

patients and control subjects.¹⁵ This relation is probably due to a Donnan effect, whereby calcium ions are attracted electrostatically to albumin in the serum within the vascular compartment. This suggests that measuring ionised calcium in the presence of albumin will overestimate the concentration of ionised calcium in the interstitial fluid. The way in which this may be clinically misleading was discussed in a recent *BMJ* article, which indicated that even ionised calcium values do not provide a true gold standard for assessing calcium state.¹⁶

A technique hitherto neglected is the measurement of the dialysable (ionised plus complexed) fraction of total serum calcium, and methods have been devised for automated use with a high degree of precision and accuracy.^{17,18} Prince *et al* in this issue (p 735) report their experience of measuring dialysable calcium in both patients and control subjects and compare this with measurements of other fractions of serum calcium. Although the clinical validation of the method requires more work, it overcomes many of the problems associated with the presence of albumin but does not take account of large changes in anion concentrations—such as the increased bicarbonate of compensated respiratory acidosis, which will increase the complexed, but not the ionised, fraction of serum calcium.

The debate will continue about the fraction of serum calcium that offers the most advantages in terms of cost, ease of analysis, and ability to reflect the biological state of patients. Whether we move towards measuring ionised or dialysable serum calcium (or the ionised fraction of dialysable calcium), probably the measurement of total

serum calcium with or without adjustment will be regarded increasingly as a second best option.

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Regular Review

Blood pressure measurement: current practice and future trends

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Most doctors and nurses appreciate the importance of recording blood pressure, but many are unaware of the limitations of the commonly used methods of indirect sphygmomanometry. Recent research has suggested that the time honoured methods of measurement may not be sufficient for accurate diagnosis and prognosis in hypertension. Automated devices for measuring blood pressure are now being marketed with more emphasis on commercial considerations than in the interest of improving the accuracy of measurement. Often the sales literature of these devices makes extravagant claims of accuracy unsupported by independent assessment. This review will consider current techniques and instruments for the routine measurement of blood pressure. The evidence that reliance on conventional clinic or office measurement may be misleading will also be examined, together with recently developed techniques that may improve the management of hypertension.

Standard method

The standard method of the indirect measurement of blood pressure is based on the principle of arterial occlusion and blood pressure detection by various techniques, the first of which was palpation, described by Scipione Riva-Rocci in 1896.¹ Theodore Janeway in 1901 was the first to recognise the occurrence of sounds during deflation of the cuff,² but it was Nicolai Sergeyovitch Korotkoff in 1905 who related these sounds to systolic and diastolic pressure, thus introducing the auscultatory method of blood pressure detection.³ Korotkoff identified three phases of sound, and in 1907 Ettinger elaborated on these by describing five phases.⁴ The technique has changed little over the years but recommendations for its standardisation have been published and revised regularly by the American Heart Association since 1939,⁵ and reviews of the subject have attempted to

identify the shortcomings of the technique so as to improve accuracy.^{6,7}

One cause for concern is the training of medical and nursing staff, who should be aware of the influence of observer bias, avoid terminal digit preference, and be assessed after training by an experienced observer.^{6,8,9} Failure to standardise conditions of measurement is another source of error: the patient should be relaxed and rested; the position (sitting, lying, or standing) should be noted⁵; the arm should be supported at the level of the heart¹⁰; and blood pressure should be measured in both arms at the initial assessment and subsequently in the arm with the highest pressure,⁵ though there is probably no significant average difference between arms.

Phase V—disappearance of sounds—should be used for measuring diastolic pressure,^{5,11,12} but as there is much variation in practice the phase used should be indicated.¹³ The sphygmomanometer is an important source of potential errors, among which the more important are a defective control valve^{14,15} and an inflatable bladder that is too short; the standard 22-23 cm bladder is suitable for normal adult arms, but in obese patients is too short and its use may overestimate pressure.^{16,17} Similarly, the use of a bladder that is too narrow will also overestimate blood pressure,¹⁸ but in practice if bladder length is adequate the width is not so critical.¹⁷ Though some questions on “cuff hypertension”¹⁹ are still unanswered, the consensus from published work suggests that sphygmomanometer cuffs for adult blood pressure measurement should contain an inflatable bladder of 13×35 cm, and manufacturers of sphygmomanometers should be persuaded to comply with this recommendation. The error from using an incorrect bladder may be reduced by positioning the cuff correctly so that the centre of the bladder is over the brachial artery.⁵

As many as one third of aneroid sphygmomanometers in general practice may be inaccurate, whereas the mercury instrument tends to remain accurate in use.¹⁵ The lack of any policy for maintaining sphygmomanometers in hospital and general practice is a cause for concern: sphygmomanometers should be serviced every six to 12 months depending on usage.^{5,15}

Surprisingly, many of the important details of blood pressure measurement are often not stated in research publications, and editors should be as diligent in ascertaining the methods used in blood pressure measurement as with other techniques.²⁰

Special recommendations apply to the measurement of blood pressure in children.^{5,21} The measurement of blood pressure in the elderly by the standard technique is as accurate as in young people,²² and the term “pseudohypertension” devised to denote an artefactual rise in blood pressure in the elderly is not justified.^{23,24}

Automated techniques

That observers may differ greatly in their interpretation of Korotkoff sounds, and be subject to bias and terminal digit preference, is a cause for particular concern in clinical research.^{5,8,25} The mercury sphygmomanometer has been modified in an attempt to remove these potential sources of inaccuracy. The London School of Hygiene sphygmomanometer was used in research for many years,²⁵ but because of a calibration error and an interpretative inaccuracy this instrument is no longer recommended.²⁶ The Hawksley random zero mercury sphygmomanometer varies the zero for each

measurement and so may lessen observer bias, but computational errors may be introduced.²⁷

Many automated devices have been invented, most of which are designed to reduce the influence of observer bias or to replace the observer altogether with either a microphone to record Korotkoff sounds or a means of detecting arterial wall movement by ultrasound,²⁸ oscillometry, or low frequency energy.²⁹ Whatever the technique employed almost all automated blood pressure recording devices depend on the principle of arterial occlusion and detection as for the standard method—and are therefore subject to many of the same errors. Moreover, the epidemiological, clinical, and research data on which decisions in hypertension are based have been obtained with the auscultatory technique. Techniques such as the oscillometric or ultrasound may be accurate when tested in a given clinical setting but these have not been assessed throughout the wide pressure ranges that may occur in practice, or with pharmacological intervention, nor has the possible effect of altered vascular compliance in the elderly been studied. Automated devices, none the less, are useful in clinical research when many measurements are made over a period of time and account can be taken of blood pressure variability. They may also help when Korotkoff sounds are difficult to detect, as in neonates.³⁰ Automated devices are not, however, a substitute for the standard sphygmomanometer in routine clinical medicine.

Several automated devices are now available for hospital use which measure blood pressure non-invasively at prescribed intervals on a digital display, and some provide a printed readout. The Arteriosonde detects arterial wall motion by ultrasound,²⁸ whereas the Vita-Stat depends on the detection of the Korotkoff sounds with a microphone,³¹ and the Dinamap on oscillometric detection.³² These devices are expensive (extremely so when compared with the standard mercury sphygmomanometer and stethoscope), and the only source of error removed is that due to the observer—for which may be substituted the technical faults to which all complex equipment is subject and the need for maintenance. Spurious readings, interdevice variability, and inaccuracy with use are additional problems.³³ Before spending money on automated equipment the clinical investigator must weigh the attraction of automation carefully against the tried, accurate, and inexpensive, if less glamorous, manual technique with a mercury sphygmomanometer. Potential purchasers of automated equipment should examine critically the claims by manufacturers, demand evidence of reputable independent assessment, and then decide if the additional cost is justified.

Coin operated automated blood pressure devices are now available in pharmacies, shopping centres, and airports in many countries. Attractive though the prospect of detecting undiagnosed hypertensives in the community may be, concern in the United States over the accuracy of the equipment and the effect of a high reading on people unaware of the variability of blood pressure has led the National High Blood Pressure Education Program Coordinating Committee to publish recommendations for this equipment.³⁴

The proliferation of automated sphygmomanometers has been greatest in the self recording market, where unsupported claims of accuracy are made for devices that often cost very much more than a standard sphygmomanometer and stethoscope. In most countries independent laboratories are left to assess these devices—a tedious and often thankless task that editors are slow to reward by publication of results. Moreover, though studies have been published on some of the many instruments available,^{28,33,35} none have retested

accuracy after a period of use, when the instrument might become inaccurate, as with aneroid manometers.¹⁵ Each country will need a policy for premarket assessment of automated sphygmomanometers in approved laboratories using a protocol designed to fulfil statistical and engineering criteria as well as medical considerations. We welcome the recommendations of the American Association for the Advancement of Medical Instrumentation, drawn up at the behest of the Bureau of Medical Devices of the Food and Drug Administration.³⁶

Newer concepts

The variability of blood pressure in differing circumstances of measurement has been known for many years,^{37 38} but the importance of these observations for clinical practice, though well documented, has begun to be appreciated only recently.³⁹ Because blood pressure tends to fall (but not always⁴⁰) with repeated measurement, and especially when the measurement is done on different occasions,⁴¹ diagnostic decisions based on a single or casual blood pressure measurement will often lead to incorrect diagnosis and unnecessary treatment.^{41 42} The reliability of clinic or office blood pressure measurements may be improved by repeating the readings on different occasions, but this is time consuming and does not always detect the swings that occur in blood pressure.⁴³

Since Brown's observation in 1930 that blood pressure measured in the home was lower than that recorded by a doctor,⁴⁴ the discrepancy between pressures recorded in the home and the clinic has been repeatedly confirmed—as has the considerable individual variability.⁴⁵⁻⁴⁹ Assessed against clinic measurements blood pressure recorded at home is accurate whether measured by patients⁴⁷ or their relatives or friends,⁵⁰ and the technique can detect small average changes in blood pressure.⁹

The concept that blood pressure might be lower if the patient was removed from the doctor and the hospital was elaborated further by Pickering and his coworkers at Oxford, who had been interested in the variability of blood pressure for many years.⁵¹ The development of a portable apparatus for direct recording of blood pressure over a 24 hour period allowed the study of the variability of blood pressure, its circadian rhythm, and the influence of drugs and environmental stimuli throughout the day.⁵²⁻⁵⁷ The Oxford system, though accurate and reproducible,⁵⁸ has the disadvantage of being invasive and so subject to hazards. In practice these are infrequent because the technique has been restricted to a few centres with the requisite skills.⁵⁹ Because the procedure is invasive, however, ethical considerations should limit its application to certain clearly defined research projects.

The development of an accurate method of recording ambulatory blood pressure non-invasively has been hampered by many technical difficulties. Several systems have been developed in recent years, however,⁶⁰⁻⁶³ of which the Remler M2000 has been studied extensively and shown to be accurate.^{62 64-69} More recently the Del Mar Avionics system has been shown to be accurate and reasonably reliable.⁷⁰⁻⁷² Both the Remler and Avionics systems record Korotkoff sounds from a microphone positioned over the brachial artery below an occluding cuff, which is manually inflated at prescribed intervals for the Remler, and automatically inflated at preset intervals for the Avionics, with cuff deflation being automatic for both systems. The Remler is considerably lighter than the Avionics and has a facility permitting the observer to confirm that the sounds being

decoded are Korotkoff sounds and not artefactual. The Avionics recorder with automatic inflation can provide 24 hour recordings, whereas the Remler can be used only during waking hours to give about 16 hours' recording. Both systems are expensive, and to obtain optimal recordings (especially with the Remler) a technician trained in ambulatory measurement is desirable.

Inevitably non-invasive techniques have been compared with the invasive with claims of greater accuracy for one method over the other.^{73 74} A fundamental difference between direct and non-invasive ambulatory measurement is that the former gives a continuous record of blood pressure, whereas the non-invasive techniques provide only intermittent measurement. Intermittent measurements correlate well with continuous recordings, however,⁷⁵ and brief periods of intermittent measurement may possibly be as informative as 12 or 24 hour recordings.⁷⁶ Another important difference between direct and non-invasive techniques is that each measures blood pressure in a different way, and the results are different for each method. In general, indirect blood pressure measurement by Korotkoff sound detection slightly underestimates systolic and overestimates diastolic blood pressure recorded directly, the difference being less if disappearance rather than muffling of sounds is the end point for diastolic pressure.^{77 78} More important than the mean difference between the results of direct and indirect measurements is the poor agreement between the two.^{22 77 78}

A device capable of providing an accurate assessment of intra-arterial blood pressure non-invasively would be a worthwhile advance, but none of the indirect measuring devices can do so. New equipment should not be assessed, therefore, against intra-arterially recorded blood pressure as there will always be a difference between the two techniques. There are, however, also many difficulties in assessing new devices against the indirect technique. The results of any direct comparison of a new piece of equipment with the standard method are difficult to interpret because of the variability of blood pressure. To overcome this the agreement between measurements by the instrument being tested and the standard method should match the agreement between repeated standard measurements.

Differences between the direct and indirect techniques have also been shown with ambulatory recording techniques and serve to emphasise that the blood pressure reading obtained directly by intra-arterial methods is different from that measured by indirect sphygmomanometry.⁷⁴

The relevant point for clinicians is that indirect measurement is the technique on which we base our practice, and it is the technique likely to prevail in the foreseeable future. Moreover, when used for ambulatory measurement the technique is safe, can be repeated, and provides useful information in the diagnosis and management of problem cases of hypertension⁷¹ in the study of antihypertensive drugs.^{79 80} In time it should elucidate more clearly the epidemiological consequences of raised blood pressure.⁶⁷ Intra-arterial ambulatory measurement has a valuable, though necessarily limited place in providing research information on the behaviour of blood pressure, particularly in physiological studies^{83 81 82} and in the study of pharmacodynamic changes that might not be apparent from the intermittent measurements provided by non-invasive techniques.⁸³ It would seem prudent, however, to reserve direct measurement for patients in whom a response to treatment has been shown by one of the simpler and safer non-invasive techniques (W A Littler, personal communication).

As with home recording, the results with ambulatory

measurement of blood pressure are generally lower than those obtained at a clinic or office measurement by a doctor.^{67 69 74 84}

Doctor versus patient

It may be helpful in practice and ultimately in understanding the behaviour of the blood pressure to break with the tradition of basing diagnostic and therapeutic decisions on a few isolated measurements of blood pressure. Blood pressure measurements may be considered to take place in two circumstances. Firstly, measurements may be made in the surgery, office, hospital clinic, or laboratory, which may be denoted as doctor recorded measurement. Secondly, more active patient participation may be elicited in home recording and ambulatory measurement. Using this classification we find that patient recorded measurements are generally lower than doctor recorded measurements,^{47 67 71 85} and that this difference is greatest in patients with borderline raised blood pressure.⁷¹

The division between patient recorded measurement and doctor recorded measurement is not absolute and there may be considerable overlap. Also, of the techniques available for doctor recorded measurement, that for measuring basal blood pressure might be expected to give a considerably lower level than that recorded in the hospital laboratory,³⁸ where the defence response may be relied on to provide the best example of "white coat hypertension," so aptly named by Laragh and his colleagues.⁸⁶ Intermediate between these extremes of doctor recorded measurement will be the levels obtained by casual or repeated clinic measurement. With patient recorded measurement the lowest pressures are obtained during sleep⁷¹ and might be expected to approximate to basal measurements obtained in hospital, whereas the highest levels (often approximating to clinic levels) are obtained at work,^{71 87} with home recorded levels being intermediate between the two. The difference between patient recorded measurement and doctor recorded measurement tends to be greater for systolic pressure and in younger people.^{47 48 87} Both methods of patient recorded measurement—that is, home recording and ambulatory measurement—whether non-invasive or direct, are reproducible,^{9 68 87-90} but patient recorded measurement cannot be predicted readily from doctor recorded measurement, especially in patients with borderline raised blood pressure.^{48 84 91} It is those patients, therefore, with smaller rises in blood pressure—the borderline hypertensives in whom the decision to diagnose and treat is most difficult—who are the most susceptible to the circumstances of measurement, and in whom a prediction of patient recorded measurement from clinic measurement which would be so helpful cannot be obtained.

The reasons for the difference between doctor recorded measurement and patient recorded measurement are not fully understood. Pickering believed that each measurement of blood pressure evoked a defence reaction, which was greatest on first measurement and lessened with repeated recordings.⁵¹ The pressor effect of doctors⁹² and its lessening by familiarisation with the circumstances of measurement, though of some importance, are not in themselves wholly accountable for the difference between patient recorded measurement and doctor recorded measurement.^{53 93 94} Hypertension as it develops may enter a labile phase of increased variability, but this seems unlikely as variability is greater the higher the pressure.^{52 95} Possibly people with so called borderline hypertension have an exaggerated pressor

response to the anxiety of a medical examination, which becomes enhanced and possibly self perpetuating when they are given a hypertensive label.⁷¹ The fate of those who respond in this way to an anxiety provoking experience such as a medical examination is not known, but the risk of cardiovascular disease does not appear to be affected by the degree of variability of the pressure.⁹⁵

Patient recorded measurement has several advantages over doctor recorded measurement, among the most important being greater diagnostic accuracy. Many patients diagnosed as having borderline hypertension at the clinic may have normal blood pressures recorded by home measurement^{47 48 93} and ambulatory measurement.^{84 91} If we accept the logic in the reasoning that the cardiovascular complications of hypertension are likely to be more severe in those whose blood pressure is raised most of the time than in those in whom the rise is intermittent, it follows that patient recorded measurement should provide more accurate prognostic information than doctor recorded measurement. Such appears to be the case: left ventricular hypertrophy correlates better with patient recorded measurement than with doctor recorded measurement,^{65 96 97} and the incidence of fatal and non-fatal complications of hypertension is predicted with greater accuracy by patient recorded measurement using ambulatory measurement, than by doctor recorded measurement.⁶⁷ The closer correlation of left ventricular hypertrophy with ambulatory blood pressure recorded during work raises interesting questions on the relation between stress responsive personalities and the risk of cardiovascular disease.^{67 98} Non-invasive techniques of ambulatory blood pressure measurement and accurate assessment of left ventricular hypertrophy by echocardiography allow researchers to observe the evolution of one important end organ lesion in borderline hypertension and its regression in established hypertension with treatment.^{97 99 100}

Patient recorded measurement has also proved useful in judging the effect of treatment with antihypertensive drugs.^{9 43 63} Indeed, patients might possibly be able to modify their own treatment according to the level of self recorded blood pressure.¹⁰¹ By providing an assessment of blood pressure throughout the day, patient recorded measurement facilitates the detection of drug induced decreases in blood pressure that may not be detected with doctor recorded measurement.^{46 53 79 102}

The value of doctor recorded treatment alone in the assessment of hypertension has been questioned, and home recording, ambulatory measurement, or both, have been suggested as preferable.⁴³ What is not clear is whether ambulatory techniques provide a better assessment of patient recorded measurement than home recording.⁹³ The accuracy and reproducibility of both techniques are reasonably good, though the usefulness of either method may depend on the frequency of measurement in a 24 hour period.¹⁰³ The high cost of non-invasive ambulatory equipment,⁶³ its maintenance, and the finance for a technician must restrict the use of this technique, but, when balanced against the difficulties of diagnosis in borderline hypertension and the potential cost of an incorrect diagnosis, ambulatory techniques may be reasonable value for money. None the less, widespread purchasing of these units cannot be advocated, and a rational policy would restrict their use to blood pressure units. By comparison, home recording is much cheaper in the initial outlay and may provide a reasonable index of ambulatory blood pressure.^{86 104} Against this the cost of training patients and the problems of compliance with the technique and of inaccurate or factitious recordings must be taken into

consideration.^{48 101 105} Moreover, doctors may be reluctant to use the technique.¹⁰⁶

Conclusions

What conclusions, then, are relevant to the clinical management of hypertension? The auscultatory method of blood pressure measurement is imperfect and subject to many errors that can be reduced by careful technique and regular maintenance of equipment. Automated devices should not be purchased unless supported by data on their accuracy from an independent, reputable laboratory. The mercury sphygmomanometer remains the cheapest and most accurate device for routine measurement of the blood pressure. Many people classified as hypertensive by doctor recorded measurement will be normotensive with patient recorded measurement. Doctor recorded measurement may be failing to detect hypertensives at risk from cardiovascular complications, especially those with borderline rises in blood pressure. Disquietingly, patient recorded measurement cannot be predicted from doctor recorded measurement, which in practice means that the time honoured method of measuring the blood pressure in the surgery or clinic may be less than ideal in the diagnosis, management, and prognosis of hypertension and should perhaps be supplemented by patient recorded measurement, be it home recording or ambulatory measurement or both.

In the past since doctor recorded measurement has

provided the data from which the epidemiological conclusions that direct practice are derived, many normotensive subjects have probably been included in epidemiological and therapeutic studies. Future well planned studies with non-invasive ambulatory techniques and perhaps also home recording should provide more accurate identification of those patients with borderline raised pressures who do not need antihypertensive drug treatment—as well as those who do. This becomes increasingly urgent as the results of recent trials lend support to recommendations for treating lower levels of blood pressure. We must begin to characterise more accurately those patients requiring intervention. In doing so considerations of benefits and cost will loom large, but if the financial, therapeutic, and social consequences of unnecessarily labelling many thousands as “hypertensives” are taken into account undoubtedly blood pressure behaviour must be assessed more accurately. In many cases this will require more than an occasional blood pressure reading taken in the clinic or office.

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