

9. Classic sphygmomanometry: *A fin de siecle* reappraisal

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Sphygmomanometry has evolved over nearly three centuries but conventional sphygmomanometry, the technique with which we are all so familiar in clinical practice, was introduced just over a century ago by Riva-Rocci in 1896 and modified by Korotkov in 1905 (1–10). However, as we enter the twenty-first century a number of developments, not least being the availability of accurate automated devices, herald the demise of so-called classic sphygmomanometry and the dawning of a new era in blood pressure measurement.

We propose in this essay, therefore, not to dwell on the classic technique of blood pressure measurement using a mercury sphygmomanometer, an occluding cuff and a stethoscope as this technique has been described in detail in 1995 (11), but rather to examine the issues that are influencing a radical change in sphygmomanometry as we enter the next millennium. These are the impending banning of mercury from clinical use, the availability of accurate automated devices and an awareness that profiles of blood pressure behaviour, such as those obtained with ambulatory measurement, facilitate the diagnosis and management of patients with hypertension.

I. BANNING OF MERCURY

Mercury and the environment

Why, we might ask, should we not continue using the mercury sphygmomanometer which has served us well for the past hundred years? The call to have mercury removed from hospitals comes from the environmental lobby which, quite correctly, sees mercury as a toxic, persistent and bioaccumable substance. What happens, they ask, to the many tons of mercury supplied for the manufacture of sphygmomanometers and then distributed throughout the world to hospitals and countless individual doctors? Quite simply it finds its way back into the environment through evaporation, sewage or in solid waste, most seriously damaging the marine environment, and it accumulates in soil and in sediments thereby entering the food chain. In truth, it is likely that the risk of mercury toxicity to a user of a sphygmomanometer is small (12) (thermometers were probably a greater source of mercury under hospital floorboards than sphygmomanometers and only one case of mercury poisoning associated with health care employees has been reported and that in a man who repaired sphygmomanometers in a poorly ventilated room (12, 13)), but this argument rather misses

the point that has been made by the ecologists and environmentalists, who in the "Final declaration from the third International Conference on the Protection of the North Sea" have resolved to reduce mercury to "levels that are not harmful to man or nature before the year 2000" (14). The mercury thermometer has been replaced in many countries, and in Scandinavian countries and in the Netherlands, where the use of mercury is no longer permitted in hospitals, the mercury sphygmomanometer is being relegated to the museum shelves (15). However, in the rest of Europe the move to ban mercury from hospital use has been resisted for the moment on the grounds that the once common alternative, the aneroid sphygmomanometer, becomes inaccurate with use and should not, therefore, be substituted for the mercury instrument (16).

Introduction of the kilopascal

Banning mercury from the wards raises another issue of even greater importance for clinical medicine. If the millimetre of mercury is no longer the unit of measurement for blood pressure, there can be no scientific argument against its replacement with the *Système International* (SI) unit, the kilopascal (8, 12). If we look back 20 years or so when it was mooted that the kilopascal should become the measure of pressure in medicine there was an indigent outcry from doctors who claimed that the confusion resulting from such a change of unitage would be unacceptable. They won the day but on the understanding that the moratorium would last only until such time as a suitable replacement could be found for the mercury sphygmomanometer (12, 16–18). So it would seem that when the mercury sphygmomanometer goes, the mainstay of the medical argument for retaining the millimetre of mercury as a unit of measurement, namely that we measure what we see, will also disappear.

How then should the medical profession react? It could fight for retention of mercury for medical use but the weight of argument from the environmentalists would overturn this tactic. Then it could be argued that even if the mercury sphygmomanometer must go, introducing the kilopascal into clinical practice as well would be unacceptable because of the resulting chaos. The same line of reasoning was used unsuccessfully against introducing SI units into the biochemistry of medicine and, again, is unlikely to succeed.

An alternative approach would be to anticipate and welcome the necessity for change and to use the next decade as an opportunity to give back to sphygmomanometry the scientific integrity on which its founders were so insistent. To begin with, we should accept that blood pressure measurement as performed in clinical practice today is a grossly inaccurate procedure, yet one on which we are prepared to base management decisions with serious long-reaching consequences for the patient. Provided we insist on certain standards, technology can now provide acceptable automated alternatives to the mercury sphygmomanometer. Let us not then persist further in arguing on behalf of the mercury sphygmomanometer other than for its retention as a gold standard to be used for the laboratory validation of equipment and the like.

With regard to the kilopascal we could take the scientific view that a common unitage for pressure measurement is desirable and, that in scientific terms, there can be little justification for retaining the archaic millimetre of mercury, especially as it would no longer exist. Indeed one of the major sources of bias in blood pressure measurement is that the mercury unitage lends itself to tidy rounding which results in a huge digit preference for zero, which is to say the least, most unscientific (12). The kilopascal (kPa) does not lend itself as readily to such behaviour. For example, 90 mmHg is equivalent to 12.00 kPa, 100 mmHg to 13.33 kPa, 150 mmHg to 20.00 kPa, 160 mmHg to 21.33 kPa, 200 mmHg to 26.66 kPa,

and so on. Indeed, if we take the scientific argument further, we would acknowledge that there is a remarkable lack of agreement internationally as to what constitutes hypertension and at which levels of blood pressure treatment should, or should not, be instigated (12). This being so, we could use the introduction of a new unit of measurement as an opportunity to prepare internationally agreed definitions of normotension and hypertension.

The message would therefore seem to be that we should begin to prepare for inevitable change. Perhaps a first step might be that when our mercury sphygmomanometers need replacement we should opt for an accurate independently validated automated device. Manufacturers of automated devices should provide both the mercury and kilopascal scales so that we may begin to familiarise ourselves with the latter in anticipation that it will be ultimately adopted as the unit for measurement of pressure in medicine.

II. AUTOMATED DEVICES

An automated alternative to mercury

Let us assume, for the sake of argument, that disappearance of mercury sphygmomanometers from clinical practice is inevitable (as it probably is) over the next decade, either gradually or ultimately by direction, and examine the consequences of this eventuality for hypertension practice. The passing of mercury sphygmomanometers should not in itself be a cause for concern. In fact, it might be argued that the sooner we rid ourselves of this most inaccurate technique, on which we base so many important decisions of management, the better. This is not to blame the mercury sphygmomanometer but rather to impugn the most fallible part of the whole procedure, the human observer (19). Automated devices are improving in accuracy and have the advantage of providing a print-out with the time and date of blood pressure measurement, thereby removing observer bias and error due to poor technique (20). But automation is not without its problems. Automated devices have been notorious for their inaccuracy (21) and though accurate devices are now appearing on the market, they are not designed for hospital use and their accuracy after a period of time in such use has not been established. Moreover, without the mercury standard against which to compare measurements generated by algorithmic interpretation of blood pressure, the clinician is dependent on the consistency and accuracy of such algorithms. Three conclusions arise, therefore. First, automated devices must be developed for a variety of clinical situations, such as hospital use; at present, most automated devices are designed for the home market of self-measurement and are unsuited for use in hospitals or general practice. Second, automated devices must be rigorously tested for accuracy according to either the protocol of the British Hypertension Society (22), or the Association for the Advancement of Medical Instrumentation (23). And lastly, the mercury sphygmomanometer will have to remain in certain laboratories as the gold standard against which algorithms may be checked from time to time. Bearing these points in mind, it may be helpful to determine what automated devices are available to us.

State of the market for automated devices in 1998

Automated devices for self-measurement of blood pressure. There is an enormous market for automated devices that permit self-measurement of blood pressure. In Germany, for example, 1.2 million such devices are sold annually (24). In 1994, Ng and Small surveyed 423 automated devices, of which 161 were for the self-measurement of blood pressure (25).

TABLE 1. Automated blood pressure measuring devices for self-measurement available on the market which have been subjected to validation by the BHS** and AAMI*** protocols

Device	Mode	AAMI	BHS	Circumstance
Omron HEM-400C (21)	Osc	Failed	Failed	At rest
Philips HP5308 (21)	Aus	Failed	Failed	At rest
Healthcheck CX-5 060020 (21)	Osc	Failed	Failed	At rest
Nissei Analogue Monitor (21)	Aus	Failed	Failed	At rest
Philips HP5306/B (21)	Osc	Failed	Failed	At rest
Systema Dr MI-150 (21)	Osc	Failed	Failed	At rest
Fortec Dr MI-100 (21)	Osc	Failed	Failed	At rest
Omron HEM-705CP (20)	Osc	Passed	B/A	At rest
Philips HP5332 (20)	Osc	Failed	C/A	At rest
Nissei DS-175 (20)	Osc	Failed	D/A	At rest
Omron HEM 706 (26)	Osc	Passed	B/C	At rest
Omron HEM 403C (27)	Osc	Passed	NA	Protocol violation
Omron HEM-703CP (29)	Osc	Passed	NA	Intra-arterial at rest
Omron R3 (24)	Wrist	Passed	NA	Intra-arterial at rest

Grades A–D according to BHS protocol; A = best agreement, D = worst agreement with mercury standard. Note in the first 7 devices grading criteria had not been established though BHS protocol was in operation.

Osc = oscillometric mode; Aus = auscultatory mode; NA = not applicable.

Intra-arterial measures were at rest.

** Criteria for fulfilment of BHS protocol: devices must achieve at least grade B/B.

*** Criteria for fulfilment of AAMI standard: mean difference ≤ 5 mmHg/SD ≤ 8 mmHg.

Only a fraction of the many hundreds of models available world-wide have been subjected to independent validation. A review of the literature in 1998 to determine which automated devices for self-measurement of blood pressure had been validated according to the BHS and/or AAMI protocols shows that ten such devices had been validated, of which one was deemed satisfactory according to the criteria of the BHS and standard AAMI protocols. However, if the intra-arterial comparisons of the AAMI protocol and the new German protocol are accepted, a further two devices may be added (Table 1).

In the first validation study in 1989 using an early version of the BHS and AAMI protocols, all seven devices tested – the Omron HEM-400C, Philips HP5308, Healthcheck ‘Cuffless’ CX-5 060020, Nissei Analogue Monitor, Philips HP5306/B, Systema Dr MI-150 and Fortec Dr MI-100 – failed to fulfil the accuracy criteria of either protocol, whereas the mercury sphygmomanometer was comfortably within the criteria of both protocols (21). The Omron company is the first manufacturer of devices for self-measurement of blood pressure to have produced a device fulfilling the requirements of the BHS and AAMI protocols, as far as we are aware. The Omron HEM-705CP achieved acceptable grades of B for systolic blood pressure and A for diastolic blood pressure according to the BHS criteria and fulfilled the accuracy criteria of the AAMI protocol, whereas in the same study the Philips HP5332 and the Nissei DS-175 achieved unacceptable BHS grades and failed the AAMI criteria for accuracy (20). In another study, the Omron HEM 706, achieved BHS grades B/C in the overall pressure range and fulfilled the AAMI accuracy criteria (26). The Omron HEM 403C has also been evaluated according to the BHS protocol but the protocol was violated by substitution of the Hawksley random zero sphygmomanometer

for the standard mercury sphygmomanometer (27). As our group has shown, devices assessed against the Hawksley sphygmomanometer may be disadvantaged and the C grades obtained for both systolic and diastolic pressures with the Omron HEM 403C are at best questionable (28). The AAMI protocol permits direct intra-arterial comparison in a small number of subjects (23), whereas the BHS protocol does not allow intra-arterial comparison for a number of reasons, the most important of which is that systolic and diastolic blood pressure values obtained by the direct technique are different to measurements by indirect methods and clinical practice derives from data obtained by the indirect rather than the direct technique (22). Using intra-arterial comparison, the Omron HEM-703CP was shown to fulfil the criteria of the AAMI protocol (29). The German protocol for validation also permits intra-arterial comparisons and using this protocol (30), the Omron R3, a device that measures blood pressure oscillometrically on the wrist has fulfilled the protocol requirements (24). It is estimated that wrist measuring devices have gained 50% of the market share of the 1.2 million blood pressure devices sold annually in Germany for self-measurement of blood pressure (24).

Automated devices for measurement of ambulatory blood pressure. The state of the market of ambulatory blood pressure measuring devices when reviewed in 1995 showed that of 43 devices on the market, 18 had been validated according to the protocols of either the AAMI or BHS, and of these nine had failed to adhere to the protocols and nine devices fulfilled their requirements (31). A further review of the literature in 1998 has yielded 25 validation studies performed on 16 ambulatory systems according to the BHS and/or AAMI protocols, of which 12 devices fulfilled the criteria for one or both protocols (Table 2); these are the A & D TM 2420 Models 6 and 7 and TM 2421, CH-Druck, Daypress 500, DIASYS Integra, Nissei ABPM DS-240, Profimat, QuietTrak, Schiller BR, SpaceLabs SL-90202 and SpaceLabs SL-90207 (32–55). It is interesting and commendable to note that many of these devices have now been validated in varying populations, such as the elderly and in pregnancy, and in special circumstances, such as in varying postures and during exercise.

However much an improvement ambulatory blood pressure measurement may be over conventional measurement, it must be remembered that the technique only permits intermittent recording of blood pressure over time, and it is somewhat surprising that even with measurements spaced as far apart as thirty minutes, it can give so much information about circadian variation in blood pressure. To be able to detect the influence of a variety of interventions, such as drugs, hormones and stress-related phenomenon, a continuous waveform of blood pressure is required, such as was obtained with direct intra-arterial measurement. In Amsterdam, Wesseling and his group have been developing the method of dynamic unloading of the finger arterial wall pulsations using an inflatable finger cuff with a built-in photo-electric plethysmograph which provides the measurement of continuous finger arterial pressure. Known as the Finapres, this device can be used to detect subtle changes in arterial pressure, which might be missed with intermittent pressure recording (56).

Automated devices for specialised hospital use. There are many automated devices available for use in specialised areas of hospital, such as theatres and intensive care units, and in the transport of patients, but these are rarely subjected to independent validation studies. Ng has reviewed the operational methodology and listed 258 such devices (57). A review of the literature in 1998 indicates that only two devices designed primarily for specialised hospital use (though these devices may be applied to other uses, such as epidemiological studies) have been validated according to the BHS and/or AAMI protocols (Table 3). The

TABLE 2. Automated devices for ambulatory blood pressure measurement available on the market which have been subjected to validation by the BHS** and AAMI*** protocols

Device	Mode	AAMI	BHS	Circumstance
Accutacker II (30/23) (32)	Aus	Passed	A/C	At rest
CH-DRUCK (103)* (33)	Aus	Passed	A/A	At rest/over pressure ranges
Daypress 500 (346)	Osc	Passed	A/B	At rest
DIASYS 200 (35)	Aus	Passed	C/C	At rest
DIASYS Integra (36)	Aus	Passed	B/A	At rest/over pressure ranges
	Osc	Passed	B/B	At rest/over pressure ranges
Nissei DS-240 (37)	Osc	Passed	B/A	At rest
Profilomat* (38)	Aus	Passed	B/A	At rest/over pressure ranges
Profilomat* (39)	Aus	Passed	B/C	Pregnancy
Profilomat II (40)	Osc	Failed	D/C	At rest/over pressure ranges
QuietTrak* (41, 42)	Aus	Passed	B/B	At rest
QuietTrak* (43)	Aus	Failed	B/B	Pregnancy
QuietTrak* (44)	Aus	Passed	A/A	At rest
				Exercise
				Posture
				Elderly
				Children
				Pregnancy
Schiller BR (45)	Aus	Passed	B/B	At rest/over pressure ranges
	Osc	Failed	D/B	At rest/over pressure ranges
SpaceLabs 90202 (46)	Osc	Passed	B/B	At rest
SpaceLabs 90207 (47)	Osc	Passed	B/B	At rest/ over pressure ranges
SpaceLabs 90207 (48)	Osc	Passed	A/C	Pregnancy
SpaceLabs 90207 (49)	Osc	Passed	B/B	Pregnancy
SpaceLabs 90207 (50)	Osc	Passed	B/C	Pregnancy
SpaceLabs 90207 (51)	Osc	SBP Passed	C	Children
		DBP Failed	D	Children
SpaceLabs 90207 (52)	Osc	Passed	A/C	Elderly
				Posture
TM-2420 Model 5 (53)	Osc	Passed	C/C	At rest
TM 2420 Model 6 (54)	Osc	Passed	B/B	At rest
TM-2421 (55)	Osc	Passed	B/A	At rest

Grades A–D according to BHS protocol; A = best agreement, D = worst agreement with mercury standard.

Osc = oscillometric mode; Aus = auscultatory mode.

* Model number not denoted.

** Criteria for fulfilment of BHS protocol: devices must achieve at least grade B/B.

*** Criteria for fulfilment of AAMI standard: mean difference ≤ 5 mmHg/SD ≤ 8 mmHg.

Dinamap Portable Monitor, Model 8100, one of the most popular automated devices in use in clinical practice and hypertension research, despite a number of reports demonstrating inaccuracy, achieved an acceptable Grade B for systolic pressure (with 66% of pressures being within 5 mmHg of the mercury sphygmomanometer), but an unacceptable D grade for diastolic blood pressure with less than 50% of pressures being within 5 mmHg of the mercury standard, using the BHS protocol. The device failed the AAMI accuracy criteria for diastolic blood pressure (58, 59).

TABLE 3. *Automated blood pressure measuring devices for specialised hospital use available on the market which have been subjected to validation by the BHS** and AAMI*** protocols*

Device	Mode	AAMI	BHS	Circumstance
The Dinamap Model 8100 (58, 59)	Osc	Failed	B/D	At rest
Colin Pilot 9200 (60)	Tonometry	Passed	NA	Intra-arterial at rest

Grades A–D according to BHS protocol; A = best agreement, D = worst agreement with mercury standard.

Osc = oscillometric mode.

** Criteria for fulfilment of BHS protocol: devices must achieve at least grade B/B.

*** Criteria for fulfilment of AAMI standard: mean difference ≤ 5 mmHg/SD ≤ 8 mmHg.

The AAMI protocol provides for intra-arterial validation of blood pressure measuring devices and using intra-arterial comparisons, the Colin Pilot 9200, a multiparameter vital signs monitor, fulfilled the accuracy criteria of the protocol (60).

Banning of mercury and creation of demand for an automated 'clinical' sphygmomanometer. The probable disappearance of the traditional sphygmomanometer will create a large market for an alternative device. Aneroid sphygmomanometers traditionally have been the alternative to the mercury device, but aneroid sphygmomanometers become inaccurate with use without the operator being aware of such inaccuracy (61). Automated devices, which are dependent on an algorithm cannot develop inherent inaccuracy, though the device may fail to function for other reasons. Efforts are presently being made to encourage the development of an accurate automated device suitable for use in the hospital environment and general practice. (Personal communication from Working Party on Blood Pressure Measurement of the BHS.) Obviously, the need for independent validation of an automated substitute for the traditional mercury sphygmomanometer in hospital use will be mandatory.

III. AMBULATORY BLOOD PRESSURE MEASUREMENT

If one had to single out the most important event in blood pressure measurement since the introduction of clinical sphygmomanometry a century ago, it would be appreciation of the variability of blood pressure whereby isolated, or casual, blood pressure measurements are likely to give misleading information, and that to overcome this problem, reliance should be placed on profiles of blood pressure behaviour over time.

The technique of ambulatory blood pressure measurement (ABPM) has provided new insights into blood pressure behaviour and is useful in the diagnosis and management of hypertension. ABPM provides an alternative method for obtaining multiple estimates of blood pressure, resulting in improved reproducibility of blood pressure measurement. Additional advantages of ABPM include a means of excluding white coat hypertension, and of obtaining a profile of circadian blood pressure behaviour thereby allowing identification of patterns of hypertension. For example, isolated systolic hypertension, isolated diastolic hypertension, white coat hypertension and nocturnal hypertension can be identified. It is known that some of these patterns have different pathophysiological aetiologies, and outcome data suggest differential prognoses (62–67). Apart from these advantages, the popularity of ABPM in clinical practice derives also from the finding that this technique

is a better predictor of cardiovascular target organ involvement than clinic measurement (68, 69), and, more recently, that the quality of hypertension management is better for patients followed with ABPM than clinic measurement (70). Furthermore, evidence exists that ABPM stratifies cardiovascular risk in essential hypertension independently of clinic pressure, and by identifying particular patterns of circadian blood pressure abnormalities, such as non-dipping blood pressure, adds extra diagnostic information to blood pressure measurement (71). ABPM has now become accepted as an accurate, reproducible and in many aspects a superior methodology to traditional measurement (70). The importance of validation requirements for device accuracy have been discussed above but it may be reiterated that prospective purchasers of expensive ambulatory systems should always ask manufacturers to produce published evidence of independent validation.

ABPM in diagnosis

ABPM profiles permit a number of phenomena in hypertension to be more clearly identified than is the case with other methods of blood pressure measurement. However, before it is reasonable to deliberate on abnormal profiles, it is necessary to establish what constitutes normality.

Defining normality. It seems strange that the definition of normality for a condition as ubiquitous as hypertension should be so difficult to agree upon. It is also an ongoing embarrassment for those with an interest in ABPM that international agreement on normal levels of ABPM seems so elusive (72).

Blood pressure is a continuous variable. It is therefore impossible to draw a line on the scale of blood pressure above which all are at risk of disease, and below which the risk does not exist. Any discussion about pathological blood pressure readings is also erroneous; it is the effect of elevation of blood pressure together with other risk factors, such as hypercholesterolaemia that determines the effect over time on the end-organs of heart, brain, eye and kidney which are the hallmarks of hypertensive pathology. It makes more sense clinically, perhaps, to talk in terms of 'soft' markers of normotension and abnormal blood pressure elevation. In fact, physicians have been doing this for years in speaking of patients with 'high' blood pressure, 'severe' or 'mild' hypertension. These phrases intentionally are scientifically vague, yet are perhaps more helpful clinically than actual numbers in terms of identifying patients who are at risk; they are patient management terms.

As a result of the increased accuracy that ABPM brings to blood pressure measurement, values can be given to delineate 'normal', 'borderline', and 'high' strata of blood pressure. These terms again are not intended to be cast-iron thresholds for treatment. They are essentially contextual, and the decision to treat or not to treat must also include other factors in the patient's cardiovascular risk profile, such as age, sex, smoking, lipid profile, family history, menopausal status, etc. Adopting this approach leads to the concept of the absolute risk in the management of cardiovascular disease. A fifty year old man with a blood pressure of 150/90 mmHg who is a non-smoker, with normal body weight, normal lipids and no evidence of target organ damage is at negligible risk compared to a male of the same age with a similar blood pressure, who smokes, is overweight, has hypercholesterolaemia and shows evidence of target organ involvement on echocardiography or retinal fundoscopy. The overall status of the patient in the context of blood pressure elevation is therefore of paramount importance when deciding on treatment.

Approaches to defining normality. Several approaches may be followed in defining normality:

- ABPM may be performed in large populations of hypertensive patients not on anti-hypertensive treatment. The levels of pressure at which cardiovascular risk begins to rise above the 'noise' of background cardiovascular events would then mark a clinically meaningful level of blood pressure at which to consider treatment. This is not acceptable as the background level may demand treatment and the approach is not feasible, practically or ethically.
- ABPM may be performed in a large normal population, and the resulting levels can then be correlated with clinic blood pressure levels (73). A clinic pressure of widely accepted significance, 140 mmHg systolic and 90 mmHg diastolic, can then be equated to a corresponding ABPM value. This is a controversial methodology; it depends on the assumption that clinic and ABPM measure the same thing, when, it is becoming increasingly clear, they do not. Clinic pressures, for example, take no cognisance of nocturnal reductions in pressure, or white coat effect.
- ABPM can be performed in a large normal population, and the 90th or 95th percentile of blood pressure, or two standard deviations from the mean pressure value can be determined. These would then be considered the population levels for normality. The problem with this approach is, most obviously, it confers clinical significance on a statistical construct. It automatically defines a set proportion of the population as being abnormal, and needing treatment. If we calculate these 'abnormal' limits for each age/sex cohort, we assume the proportion of the population with hypertension is constant with age, whereas the converse is known to be true.
- ABPM can be performed in a large population, and the level of ABPM below which end-organ damage, such as left ventricular hypertrophy, is rare (74) can be determined; this has the advantage of giving a level which is clinically relevant, and will mean that treatment determined by this level will actually treat a higher risk group. The disadvantage is that it will perforce lead to high levels of pressure before treatment is initiated, whereas treatment below this level might ideally prevent complications.
- Finally, one can choose a level of blood pressure from any or all of the above methods, and test the theory that treatment is beneficial above this level. This is the conventional approach used for clinic BP, but has the disadvantages of being slow and fraught with practical and ethical difficulties. A number of studies using this approach are underway, though it will be some years before results are available.

A working recommendation has been arrived at independently by the American Society of Hypertension (75) and O'Brien and Staessen (69), who have extensively analysed the international literature (Table 4), and whose recommendations are broadly in agreement with the recent report of the Joint National Committee in the USA (76), and a recent international consensus paper (72). On the basis of present knowledge, summary management recommendations might be as shown in Table 5.

ABPM in clinical practice. Having arrived at a working set of figures for ABPM, it is now possible to turn attention to the clinical application of ABPM. In fact ABPM permits detection of a number of patterns of diurnal blood pressure which is not possible with the conventional technique. The use of ambulatory monitoring in clinical practice has demonstrated that hypertension is not a single pathological entity, denoted by a single blood pressure reading above an arbitrary level, but rather a clinical syndrome manifest by a number of patterns within the 24-hour blood pressure profile. These patterns can be

TABLE 4. Working levels for normal ambulatory blood pressure

		Normal	Borderline	Abnormal
ASH (75)	Daytime	<135/85	135–140/85–90	>140/90
	Night-time	<120/75	120–125/75–80	>125/80
	24-hour	<130/80	130–135/80–85	>135/85
O'Brien/Staessen (69)	Daytime	< 135/85	135–139/85–89	≥140/90
	Night-time	<120/70	120–124/70–74	≥125/75
	24-hour	<130/80	130–134/80–84	≥135/85

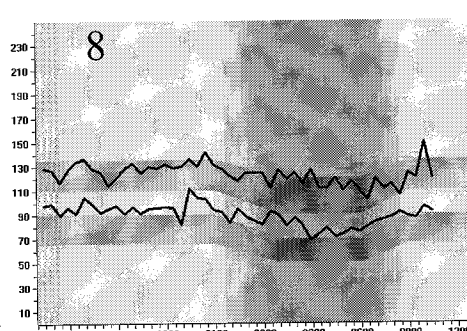
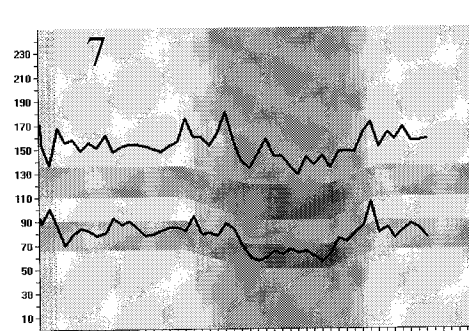
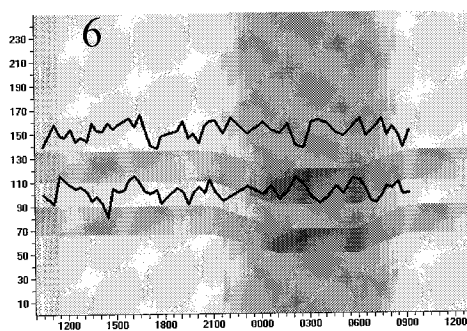
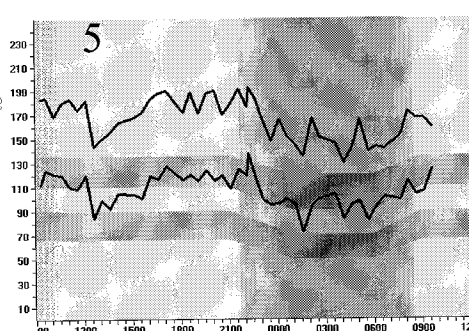
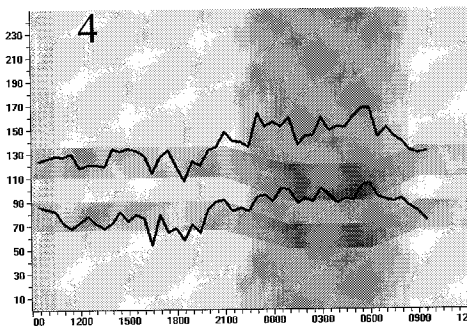
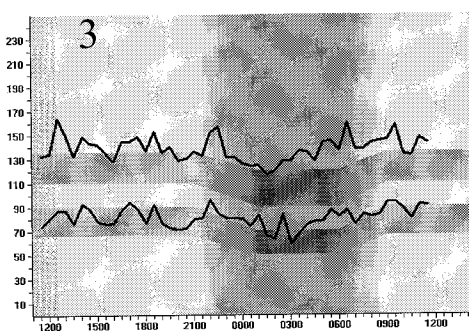
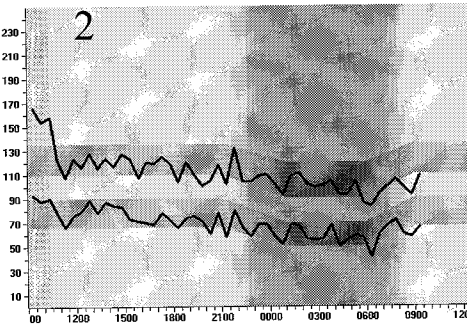
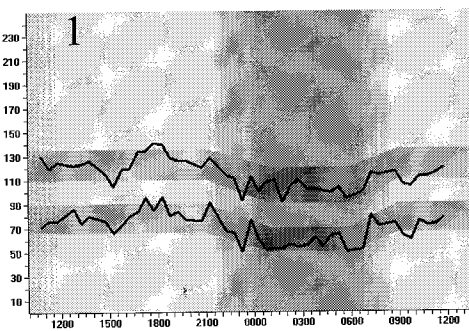
TABLE 5. Levels of ABPM as a guide to management

ABPM (day)	<135/85	135–140/85–90	140–150/90–95	>150/95
Management	No treatment	Treat only if significant other risk factors	Treat unless patient is young, without other risk factors	Always treat

categorised as white coat hypertension, borderline hypertension, isolated systolic hypertension, isolated diastolic hypertension, systolic and diastolic hypertension, and nocturnal hypertension (Fig. 1). There is evidence (62–67) that these clinical patterns may differ in aetiology, and that they may have implications for prognosis and for the treatment of hypertension. The prevalence of these sub-forms of hypertension has recently also been described in the hypertensive population (77) (Fig. 2).

Borderline hypertension. ABPM is particularly helpful in deciding whether subjects with borderline elevation of clinic/office blood pressure, who may be subjected to unnecessary treatment or penalised for insurance cover and employment, should be labelled as hypertensive. In practice, this means that all newly diagnosed hypertensive patients with borderline hypertension should have their 24-hour profile characterised; this should certainly be done before antihypertensive drugs are prescribed. In subjects with borderline hypertension and evidence of target organ involvement but in whom ABPM is normal, hypertension may be excluded as a cause for the target organ damage (Fig. 1).

White coat hypertension. White coat hypertension is the term used to describe a transient hypertensive state whereby blood pressure is elevated when measured by medical personnel – classically in a hospital clinic or doctor's surgery – but normal on 24-hour ambulatory monitoring when the subject has left the medical environment (78) (Fig. 1). Perhaps, the greatest use for ABPM is identification of subjects with white coat hypertension. Though white coat hypertension was recognised shortly after the technique of blood pressure measurement was introduced at the beginning of the century, it was the advent of techniques for measuring blood pressure over 24-hours that demonstrated the condition to be common – some 10 to 20% of so-called hypertensive patients – and a potential cause for mislabelling patients and of overtreating them (79). There is now a substantial literature on the condition examining its prevalence, the possible mechanisms governing the phenomenon and whether or not subjects with white coat hypertension are at increased risk from cardiovascular disease. If they are not at risk, then establishing this diagnosis



using ABPM has profound implications, not just for the individual patient, who can be reassured, but for a large proportion of the patients who have been labelled as 'hypertensive', from whom the burden of unnecessary drug therapy may often be lifted (80).

A study of the available evidence permits some conclusions to be drawn. First, it is necessary to be clear on definition. The term white coat hypertension should be reserved for those subjects whose blood pressure is elevated when measured in the medical environment but then settles to normal throughout the remainder of the 24-hour period. This condition should be differentiated from the white coat response that occurs in patients with hypertension in whom blood pressures are higher when measured by the conventional technique and though pressures are lower when measured by ambulatory techniques they do not return to normal levels. This white coat response occurs in the majority of hypertensive patients. In attempting to answer the important question as to whether or not subjects with white coat hypertension are at increased risk from the cardiovascular complications of hypertension, it should be borne in mind that white coat hypertension is a recently recognised clinical entity and that the necessary longitudinal outcome studies necessary to answer this question are now proceeding. However, there is interesting evidence emerging from a number of studies which have examined the impact of white coat hypertension on surrogate end-points, such as left ventricular mass on echocardiography. These studies show in general that subjects with white coat hypertension are indeed at risk of developing target organ involvement, albeit at a much lesser rate than patients with sustained hypertension (81, 82). It remains to be established satisfactorily however that white coat hypertension is not a pre-hypertensive state (83).

The message from the literature would seem to be this: Subjects with white coat hypertension are not 'normal', and though they may be at risk from the cardiovascular complications of hypertension, this risk is very much less than in subjects with sustained hypertension. Whereas the non-pharmacological means of managing hypertension should be instituted in subjects with white coat hypertension, antihypertensive medication is often not required. Finally, subjects with white coat hypertension should be followed at yearly or two yearly intervals to ensure that sustained hypertension does not develop and to control other relevant risk factors, such as obesity and hyperlipidaemia.

Isolated systolic hypertension in elderly people. Isolated systolic hypertension carries risk for elderly subjects and this risk can be greatly reduced by antihypertensive medication (84). However, as elderly people are particularly susceptible to the adverse effects of

Fig. 1 (left). Patterns of blood pressure elevation evident on ambulatory measurement.

1. White Coat Hypertension (WCH)	Clinic SBP ≥ 140 or DBP ≥ 90 , with normotensive ABPM
2. Borderline Hypertension (BH)	Normotensive bar at least one of: Diurnal SBP 135–39, DBP 85–9 Nocturnal SBP 120–124, DBP 70–74
3. Systolic & Diastolic Hypertension (SDH)	Diurnal SBP ≥ 140 & DBP ≥ 90
4. Nocturnal Hypertension (NH)	Diurnal SBP < 140 , DBP < 90 , Nocturnal SBP ≥ 125 , DBP ≥ 70
5. Normotension	Diurnal SBP < 135 , DBP < 85 Nocturnal SBP < 120 , DBP < 70
6. Systolic & Diastolic Hypertension	Diurnal SBP ≥ 140 & DBP ≥ 90
7. Isolated systolic hypertension (ISH)	Diurnal SBP > 150 , DBP < 90
8. Isolated diastolic hypertension (IDH)	Diurnal SBP < 140 , DBP > 90

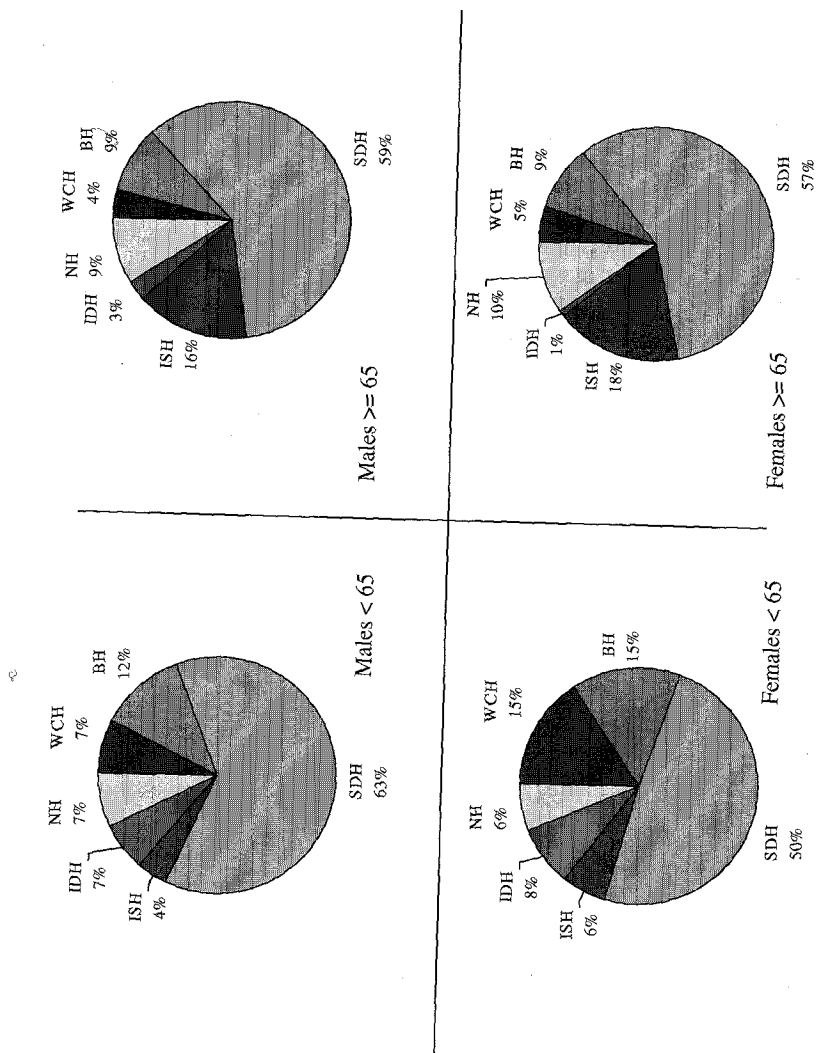


Fig. 2. Prevalence 24-hour ambulatory patterns in hypertensive subjects. F - female, M - male, BH - borderline hypertension, IDH - isolated diastolic hypertension, WCH - white coat hypertension, SDH - systo-diastolic hypertension, ISH - isolated systolic hypertension, NH - nocturnal hypertension.

antihypertensive drugs, those really needing drugs must be identified so that unnecessary treatment is avoided. Furthermore, a number of patients with isolated systolic hypertension will not have sustained elevation of pressure on ABPM and probably do not need treatment (85). ABPM allows identification of elderly patients with sustained elevation of systolic blood pressure and selection of those in need of treatment (Fig. 2). It also shows a characteristic age distribution, with a prevalence in the hypertensive population of less than 5% in the under 40's to over 20% in the over 70's.

Nocturnal dipper status. There is growing evidence that subjects whose blood pressure does not decline at night – non-dippers – may be at higher risk than those who have a nocturnal fall in blood pressure – dippers. These hypertensive patients may be in need of careful blood pressure control and their identification is important. The only means of determining a patient's nocturnal dipping status is by ABPM (Fig. 1). It is known, for example, that nocturnal blood pressure levels are independently associated with end-organ damage (86), over and above the risk associated with day-time values. It has also been shown that absence of nocturnal 'dipping' of blood pressure (87) to lower levels than during the day is associated with target organ involvement and may be a useful clue as to the presence of secondary hypertension (88). The use of absent dipping to predict secondary hypertension has a high negative predictive value, but a low positive predictive value. It is therefore of poor discriminant value as a screening test. It has been argued that the blood pressure at night does not truly reflect the sleeping pressure, as the process of monitoring at night interferes with the quality of sleep (89). However, as the nocturnal data has been shown to provide independently predictive morbidity data, nocturnal blood pressure can be a useful feature of ABPM.

Evaluation of hypotensive symptoms. ABPM is proving useful in diagnosing symptoms due to low blood pressure, especially in elderly patients with autonomic failure. Whereas low blood pressure has been accepted as a cause of debility in mainland Europe, there has been a tendency to dismiss hypotension as of no consequence in the UK and Republic of Ireland. ABPM is permitting a revaluation of this concept through the association of symptoms with the level of blood pressure. Episodes of hypotension are frequently found on ABPM (90). ABPM provides a useful methodology for assessing hypotension and it may also demonstrate drug induced drops in blood pressure which may have untoward effects in patients with compromised arterial circulation, such as those with coronary or carotid stenotic disease.

Pregnancy. Blood pressure in pregnancy is important to measure and quantify accurately. Normal values for ambulatory blood pressure in the pregnant population are available, and have defined the changes in pressure which occur during the trimesters of pregnancy and in the postpartum period (91). As a method of predicting pre-eclamptic toxæmia it has been found to be somewhat limited (92), though maternal hypertension in pregnancy, as diagnosed using ABPM, has been shown to be associated with lower birth weight infants than normotensive women (93).

Other patterns of blood pressure elevation. A number of other patterns of blood pressure elevation are evident using ABPM. Various pressor responses may be demonstrated, the most common being white coat hypertension, but pressor responses to alcohol and catecholamine excretion in pheochromocytoma have also been reported. Isolated diastolic

hypertension (IDH) has also been described (63) (Fig. 1). ABPM data shows a characteristic age distribution, with IDH comprising approximately 10% of hypertensive patients in the under 40's, but falling with age to become a rare finding in the over 70's (77). It would also appear to be a relatively benign finding in terms of outcome (63).

Selection and evaluation of antihypertensive drug treatment in clinical practice

ABPM is proving valuable in selecting a drug regimen suitable for the individual patient rather than relying on the step-care approach.

Selection of drug and dosing regimen. Reference to the plot of 24-hour pressures enables the prescribing doctor to select the drug with a duration of action appropriate to the period of blood pressure elevation for a particular patient. There is some evidence that different groups of drugs may have different effects on the 24-hour blood pressure profile (94).

Efficacy of treatment. Efficacy of blood pressure control with antihypertensive drugs can be more clearly demonstrated on the 24-hour blood pressure profile than with sporadic measurements. ABPM can be particularly helpful in assessing drug efficacy in patients in whom office blood pressures indicate poor control – the resistant hypertensive.

Withdrawal of antihypertensive medication. Patients whose blood pressure was initially diagnosed by office measurement and whose blood pressure has been well controlled may merit a drug-free period for reassessment with ABPM.

Assessment of symptoms on treatment. Excessive reduction in blood pressure with antihypertensive drugs below the lower limit of normal may not only cause symptoms of hypotension, but may carry risk for hypertensive patients (95); this phenomenon, which may occur most often at night in extreme dippers can be readily detected with ABPM. There is now evidence that hypertensive patients whose treated blood pressures are the lowest have the highest incidence of myocardial infarction (96) although this association may not represent cause and effect. Attention must be directed, therefore, not only to the efficacy of blood pressure reduction in studies of antihypertensive drugs but also to the magnitude of this reduction.

ABPM in studies of antihypertensive drug efficacy. ABPM, although relatively new as a technique in clinical practice, is no stranger to hypertension research, where it has played an important part in the evaluation of antihypertensive drugs for many years. In fact, the limitations of conventional measurement are such that ABPM is now considered indispensable for the full assessment of antihypertensive drug efficacy. The advantages of ABPM over conventional techniques may be considered in relation to the ability of the technique to detect drug effects that may not be evident with conventional measurement, to providing information on the duration of antihypertensive drug effect, to improving the design of studies of antihypertensive drug efficacy, to the ability of the technique to demonstrate the effect of drugs on nocturnal blood pressure, and to detecting the potential problems associated with excessive lowering of blood pressure.

One of the most surprising aspects of research into antihypertensive drug efficacy is the readiness with which a blood pressure lowering effect observed at one moment in the 24-hour cycle has been taken to indicate therapeutic efficacy for the whole day. With the

increasing use of new formulations of drugs that permit once and twice daily dosage, it is now more important than ever to be able to assess the pattern as well as the duration of drug effect.

There is some evidence that different groups of antihypertensive drugs may perturb the circadian pattern of blood pressure in different ways (94). Hypertensive individuals on angiotensin converting enzyme inhibitors have been shown to have had markedly accentuated systolic and diastolic dipping patterns when compared with untreated hypertensives and patients on B-blockers; however hypertensive patients treated with B-blockers, calcium antagonists or diuretics had diastolic and systolic dipping patterns similar to those of the untreated groups.

IV. A LAST CONUNDRUM: THE NEED TO SOLVE THE CUFF CONTROVERSY

However sophisticated a blood pressure measuring device may be, if it is dependent on cuff occlusion of the arm (as are the majority of devices), it will then be prone to the inaccuracy induced by miscuffing, whereby a cuff containing a bladder that is either too long or too short relative to arm circumference is used (97).

A review of the literature on the century-old controversy relating to the error that may be introduced to blood pressure measurement by using an cuff with a bladder of inappropriate dimensions for the arm for which it is intended has shown that miscuffing is a serious source of error which must inevitably lead to incorrect diagnosis in practice and erroneous conclusions in hypertension research (98). There is unequivocal evidence that either too narrow or too short a bladder (undercuffing) will cause overestimation of blood pressure and there is growing evidence that too wide or too long a bladder (overcuffing) may cause underestimation of blood pressure. Undercuffing has the effect in clinical practice of over-diagnosing hypertension and overcuffing leads to hypertensive subjects being diagnosed as normotensive. Either eventuality has serious implications for the epidemiology of hypertension and clinical practice (89). A review of the literature shows that a number of approaches have been used over the years to cope with the difficulty of mismatching and none has been ideal; (98) these have included:

Application of correction factors. Correction formulae to adjust measurement errors deriving from the use of an inappropriate bladder have been recommended but this option has the disadvantage of further complicating the procedure of blood pressure measurement and it has not found acceptance even when incorporated as a correction band in the standard cuff.

A range of cuffs. Many national bodies have recommended a range of cuffs to cater for all eventualities. However, this solution, presupposes that the user will firstly measure the arm circumference and that, having done so, an adequate range of cuffs will be available. In practice, neither of these requirements is easily fulfilled.

Cuffs containing a variety of bladders. A cuff containing three inflatable bladders of varying dimensions has been designed to permit the choice of the most suitable bladder for the arm in which pressure is being measured – (Tricuff, Pressure Group AB, Sweden). This cuff, though improving the accuracy of measurement, has a number of disadvantages which include cost, the difficulty of applying the cuff in routine practice and the stiffness of the cuff.

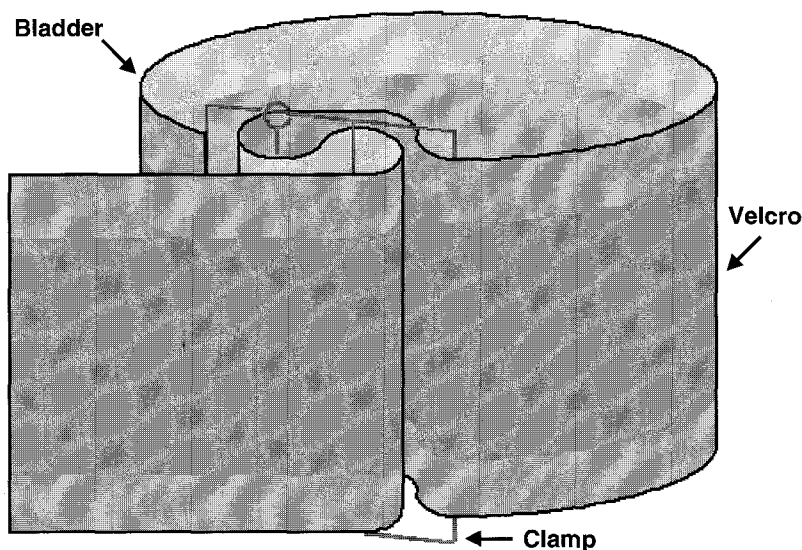


Fig. 3. Diagram for an 'Adult Cuff'. The inflatable bladder occupies the entire cuff and can be clamped according to the arm circumference so that regardless of the arm circumference, the inflated bladder always completely encircles the arm, thus removing the error due to 'overcuffing' or 'undercuffing'.

A cuff for the majority of arms. In an effort to overcome the problem of having a large selection of bladders available, the British Hypertension Society and the British Standards Institution, recommended a cuff containing a bladder measuring 35×12 cm on the basis that such a bladder would encircle the majority of adult arms. This recommendation presupposed, however, that an error would not be introduced by overcuffing of lean arms. The review of the literature suggests that this presupposition is no longer tenable, though the degree of error remains to be quantified (98).

A detailed review of the literature permits a definitive statement on bladder dimensions for a given arm circumference and clearly indicates that substantial error is caused by the use of inappropriate cuffs. The concept of a cuff that would satisfy most clinical requirements, as is intended with the BHS cuff for the majority of arms and the Tricuff, is the most practical approach to the problem but each has limitations, which could, however, be overcome.

A proposal for the future – the 'Adult Cuff'. On the basis of a thorough examination of the literature and aware of the advances in cuff design, the design features for an 'Adult Cuff' which would be applicable to all adult arms, have been proposed, and it is hoped that manufacturers may take up the challenge of producing such a cuff (98) (Fig. 3).

Concluding comment

We are moving into an age in which automated measurement of blood pressure will soon replace the conventional technique sphygmomanometry. It may be anticipated that computer technology will facilitate the development of innovative measuring techniques.

While welcoming these advances, we must ensure that accuracy does not fall victim to technological ingenuity.

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