but it may be an aneroid manometer provided it is calibrated with a mercury manometer at least once a year. The cuff must be sufficiently wide so that the cuff pressure will be transmitted to the deeply situated artery. The width should be 40% of the circumference of the upper extremity (Cullhed, Michaelsson and Wranne, 1968; Ström and Werkö, 1958; Table 1). In practice this means that the inflatable rubber bag must be at least 12 cm wide and 35 cm long—the standard adult blood pressure cuff. The size of the cuff sheath is of no significance (Cullhed *et al.*, 1968; Kirkendall *et al.*, 1967). The cuff pressure is spread like a pressure

TABLE 1. The shape of the rubber bag in the blood pressure cuff. In measuring, the circumference of the arm may not exceed the length of the bag. In such a case, choose the next larger cuff size. Permissible variation of the dimension is proposed to be ± 2 cm for the length and ± 0.5 cm for the width

Circumference of arm (cm)	Width (± 0.5 cm)	Length (± 2 cm)
45	18	60
37.5	15	43
30	12	35
22.5	9	28
15	6	20
7.5	3	20

cone with the apex pointing downward. Using too narrow a cuff the pressure must be elevated disproportionately to the intra-arterial pressure, giving a falsely high blood pressure reading, the most common source of error with indirect measurements (Fig. 2). A cuff that is a little too wide does not give unduly low values, but an unduly wide cuff, e.g. an adult cuff used for children, should be avoided. The length of the cuff must be adapted in a way that the compressing rubber bag surrounds the whole of the arm. If the cuff is too short, this will result in erroneously high blood pressure values (Bordley *et al.*, 1951; King, 1969; Simpson *et al.*, 1965).

The cuff is placed around the upper arm with the lower edge about 2 cm above the bend in the elbow. The arm should rest comfortably and the cuff on the arm should be on a level with the patient's right atrium, which means that the cuff is at the same height as the middle of the rib cage, 5 cm below the angular transition between the upper and middle third of the sternum. If the arm with the cuff is held 13.6 cm below the heart level, the blood pressure will be 10 mmHg too high. If the arm is elevated above the level of the heart, the blood pressure will decrease correspondingly (Bjurö and Westling, 1966).

FIG. 2. The expansion of the pressure cone in the tissues of the arm downward towards the brachial artery in a sufficiently wide cuff (a) and in a cuff that is too narrow (b) in proportion to the circumference of the arm.

The pressure in the manometer must be rapidly elevated to about 30 mmHg above the blood pressure value at which the pulsations have palpably disappeared in the radial artery. The stethoscope is placed over the brachial artery immediately below the lower edge of the cuff. The pressure in the cuff is reduced at the rate of 2–3 mm/pulse beat. The pressure when the first pulse beat is audible is read as the systolic blood pressure, and the pressure at which the pulse beats become completely inaudible is recorded as the diastolic blood pressure. More or less deliberate rounding-off of the blood pressure value to uneven or even numbers, so-called digit preference, should not be practised. Most frequently the preference is 10 mmHg. It is recommended that the blood pressure measurements be taken to the nearest 5 mmHg.

Recently, various semi-automatic blood pressure appliances have been introduced. The measurement of blood pressure with these is often unsatisfactory, especially in individuals with stout upper arms. Often, the microphone misses the sounds in Phase I of Korotkoff, so that a falsely low systolic blood pressure is read. The diastolic blood pressure becomes falsely high because the sound is erroneously recorded in Phase IV of Korotkoff. In some individuals no blood pressure values at all are obtained.

Technical sources of error in measuring blood pressure

A number of possibilities for technical errors exist in the measurement of blood pressure. The blood-pressure manometer with an ascending tube containing mercury is the most reliable blood pressure

instrument and rarely gives rise to technical errors. However, the overhead valve can become clogged, causing unduly low values to be recorded.

Aneroid manometers may have several shortcomings. They are sensitive to jolts, and must therefore be regularly checked and compared with a mercury manometer (calibrated). This is accomplished most easily with the aid of a T-tube (glass and rubber tubing) connecting the blood-pressure cuff to the aneroid manometer as well as to the mercury manometer. The aneroid manometer is checked to determine if it coincides with the Hg manometer at various levels of pressure up to 300 mmHg (Fig. 3). Thulesius (1972) found in a routine investigation of 100 blood-pressure cuffs equipped with aneroid manometers that thirty-five of the manometers had technical defects and that the greatest deviation in testing against the mercury manometer was 20 mm Hg. At the University Hospital of Lund, it has been found in checking the aneroid manometers at the Department of Clinical Physiology that almost every tenth manometer shows an error of 10 mmHg or more when tested against a mercury manometer. Zero-point correction with the adjustable scale on the aneroid manometer is often done incorrectly, in that the correction is made after having attached the cuff on the arm. If this occurs at a certain pressure, naturally, no zero value will be obtained with the valve closed. Furthermore, the adjustable scale may be loose and this can lead to shifts while the blood pressure is being taken.

It is important that the blood-pressure cuff is correctly placed and is wrapped so that it is comfortable and snug around the arm. A source of error

FIG. 3. Calibration of the aneroid manometer with the aid of the mercury manometer.

that has been neglected is the elevation of the blood pressure owing to tightness of the cuff, which may 'squeeze' so hard as to cause pain. This occurs most frequently in women with thick upper arms and may result in misleading values (Westling, personal communication). If the cuff is allowed to be too loose on the arm there is the risk that erroneously high values will be recorded.

Prolonged venous stasis of the arm veins may occasion erroneous readings. This arises when the cuff pressure is pumped up too slowly or if repeated measurements of blood pressure are made without allowing the pressure to return to zero before each new measurement. A rapid reduction of the pressure can result in too low a systolic, and too high a diastolic, blood pressure, because the systolic blood pressure is recorded in Phase II of Korotkoff instead of in Phase I (Ragan and Bordley, 1941) and the diastolic blood pressure is recorded in Phase IV instead of in Phase V. Excessively strong pressure applied over the brachial artery with the stethoscope may completely or partially compress the vessel, and in this way function like a blood-pressure cuff. False turbulence may then occur and give rise to spurious sounds that are in turn recorded. Muscular spasm in the arm at the time of the measurement of blood pressure can precipitate falsely high values.

Some examples of diseases that affect blood pressure

Cardiovascular diseases occasionally give rise to certain characteristic changes of the systolic and diastolic blood pressures. In certain disease states it may be difficult to effect a correct measurement of the blood pressure because the pulse wave form deviates from normal. The pressure in the vascular system is dependent on the amount of blood that is received from the left ventricle during systole (stroke volume of the heart) and the volume of blood that empties in diastole. The amount of blood that empties is, above all, dependent on the peripheral vascular resistance, but also on the condition of the aortic valves.

Normally, the systolic blood pressure is moderated by the elasticity of the vessels. In arteriosclerosis this elasticity decreases because the vessel wall has become stiff as a result of 'calcification', and thus is less resilient. Pathologically, arteriosclerosis results in high systolic blood pressure, but the diastolic blood pressure remains low, with a high pulse pressure. In aortic insufficiency, the systolic blood pressure is high because the left ventricle is filled up from two directions during diastole, in part normally from the left atrium and in part as a result of regurgitation from the aorta. This increased filling of the left ventricle causes an increased stroke volume. Owing to the high systolic blood pressure, there will be an abnormally rapid outflow of blood from the vascular

bed into the peripheral vessels. Some of the outflowing blood returns to the heart through the diseased aortic valve. As a result, the vascular system is rapidly emptied of blood and the diastolic pressure is low. In association with the diseases in the musculature of the heart (e.g. coronary sclerosis), arrhythmias often develop (e.g. atrial flutter). Heart arrhythmias cause variations in the blood pressure, among other things, as a consequence of differentially large stroke volumes.

Practical application of measuring blood pressure

In addition to a knowledge of the sources of error and the technique in measuring blood pressure, it is imperative to standardize the measurement of blood pressure so that it can be executed consistently. This has been achieved in the special outpatient blood-pressure centres that have been established in Sweden in recent years. But it is equally important that others who are engaged in outpatient and inpatient medical care, namely, the district nurses, physicians and personnel at other centres and departments, also perform blood pressure measurements in a similar way.

Today, blood pressure is often measured at many medical care centres without the method having been standardized. At most of these centres the blood pressure is measured after various periods of rest in the supine position. Chance often determines the way in which the blood pressure is taken. Occasionally, the patient is allowed to lie down and rest for half an hour, or perhaps longer, before it is measured. At the next visit the patient may hardly be given time to lie down and get comfortable before the blood pressure is taken. The difference between the blood pressure that is measured on the spur of the moment, without prior rest (casual blood pressure), and the blood pressure that is measured after a long rest is often great. For these reasons, different criteria for normal blood pressure must be applied depending upon how the blood pressure determination is conducted. In conjunction with screening investigations with a large flow of patients, the blood pressure measurement sometimes has been carried out in a sitting position before and after a short period of rest. Results of blood pressure measurements taken in the sitting position differ somewhat from corresponding ones taken in recumbency.

The measurement of blood pressure in the right arm should be a standard procedure according to WHO (1959). The blood pressure should on some occasion be measured in both arms with a short time interval in order to ascertain if there are possible vascular changes in the aortic arch or in the vessels of the brachium.

With the introduction of more effective and specific therapy in the hypertensive diseases, blood pressure

is also measured while the patient is standing up. Some of the hypotensive drugs cause the blood pressure to fall in the standing position—orthostatic hypotension—with or without subjective difficulties for the patient. For the same reason, it may also be necessary at times to measure the blood pressure during exertion.

The assessment of the pulse rate is important when checking the blood pressure. Since the heart rate affects the blood pressure, the pulse rate should be simultaneously recorded during the blood pressure examination. In some subjects, especially younger persons with elevated blood pressure, it has been demonstrated that the heart rate at rest is higher than it is in individuals with normal blood pressure. Tachycardia often occurs in anxious and nervous persons.

At one time or another, some physicians have permitted their patients or relatives to measure the blood pressure in the home. This procedure may give a better basis for treatment particularly in those patients whose blood pressure tends to vary a great deal in conjunction with checks at the centre or at consultation. In general, it is not very difficult to instruct the patient how to measure the blood pressure, and for this reason the results obtained in other milieus ought to be regarded as dependable.

When hypertension is suspected the patient should be asked to return for repeat blood-pressure determinations on at least two or three or more occasions, as there is normally some variation in the blood pressure. In most patients with elevated blood pressure, therapy should not be increased too rapidly. There is plenty of time, as a rule, to conduct a complete and careful investigation of the hypertensive patient. Repeated blood-pressure measurements thus constitute the most important part of the investigation. The diagnosis of hypertension must be well documented before starting treatment with anti-hypertensive drugs.

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