Journal of Human Hypertension (1991) **5**, (Suppl. 2), 23–30

Ambulatory blood pressure measurement in the diagnosis and management of hypertension

Eoin O'Brien, Kevin O'Malley, Fáinsía Mee, Neil Atkins & John Cox

Blood Pressure Unit, Beaumont Hospital, Dublin 9, Ireland

Summary: **Before the diagnostic potential of 24-hour non-invasive BP measurement can be assessed, the accuracy of ambulatory recorders must be established, and normal reference values determined. The accuracy criteria of four ambulatory BP measuring systems (the SpaceLabs 90207, the Novecor DIASYS 200, the Takeda TM-2420 and the Del Mar Avionics Pressurometer IV) have been assessed according to the British Hypertension Society (BHS) protocol, and the Medilog, Suntech Accutracker II and the Spacelabs 90202 according to the standard of the Association for the Advancement of Medical Instrumentation (AAMI). The Spacelabs 90202 and 90207, the DIASYS 200 and the Medilog fulfilled the AAMI criteria. The best devices with the BHS grading system are the Spacelabs 90207 and the DIASYS 200.**

Normal reference values for daytime, night-time and 24-hour ambulatory BP have been provided by the Allied Irish Bank study of 815 healthy individuals, which showed clear age and sex differences. The mean 24-hour ambulatory pressure for the entire group was 118/72 mm Hg.

24-hour ambulatory BP measurement possesses clear advantages over conventional clinic measurement in evaluating drug efficacy, as it provides many more readings, allowing for the possibility of reducing the number of patients in antihypertensive drug studies and eliminating the need for a placebo-controlled crossover design. It allows assessment of night-time BP, which is important in view of the fact that excessive BP reduction may put patients at risk of myocardial infarction. Patterns of BP behaviour, such as white-coat hypertension and the effects of work and sleep on BP become apparent on 24-hour ambulatory monitoring, allowing accurate assessment of the patient and evaluation of the medication prescribed.

Historical perspective

It is just over 250 years since The Reverend Stephen Hales discovered BP and provided the crude principles of direct measurement.[1] It is a little over 100 years since von Basch and Riva Rocci devised instruments enabling the measurement of systolic BP in clinical practice,[2,3] and just 85 years since Nicolai Korotkov introduced the auscultatory technique of BP measurement which remains the 'gold standard' of measurement to this day.[4]

We may wonder in critical retrospect at the lapse of a century between Harvey's discovery of the circulation[5] and Hales's description of BP,[1] and the similar delay before BP measurement was applied to man. These lacunae in the development of scientific thought and knowledge can be excused, at least to some extent, by the inadequacy of the technical facilities at the disposal of these pioneering scientists. No such reasoning can absolve the paucity of development in BP measurement in this century, most particularly in the past quarter, a period which future historians will refer to as 'the technological age'.

The late George Pickering and his group at Oxford were the first to demonstrate the fluctuations in pressure during the course of 24 hours, and how constant and profound was the fall in BP recorded during sleep.[6] They went on to develop an ambulatory technique whereby pressure could be measured directly from the brachial artery with a small plastic catheter.[6,7]

In the 1960s attempts were made to provide a non-invasive alternative to direct intra-arterial measurement of ambulatory BP.[8] In 1962, Hinman and his colleagues described the first truly portable ambulatory system for the non-invasive measurement of BP.[9] The Remler

Correspondence: Professor E. O'Brien, MD

Company of California developed this system commercially,[10] and so began an important era in hypertension research and management.

With the development of compact pumps and solid-state memory systems, the Remler system was replaced by devices capable of automatically inflating the cuff and providing pressures intermittently over 24 hours. In 1979, Harshfield and his colleagues at Cornell validated the Del Mar Avionics Pressurometer II Ambulatory ECG and Blood Pressure Recording System.[11] The Avionics system was followed by a number of automated devices for the measurement of 24-hour BP.[12] The latest systems, such as the SpaceLabs 90207 device, are pocket-sized with an almost noiseless pump.[13] These instruments are expensive and strict accuracy criteria are being demanded of manufacturers.[14]

The main disadvantages of these systems are that they only provide intermittent measurement of BP and that the subject has to cease activity during the measurement of BP. Although intermittent BP measurements give circadian BP patterns that are surprisingly close to intra-arterial pressures,[15] there is a limit to the number of pre-set measurements a subject can be expected to tolerate, and moreover, there comes a point at which intermittent measurements interfere with normal ambulatory activity. In practice, therefore, ambulatory measurements are usually made at no less than 15-minute intervals, and in clinical practice at 30-minute intervals. The next advance in BP measurement is likely to be the development of accurate systems that will provide continuous 24-hour BP measurements allowing detailed wave-form scrutiny and beat-to-beat analysis — in short, the equivalent of direct intra-arterial measurement without the inherent dangers of invasive catheterization.[16]

The development of devices capable of measuring BP over 24 hours will influence the future management of hypertension possibly more than any other development in this century. Before discussing the clinical potential for the technique, however, it is important to consider two empirical questions. First, how accurate are ambulatory devices? Secondly, what are the normal reference values for 24-hour pressures?

Accuracy of ambulatory BP measuring devices

The development of non-invasive 24-hour ambulatory BP measurement has resulted in a reappraisal of our approach to the diagnosis and clinical management of hypertension, to such an extent that clinical decisions are becoming increasingly dependent on the technique. The result has been the creation of a market with enormous potential for device manufacturers. The increased manufacture of ambulatory devices in recent years reflects this growing market. Thirteen ambulatory systems are presently available commercially, and others are in the later stages of development. These systems are expensive, ranging from about $4000 to in excess of $20,000 for one recorder and decoding system, depending on the accessories, computer facilities and software options purchased. There are also substantial costs in running an ambulatory BP service. Against these costs, however, the potential savings associated with ambulatory monitoring (whereby antihypertensive drug prescribing may be substantially reduced) have to be considered.[17]

Faced with the growing demand for ambulatory measurement, hypertension researchers have an obligation to ensure that the need for devices that accurately measure ambulatory BP is not overlooked by manufacturers anxious to fulfil the market demand. If high standards of performance and accuracy are not demanded, continued uncontrolled marketing will inevitably result in the manufacture and sale of inaccurate devices; this has clear implications for clinical practice, the most important of which is inappropriate diagnostic and management decisions. In reviewing the literature, it is often difficult to make comparisons between validation studies, and it may not be possible to assess the relative merits of one system against another. A standardized approach to the validation procedures used in evaluating ambulatory BP measuring systems is therefore needed.[18]

The first body to appreciate the need for a standardized approach to the validation of BP measuring devices was the American Association for the Advancement of Medical Instrumentation (AAMI), which published its recommendations for validation of electronic and automated sphygmomanometers in 1987 as an American National Standard.[19]

In 1987, the Working Party on Blood Pressure Measurement of the British Hypertension Society (BHS) was given the task of examining the need for recommendations for the growing demand for ambulatory BP measuring devices, and in 1990 the BHS protocol was published.[14] This differs from the AAMI standard in a number of respects, the most important of which are that it makes provision for testing devices after they have been subjected to a period of use, and a grading system for evaluating the results of the

validation is provided, rather than basing a decision on absolute differences between the test and standard device.

The BHS protocol has been used to evaluate four ambulatory systems — the SpaceLabs 90207,[13] the Novacor DIASYS 200,[20] the Del Mar Avionics Pressurometer IV,[21] and the Takeda TM-2420.[22] The Medilog,[23] the SpaceLabs 90202[24] and the Accutracker II[25] have been evaluated using the AAMI standard. The SpaceLabs 90207 achieved B grading for systolic and diastolic pressures, and the DIASYS 200 achieved B grading for systolic pressure and C grading for diastolic pressure; both fulfilled the AAMI criteria. The Del Mar Avionics Pressurometer IV and the Takeda TM-2420 achieved C and D grading, respectively, for systolic pressure and both achieved D grading for diastolic pressure, with both failing to fulfil the AAMI criteria.[26] The Medilog fulfilled the criteria of the AAMI standard for both systolic and diastolic pressures,[23] whereas the Pressurometer IV failed to provided measurements of diastolic pressure according to the AAMI standard in one study[27] and of both systolic and diastolic pressure in another.[21] The Accutracker II failed the AAMI criteria for both systolic and diastolic pressures.[25] On the basis of the AAMI criteria, therefore, the only systems that can be recommended at present for 24-hour ambulatory measurement of BP are the SpaceLabs 90202 and 90207, the DIASYS 200 and the Medilog, whereas the best devices with the BHS grading system are the SpaceLabs 90207 and the DIASYS 200.

Normal values for 24-hour BP

It is perhaps somewhat surprising that the growing use of ambulatory BP measurement has occurred in the absence of reference values for normal 24-hour pressures being available. The earliest estimates of normal ambulatory pressure were provided from direct intra-arterial measurement of 24-hour BP,[28] but these studies were performed on patients who had been referred for assessment because of previous BP elevation, and they cannot therefore be taken as representative of the 'normal' population. Furthermore, direct intra-arterial measurement provides different BP levels than the non-invasive techniques used in clinical practice. Measurements obtained by the two techniques, though capable of detecting similar trends, do not give the same absolute values. Moreover, ethical considerations in using the direct technique have precluded its use in large numbers, and studies in normotensive subjects have consequently been small.

With the introduction of techniques for non-invasive measurement of 24-hour BP, larger studies have been performed in an attempt to determine the normal reference values.[28] In many of these studies the numbers are too small to permit adequate stratification for sex and age, and in others the subjects have been referred for assessment of an observed rise in BP which subsequently settles to normal, and they cannot, therefore, be regarded as representative of the normal population. Recent studies have sought to redress these deficiencies.[28,29]

To date, the largest published study of normal subjects is the Allied Irish Bank Study, in which 24-hour ambulatory measurements were obtained from 815 healthy bank employees stratified for age and sex.[28] A total of 36,804 ambulatory measurements were obtained. The results are shown in Table I. Definite differences in relation to age and sex were observed. For all age groups, men had higher daytime and night-time BPs. The differences tended to lessen with advancing years for systolic but not diastolic pressure. Above the age of 40 years, both men and women had higher office and daytime BPs than the younger age groups, and this tendency was also seen at night-time, but more so for diastolic than systolic pressure. Office BPs were lower than daytime ambulatory pressures in subjects under the age of 50 years; the difference was greatest for the 17-29-year-old men and women, and by the age of 50 years this trend had been reversed, with office pressures being higher than daytime pressures for both men and women. The mean 24-hour ambulatory BP for the entire group was 118/72 mm Hg. If the mean + 2SD is chosen as the upper limit of normal, these data yield values of 139/87 mm Hg. The corresponding values for daytime and night-time BPs are 147/94 mm Hg and 127/76 mm Hg. The 95th centile values were 134/85 mm Hg for 24-hour pressures, 143/91 mm Hg for daytime and 123/75 mm Hg for night-time pressures.

As there are substantial independent effects of age and sex on ambulatory BP, normalcy should be considered in relation to age and sex.

Evaluation of drug efficacy by 24-hour ambulatory BP measurement

The measurement of BP, whether with conventional sphygmomanometry, expensive and elaborate automated devices, non-invasive ambula-

Table I Means ± SD, medians and 95th centiles, and coefficients of variation for office and 24-hour ambulatory BP measurements in 815 people according to age and sex. Reproduced with permission from O'Brien *et al.*[28]

	Age (years) and number of subjects										
	Men				*All*	*Women*				*All*	*Both*
	17–29 (107)	*30–39 (123)*	*40–49 (109)*	*50–79 (60)*	*17–79 (399)*	*17–29 (174)*	*30–39 (149)*	*40–49 (55)*	*50–79 (38)*	*17–79 (416)*	*17–79 (815)*
Office measurements:											
SBP (mm Hg)											
Mean ± SD	121 ± 12	122 ± 11	125 ± 16	133 ± 15	124 ± 14	110 ± 11	113 ± 10	121 ± 17	130 ± 24	115 ± 15	119 ± 15
Median	121	122	122	130	122	110	113	116	123	114	118
95th centile	140	142	153	160	150	130	131	154	193	139	145
CV	10	9	13	11	11	10	9	14	19	13	13
DBP (mm Hg)											
Mean ± SD	73 ± 9	77 ± 8	81 ± 10	85 ± 11	78 ± 10	71 ± 8	72 ± 8	78 ± 9	81 ± 12	73 ± 9	76 ± 10
Median	73	77	80	84	78	70	72	76	80	72	75
95th centile	89	90	99	110	96	83	84	96	103	88	93
CV	12	10	13	13	13	11	11	12	15	12	13
Ambulatory measurements:											
Daytime:											
SBP (mm Hg)											
Mean ± SD	129 ± 8	128 ± 9	129 ± 12	132 ± 12	129 ± 10	118 ± 8	117 ± 8	121 ± 12	126 ± 18	118 ± 10	124 ± 12
Median	129	128	127	134	128	118	116	120	122	118	123
95th centile	144	143	150	155	146	131	132	150	177	135	143
CV	6	7	9	9	8	7	7	10	14	9	9
DBP (mm Hg)											
Mean ± SD	77 ± 7	80 ± 6	83 ± 9	84 ± 9	81 ± 8	74 ± 6	75 ± 7	76 ± 9	78 ± 9	75 ± 7	78 ± 8
Median	77	80	82	85	80	73	74	74	76	74	77
95th centile	88	91	98	103	92	83	85	94	97	88	91
CV	8	8	10	11	10	8	9	12	12	10	10
Night-time:											
SBP (mm Hg)											
Mean ± SD	110 ± 9	108 ± 8	109 ± 12	113 ± 13	110 ± 10	102 ± 9	101 ± 9	103 ± 11	108 ± 12	102 ± 9	106 ± 11
Median	110	108	107	110	109	101	100	101	106	101	105
95th centile	125	121	128	140	126	117	116	125	133	120	123
CV	8	8	11	11	9	9	8	10	11	9	10
DBP (mm Hg)											
Mean ± SD	59 ± 6	62 ± 6	66 ± 10	68 ± 9	63 ± 8	57 ± 6	58 ± 7	61 ± 8	63 ± 7	58 ± 7	61 ± 8
Median	59	61	65	66	62	56	57	59	63	57	60
95th centile	70	71	80	90	77	68	71	77	75	72	75
CV	10	9	15	14	13	10	11	13	10	12	13
24-hour:											
SBP (mm Hg)											
Mean ± SD	123 ± 8	121 ± 8	122 ± 11	126 ± 12	122 ± 10	112 ± 7	111 ± 8	114 ± 10	120 ± 15	113 ± 9	118 ± 11
Median	123	120	122	125	122	112	110	112	118	112	117
95th centile	136	133	136	151	137	125	126	141	160	129	134
CV	6	7	9	9	8	7	7	9	13	8	9
DBP (mm Hg)											
Mean ± SD	71 ± 5	74 ± 5	77 ± 8	79 ± 9	75 ± 7	68 ± 5	69 ± 6	71 ± 8	73 ± 8	69 ± 6	72 ± 7
Median	71	74	76	77	74	67	68	69	72	68	71
95th centile	81	82	89	98	86	78	78	87	87	82	84
CV	8	7	11	11	10	8	9	11	10	9	10

CV = coefficient of variation.

tory systems, self-measuring devices or direct intra-arterial techniques, is fraught with many potential errors. Far-reaching decisions have often been made, in relation both to patient management and to scientific research, without due consideration being given to the limitations of the techniques available.

Traditionally, BP measurement for the evalu-

ation of the efficacy of antihypertensive drugs has been made by conventional sphygmomanometry using a mercury or research sphygmomanometer, such as the Hawksley random zero sphygmomanometer, and static semi-automated or automated devices. The limitations of conventional measurement in the assessment of antihypertensive drug efficacy have been reviewed elsewhere.[30]

The advantages of 24-hour ambulatory measurements over conventional techniques in such evaluations lie in its ability to detect drug effects that may not be evident with conventional measurement and to provide information on the duration of antihypertensive drug effects, its role in improving the design of studies of antihypertensive drug efficacy, and its ability to demonstrate the effect of drugs on nocturnal BP and the potential problems associated with excessive lowering of BP.

White *et al.* have demonstrated that BP 'load', indicated by the percentage of systolic or diastolic measurements above normal during a 24-hour period, is a good predictor of left ventricular enlargement.[31] Changes in the other direction, that is, excessive reductions in BP outside the lower limits of the normal range, also need to be denoted, and the concept of *load* (to indicate increases in BP above the upper limits of normality) and *leese* (meaning literally the release or relaxation) to denote a reduction in BP below the lower limits has been proposed.[30]

One of the most surprising aspects of research into the efficacy of antihypertensive drugs is the readiness with which a BP lowering effect observed at one moment in the 24-hour cycle has been taken to indicate therapeutic efficacy throughout the day, often without reference to the time of drug administration. With the increasing use of new formulations of drugs that permit once and twice daily dose regimens,[32] it is now more important than ever to be able to assess accurately the duration of drug effect.

For the past decade, it has been our policy to incorporate ambulatory measurement into protocols for the study of BP lowering drugs.[32] The ambulatory technique demonstrates what can never be shown by single measurements in the clinic, that is, the pattern of antihypertensive drug effect over time. It is of considerable practical importance that many preparations that would have appeared efficacious as BP lowering agents by conventional measurement have been shown by ambulatory measurement to have a far less impressive pattern of activity.

Conventional BP measurement possesses a number of limitations that must be overcome in studies of antihypertensive drug efficacy. This is achieved at a considerable cost, because a placebo control is required and the sample size has to be large because of the paucity of data obtained. Moreover, the alerting reaction and regression to the mean may result in the inclusion of apparently hypertensive subjects, who in reality become normotensive with time or when removed from the situation of BP measurement. Clearly the inclusion of such subjects in a study of antihypertensive drug efficacy study will greatly distort the results. If, for example, patients with white-coat hypertension are included in a study, as is often the case when patients are recruited on the basis of conventional clinic measurement, as many as 20% of these patients may not have sustained hypertension[33] and are unsuitable for the study.

Among the major advantages of ambulatory measurement over conventional measurement are the ability to detect white-coat responders, the absence of a placebo effect, little regression to the mean, and the provision of a large number of readings. All these factors contribute to considerable simplification of the design of studies of antihypertensive drug efficacy, by reducing the sample size required and by permitting omission of the placebo-controlled crossover design. The influence of these factors has been previously reviewed.[30]

Ambulatory measurement provides what was obtainable previously only with direct invasive intra-arterial measurement — an assessment of antihypertensive drug effect over 24 or 48 hours. Until recently, interest in this aspect of 24-hour measurement centred on the desirability of being able to demonstrate that a drug was efficacious for the appropriate period related to dosing. This facility proved useful in demonstrating that drugs possessed or did not possess the duration of action claimed for them. With recent interest in the potential danger of excessive lowering of BP with antihypertensive medication,[34] the role of 24-hour BP monitoring in detecting such a reduction in pressure, particularly during the night, may prove to be an important one.

Some evidence now suggests that those treated hypertensive patients who achieve the lowest BPs have the highest incidence of myocardial infarction.[35,36] For this reason we must now direct our attention not only to the efficacy of BP reduction but also to the magnitude of this reduction.[30] There is some evidence that hypertensive patients who do not have a nocturnal fall in BP (non-dippers) are at greater risk than the majority who show a significant reduction in nocturnal BP (dippers).[37,38] Moreover, it has

recently been demonstrated that end-organ damage, as judged by left ventricular size, is more severe in non-dippers than in dippers.[38] The possibility also exists that antihypertensive drugs with a prolonged duration of effect, or those administered frequently, may cause a profound reduction in nocturnal BP in dippers, and that such hypotension might lead to myocardial ischaemia and infarction.[39]

Antihypertensive drugs may also differ in their effects on nocturnal BP.[40] In patients with an accentuated dip, it may be advisable to use shorter acting drugs taken in the morning, or to prescribe drugs that are known not to affect nocturnal pressure. On the other hand, hypertensive non-dippers require smooth BP reduction throughout the 24-hour period, and it may be advantageous to attempt to restore a normal circadian pattern by using drugs known to be efficacious in reducing nocturnal pressure. While the therapeutic and prognostic implications of these findings require further evaluation, they provide cogent evidence in favour of assessing the effects of antihypertensive therapy on sleeping BP.

The benefits of ambulatory BP monitoring in assessing the efficacy of drug treatment are now well established, which is not to say that considerable study of, and deliberation on the research amassed over the past decade are not now needed. Conventional clinic measurement is influenced by many factors that make the technique unsuitable for research into drug efficacy, but more importantly, clinic measurement cannot provide a comprehensive assessment of the duration of effect, nor of the effect of antihypertensive drugs on sleeping BP. Home measurement of BP, though valuable in assessing BP control in clinical practice, is not as informative as ambulatory BP measurement and cannot provide nocturnal pressures. The information to be derived from 24-hour ambulatory measurement is such that the technique should be mandatory in studies of antihypertensive drug efficacy.

Clinical applications of 24-hour ambulatory BP measurement

Non-invasive ambulatory BP measurement has become increasingly popular in recent years. The technique is now used in clinical practice where it is proving particularly useful in diagnosing borderline hypertension,[41] in determining the severity of hypertension and consequently in identifying those patients in need of therapeutic intervention.[42] Ambulatory measurement is also helpful in determining the efficacy of antihypertensive medication over the 24-hour period so that optimal therapy can be prescribed.[31,32,43] Patterns of BP behaviour, such as 'white-coat hypertension'[34] and the effect of work[44,45] and sleep[37,46] on BP, which cannot be detected by conventional techniques, become apparent with ambulatory measurement. These applications to clinical practice must not be misused, and it is imperative as the technique moves from the research environment to clinical practice to ensure that adequate guidelines are provided by those who have had wide experience of using ambulatory measurement in research.

Acknowledgements

Work cited from the Blood Pressure Unit was supported by grants from the Charitable Infirmary Charitable Trust, the Royal College of Surgeons, the Irish Heart Foundation, the Health Research Board and ICI.

References

1. Hales, S. *Statistical Essays: Containing Haemostatics. Vol ii.* W. Innys & R. Manby, London, 1733.
2. Von Basch, S. Ueber die Messung des Blutdrucks am Menschen. Zit Klin Med 1880, **2:** 79–96. English translation in: Ruskin, A. *Classics in Arterial Hypertension.* Charles C. Thomas, Springfield, Illinois, 1956, 83–102.
3. Riva Rocci, S. Un nuovo sfigmomanometro. *Gazz Med di Torino* 1896, **50:** 981–996, and **51:** 1000–1017.
4. Korotkov, N.C. To the question of methods of determining the blood pressure (from the clinic of Professor CP Federoff). *Reports of the Imperial Military Academy* 1905, **11:** 365–367.
5. Harvey, W. Exercitatio Anatomica De Motu Cordis et Sanguinis in Animalibus. *Facsimile edition.* The Classics of Cardiology Library, Birmingham, Alabama, 1985.
6. Pickering, G. *High blood pressure. 2nd edition.* J. & A. Churchill, London, 1968, 12–20.
7. Bevan, A.T., Honour, A.J. & Stott, F.H. Direct arterial pressure recording in unrestricted man. *Clin Sci* 1969, **36:** 329–344.
8. O'Brien, E. & Fitzgerald, D. The history of blood pressure measurement. In: O'Brien, E. & O' Malley, K. (eds) *Handbook of Hypertension* (Series editors: Birkenhager, W. & Reid, J.). *Vol 12. Blood Pressure Measurement.* Elsevier, Amsterdam (in press).
9. Hinman, A.T., Engel, B.T. & Bickford,, A.F. Portable blood pressure recorder. Accuracy and preliminary use in evaluating intradaily variations in pressure. *Am Heart J* 1962, **63:** 663–668.

42. White, W.B., Schulman, P., McCabe, E.J. & Dey, H.M. Average daily blood pressure, not office blood pressure, determines cardiac function in patients with hypertension. *JAMA* 1989, **261**: 873–877.
43. Garrett, B.N. & Kaplan, N. Ambulatory blood pressure monitoring: a question for now and the future. *J Clin Hypertens* 1987, **3**: 378–380.
44. Clark, L.A., Denby, L., Pregibon, D. *et al.* A quantitative analysis of the effects of activity and time of day on the diurnal variations of blood pressure. *J Chronic Dis* 1987, **40**: 671–681.
45. Harshfield, G.A., Pickering, T.G., Kleinert, H.D., Blank, S., Laragh, J.H. Situational variations of blood pressure in ambulatory hypertensive patients. *Psychosom Med* 1982, **3**: 237–245.
46. Pickering, T.G., Harshfield, G.A., Kleinert, H.D., Blank, S. & Laragh, J.H. Blood pressure during normal daily activities, sleep and exercise. *JAMA* 1982, **247**: 992–996.

Discussion

Dr Beevers (UK): What is the relative accuracy of oscillometric readings *vs* auscultatory?

Professor O'Brien (Ireland): I do not think we should concern ourselves too much about that question. Our real concern is whether we obtain correct pressure readings, irrespective of how that is achieved.

Dr Cruickshank (UK): Could you comment on measurement of BP by the finger method, which is attractive, but I am not sure if it is accurate?

Professor O'Brien: That is a good subject to discuss, because substantial as the advance is in having ambulatory measurement, it is only one stage in development. The ambulatory devices presently available allow intermittent BP measurement over the 24-hour period. The intervals can be selected, either 15 or 30 minutes, but the patient has to cease activity and keep his arm steady during the actual measurement. Such measurements are thus not strictly ambulatory.

The device you are referring to is the Portapres, which measures BP continuously from the finger. It is still in development, but when it is available and validated it should give results analogous to those from direct intra-arterial measurement — a continuous wave-form over the 24-hour period. That in turn will present the same problems as intra-arterial measurement, that is, how can all the data be handled?

Question: Does posture affect the validation procedures, as the majority of daytime readings are probably taken in an upright position and the majority of night-time readings in a supine position, whereas the validation studies are carried out in a sitting position?

Professor O'Brien: Yes. The validation procedures that we use are limited. The British Hypertension Society (BHS) protocol is already in need of updating, even though it was only published in 1990, and it is moving forward into its next phase of development which includes a consideration of posture. We standardize for posture very carefully in the laboratory, but when people are out and about it is difficult to control for posture.

Exercise activity is also difficult to control, and we have been considering various ways of approaching this problem. The US Air Force have developed small devices that can be strapped to wrist or ankle to assess the activity of their pilots. In the future, validation procedures will have to take exercise into account as well as posture.

Question: All the previous estimations of prognosis, and morbidity and mortality studies, have been based on patients with obvious hypertension. What can be said about the prognosis and sequelae of hypertension based on ambulatory monitoring studies? Should the parameters for hypertension be lower?

Professor O'Brien: We do not have the longitudinal studies to answer that question, so we have to rely on circumstantial evidence. The study of Sokolov and Perloff definitely suggests that ambulatory measurement is a more accurate predictor of cardiovascular risk than casual office BP measurements. Many other studies have suggested that ambulatory measurement is more accurate than casual office BP measurement in predicting the risk of target organ damage. Longitudinal studies are difficult to set up, but a number of them are about to begin and one is underway, but it will be some years before the data can be analyzed. In the meantime, all we can do is rely on surrogate end-points, to give us confidence in recommending ambulatory measurement over office measurement.

10. Kain, H.K., Hinman, A.T. & Sokolow, M. Arterial blood pressure measurements with a portable recorder in hypertensive patients. I. Variability and correlation with 'casual' pressures. *Circulation* 1964, **30:** 882–892.
11. Harshfield, G.A., Pickering, T.G. & Laragh, J.H. A validation of the Del Mar Avionics ambulatory blood pressure system. *Ambulatory Electrocardiography* 1979, **1:** 7–12.
12. O'Brien, E. & O'Malley, K. Twenty-four-hour ambulatory blood pressure monitoring: a review of validation data. *J Hypertens* 1990, **8** (Suppl 6): S11–S16.
13. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. Accuracy of the SpaceLabs 90207 determined by the British Hypertension Society Protocol. *J Hypertens* 1991, **9:** 573–574.
14. O'Brien, E., Petrie, J., Littler, W.A. *et al.* British Hypertension Society Protocol: evaluation of automated and semi-automated blood pressure measuring devices with special reference to ambulatory systems. *J Hypertens* 1990, **8:** 607–619.
15. Di Rienzo, M., Grassi, G., Pedotti, A. & Mancia, G. Continuous vs intermittent blood pressure measurements in estimating 24-hour average blood pressure. *Hypertension* 1983, **5:** 264–269.
16. Parati, G., Casadei, R., Groppelli, A., Di Rienzo, M. & Mancia, G. Comparison of finger and intra-arterial blood pressure monitoring at rest and during laboratory testing. *Hypertension* 1989, **13:** 647–655.
17. Hypertension prevalence and the status of awareness, treatment, and control in the United States: final report of the Subcommittee on Definition and Prevalence of the 1984 Joint National Committee. *Hypertension* 1985, **7:** 457–468.
18. O'Brien, E., O'Malley, K. & Sheridan, J. The need for a standardized protocol for validating non-invasive ambulatory blood pressure measuring devices. *J Hypertens* 1989, **7** (Suppl 3): S19–S20.
19. American National Standard for electronic or automated sphygmomanometers. Association for the Advancement of Medical Instrumentation, USA, 1987.
20. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. Accuracy of the Novacor DIASYS 200 determined by the British Hypertension Society Protocol. *J Hypertens* 1991; **9:** 569–570.
21. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. Accuracy of the Del Mar Avionics Pressurometer IV determined by the British Hypertension Society Protocol. *J Hypertens* 1991, **9:** 567–568.
22. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. Accuracy of the Takeda TM-2420/TM-2020 determined by the British Hypertension Society Protocol. *J Hypertens* 1991, **9:** 571–572.
23. Hope, S.L., Alun-Jones, E. & Sleight, P. Validation of the accuracy of the Medilog ABP non-invasive blood-pressure monitor. *J Ambulatory Monitoring* 1988, **1:** 39–51.
24. O'Brien, E., Atkins, N., Mee, F. & O'Malley, K. Validation of the SpaceLabs 90202 according to the AAMI standard. *J Hum Hypertens* 1991 (in press).
25. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. An evaluation of the Accutracker II according to the AAMI standard. *J Ambulatory Monitoring* 1991 (in press).
26. O'Brien, E., Mee, F., Atkins, N. & O'Malley, K. Accuracy of the SpaceLabs 90207, the Novacor DIASYS 200, the Del Mar Avionics Pressurometer IV and the Takeda TM-2420/TM-2020 according to the BHS protocol. *J Hypertens* 1991 (in press).
27. Harshfield, G.A., Hwang, C. & Grim, C.E. A validation study of the Del Mar Avionics Pressurometer IV according to the AAMI guidelines. *J Hypertens* 1988, **6:** 913–918.
28. O'Brien, E., Murphy, J., Tyndall, A. *et al.* Twenty-four-hour ambulatory blood pressure in men and women aged 17 to 65 years: the Allied Irish Bank Study. *J Hypertens* 1991, **9:** 355–360.
29. Staessen, J., Amery, A., Bulpitt, C.J. *et al.* Comparison between home and ambulatory blood pressure measurement in a random population sample. *J Hum Hypertens* 1991 (in press).
30. O'Brien, E., Cox, J., O'Malley, K. Ambulatory blood pressure measurement in the evaluation of drug efficacy. *Am Heart J* 1991, **12:** 999–1006.
31. White, W.B., Dey, H.M. & Schulman, P. Assessment of the daily blood pressure load as a determinant of cardiac function in patients with mild to moderate hypertension. *Am Heart J* 1989, **118:** 782–795.
32. O'Brien, E., Cox, J. & O'Malley, K. Ambulatory blood pressure measurement in the evaluation of blood pressure lowering drugs. *J Hypertens* 1989, **7:** 243–247.
33. Pickering, T.G., James, G.D., Boddie, C., Harshfield, G.A., Blank, S. & Laragh, J.H. How common is white coat hypertension? *JAMA* 1988, **259:** 225–228.
34. Berglund, G. Goals of antihypertensive therapy: is there a point beyond which reduction is dangerous? *Am J Hypertens* 1989, **2:** 586–593.
35. Cruickshank, J.M., Thorp, J.M. & Zacharias, F.J. Benefit and potential harm of lowering high blood pressure. *Lancet* 1987, **i:** 581–584.
36. Alderman, M.H., Ooi, W.L., Madhavan, S. & Cohen, H. Treatment-induced blood pressure reduction and the risk of myocardial infarction. *JAMA* 1989, **262:** 920–924.
37. O'Brien, E., Sheridan, J. & O'Malley, K. Dippers and non-dippers. *Lancet* 1988, **ii:** 397.
38. Pickering, T.G. The clinical significance of diurnal blood pressure variations: dippers and non-dippers. *Circulation* 1990, **81:** 700–702
39. Floras, J.S. Antihypertensive treatment, myocardial infarction and nocturnal myocardial ischaemia. *Lancet* 1988, **ii:** 994–996.
40. Stanton, A.V., Atkins, N., O'Malley, K. & O'Brien, E. Circadian blood pressure and antihypertensive drugs. *Am J Hypertens* 1991 (in press).
41. O'Brien, E. & O'Malley, K. Overdiagnosing hypertension. *Br Med J* 1988, **297:** 1211–1212.