Twenty-four-hour ambulatory blood pressure in men and women aged 17 to 80 years: the Allied Irish Bank Study

Eoin O'Brien, Joan Murphy, Anne Tyndall*, Neil Atkins, Fáinsía Mee, Gerry McCarthy*, Jan Staessen**, John Cox and Kevin O'Malley

In order to determine reference values for ambulatory blood pressure, a sample of 815 healthy bank employees (399 men and 416 women), aged 17–79 years, were investigated. Ambulatory blood pressure was recorded over 24 h, taking measurements at 30-min intervals. Blood pressure was also measured by trained observers in the clinic. Ambulatory blood pressure in the 815 subjects averaged 118/72 mmHg over 24 h, 124/78 mmHg during the day (1000–2259 h) and 106/61 mmHg at night (0100–0659 h). Office blood pressure, measured by an observer, was 4/2 mmHg lower ($P < 0.0001$) than daytime ambulatory pressure. The 95th centiles for the daytime ambulatory pressure in men were: 114/88 mmHg for the age group 17–29 years (n = 107); 143/91 mmHg from 30–39 years (n = 123); 150/98 mmHg from 40–49 years (n = 109); and 155/103 mmHg in 50–79 year old men (n = 60); for the corresponding age groups in women, the 95th centiles of the daytime pressure were: 131/83 mmHg (n = 174); 132/85 mmHg (n = 149); 150/94 mmHg (n = 55); and 177/97 mmHg (n = 38).

Journal of Hypertension 1991, 9:355–360

Keywords: Daytime, nocturnal, 24 h, blood pressure, sex, age.

Introduction

The conventional technique of blood pressure measurement in the hospital clinic or doctor's surgery, providing a reading representative of only a fraction of the 24-h blood pressure profile under what are often stressful circumstances, may result in excessive diagnosis and treatment of hypertension [1]. With the development of devices capable of accurately measuring 24-h blood pressure non-invasively, the use of the technique in clinical practice has increased greatly in the last decade [2,3]. Surprisingly, the growing application of the technique has occurred in the absence of available reference values for 24-h ambulatory blood pressure. This study was established to determine 24-h blood pressure in healthy people stratified for sex and four age groups.

Subjects and methods

Subjects

Subjects for the study were recruited by the Medical Centre of the Allied Irish Bank (AIB) in Dublin from among its employees in the offices and branches of the bank throughout Ireland. Volunteers from the bank staff were invited to bring their spouses for 24-h ambulatory measurement if they wished. Retired bank employees were also invited to participate in the study.

Methods

Blood pressure was measured in the sitting position by a trained nurse on two occasions, using a mercury sphygmomanometer according to the recommendations of the British Hypertension Society [4]. A mercury sphygmomanometer was used in preference to a Hawksley sphygmomanometer because a systemic tendency to underestimate pressure has been demonstrated with this device [5]. The majority of subjects had the first and second office blood pressure measurement performed at the first attendance, before and after completing a questionnaire seeking details of postcardiovascular history, family history, weight, height, smoking habits, alcohol consumption and current drug treatment (including anovulant drugs). In some subjects, the first office blood pressure measurement was separated from the second measurement by an interval of some days. The mean of the

From the Blood Pressure Unit, Beaumont Hospital, Dublin, the *Medical Centre, Allied Irish Bank, Ballsbridge, Dublin, Republic of Ireland and the **Hypertension and Cardiovascular Rehabilitation Unit, University of Leuven, Leuven, Belgium.

Sponsorship: This study was supported by grants from the Irish Heart Foundation, the Charitable Infirmary Trust and the Royal College of Surgeons in Ireland. SpaceLabs International kindly made the 90202 recorders available for the study at a concessionary price.

Requests for reprints to: Dr E. O'Brien, Blood Pressure Unit, Beaumont Hospital, Dublin 9, Republic of Ireland.

Date of receipt: 4 July 1990; revised: 29 October 1990.

two office measurements has been used in the analysis. Subjects undergoing treatment for hypertension were excluded from the analysis, but hypertensive subjects not on antihypertensive medication were not excluded.

Twenty-four-hour ambulatory blood pressure measurement was performed using the SpaceLabs 90202 (Spacelabs Inc., Redmond, Washington, USA; Spacelabs, Wokingham, Berkshire, UK) which we have shown to be accurate [6] and, latterly, the SpaceLabs 90207 which we have also validated (unpublished data). Subjects were seen between 0900 and 1100 h for fitting of the recorder which was programmed to deflate in 4 mmHg bleed steps (Spacelabs 90202) and in 8 mmHg bleed steps (Spacelabs 90207) at 30-min intervals for 24 h. Subjects were instructed to keep still the arm in which blood pressure was being measured, from the first bleeps, indicating measurement was about to begin, until the signing off bleep, indicating completion of measurement. Arm circumference was measured as the mid-point between the olecranon and acromial processes [7]. A cuff containing a bladder with suitable dimensions for the arm circumference was selected.

Data analysis

Twenty-four-hour ambulatory blood pressure recordings were unedited as it was considered that any editing process introduced a potential source of bias. A half-hour period was taken as commencing from the hour or half-hour and ending the minute before the next hour or half-hour. If more than one recording was taken within a half-hour period (either by the subject activating the recorder or the recorder attempting a second measurement), the value for that period was calculated from the mean of all readings taken during it. The 24-h interval was divided into daytime and night-time periods. Daytime was defined as the period from 1000 to 2259 h and night-time from 0100 to 0659 h. The daytime period was determined by the fact that all blood pressure readings outside of this period were significantly different from all blood pressures within this period. A similar approach was used to determine the night-time periods. A 24-h record was rejected for analysis if more than one-third of potential daytime and night-time measurements were absent (daytime minimum, 18; night-time minimum, 8). For analysis, the SAS Software Package (SAS Institute Inc., Carey, North Carolina, USA) was used [8].

Results

Characteristics of the participants

A total of 948 subjects participated. Fifty-six subjects had a personal history of hypertension. Circumference of the upper arm averaged less than 32 cm in 880 subjects in whom a standard cuff with bladder dimensions 23 × 12 cm was designated; in 68 subjects in whom arm circumference was greater than 32 cm, a cuff containing a bladder 15 × 32 cm was designated for both office and 24-h blood pressure measurement.

One hundred and thirty-three subjects were excluded from analysis: 42 were on treatment for hypertension, 85 records were lacking more than one-third of measurements and, in the remaining six subjects, necessary clinical information was unavailable.

Of the remaining 815 subjects, 399 were men and 416 women, aged 17–79 years (mean age 36 ± 11 years). There were 107 men and 174 women in the 17–29 age group, 123 men and 149 women in the 30–39 age group, 109 men and 55 women in the 40–49 age group and 60 men and 38 women in the 50–79 age group.

One hundred and ninety-four subjects had a family history of hypertension (81 men and 113 women); 229 subjects were smokers; 658 reported alcohol consumption; 49 women were taking the contraceptive pill; and four were on hormone replacement therapy.

Ambulatory measurements

Analysis of variance showed that daytime and night-time systolic and diastolic blood pressure were significantly and independently related to gender and age, but the interaction between age and sex was not significant. Results are, therefore, presented separately for men and women and for age groups. Ambulatory recordings were performed only on working days (Monday to Friday inclusive). A total of 35 890 ambulatory measurements were obtained (19 035 daytime, 9436 night-time were used in analysis of day and night pressures).

Office measurements

The second office blood pressure measurement was slightly lower than the first in all age groups and this reached statistical significance (1.7 ± 7.6, $P < 0.01$) for diastolic blood pressure in women aged 40–49 years. The mean ± s.d., median, 95th centiles and coefficients of variation for office blood pressure for men and women and the four age groups are given in Table 1.

Analysis of ambulatory blood pressure

The means ± s.d., median, 95th centiles and coefficients of variation for daytime and night-time systolic and diastolic blood pressure for men and women and all age groups are shown in Table 1. The mean 24-h pressure for each age group and for both sexes is plotted in Fig. 1.

Discussion

Non-invasive ambulatory blood pressure 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 [1,9], in determining the severity of hypertension and, consequently, the patients in need of therapeutic intervention [10]. Ambulatory blood pressure measurement is also helpful in determining the efficacy of antihypertensive medication over the 24-h period so that optimal therapy can be prescribed [11,12]. Patterns of blood pressure behaviour such as 'white coat hyper-

Table 1. Mean ± s.d., median and 95th centiles and coefficients of variation (coeff. var.) for office and 24-h ambulatory blood pressure in 815 people according to age and sex.

	Men				All	Women				All	Both
Age range (years)	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 (mmHg)											
Mean ± s.d.	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	140	142	153	160	150	130	131	154	193	139	145
Coeff. var.	10	9	13	11	11	10	9	14	19	13	13
DBP (mmHg)											
Mean ± s.d.	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	89	90	99	110	96	83	84	96	103	88	93
Coeff. var.	12	10	13	13	13	11	11	12	15	12	13
Ambulatory measurements:											
Daytime:											
SBP (mmHg)											
Mean ± s.d.	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	144	143	150	155	146	131	132	150	177	135	143
Coeff. var.	6	7	9	9	8	7	7	10	14	9	9
DBP (mmHg)											
Mean ± s.d.	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	88	91	98	103	92	83	85	94	97	88	91
Coeff. var.	8	8	10	11	10	8	9	12	12	10	10
Night-time:											
SBP (mmHg)											
Mean ± s.d.	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	125	121	128	140	126	117	116	125	133	120	123
Coeff. var.	8	8	11	11	9	9	8	10	11	9	10
DBP (mmHg)											
Mean ± s.d.	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	70	71	80	90	77	68	71	77	75	72	75
Coeff. var.	10	9	15	14	13	10	11	13	10	12	13
24 h:											
SBP (mmHg)											
Mean ± s.d.	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	136	133	136	151	137	125	126	141	160	129	134
Coeff. var.	6	7	9	9	8	7	7	9	13	8	9
DBP (mmHg)											
Mean ± s.d.	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	81	82	89	98	86	78	78	87	87	82	84
Coeff. var.	8	7	11	11	10	8	9	11	10	9	10

Numbers are indicated in parentheses. SBP, systolic blood pressure; DBP, diastolic blood pressure.

tension' [13] and the effect of work [14,15] and sleep on blood pressure [16,17], which cannot be detected by conventional techniques, become apparent with ambulatory measurement. There are many studies showing that ambulatory blood pressure gives lower readings than casual, office or home measurement [2,3,18–20] and there is evidence that ambulatory blood pressure may be a better predictor of cardiovascular morbidity and mortality than conventional methods of measurement [10,21,22–25]. Until recently, the technique of ambulatory blood pressure measurement has been largely confined to hypertension research. However, manufacturers of ambulatory systems, alert to the vast potential market that exists, are now directing their sales drive to hospitals, general practices and private clinics. Surprisingly, this expansion in the use of a technique has taken place in the absence of reference values for 24-h ambulatory blood pressure being available.

The earliest estimates of normal ambulatory pressure were provided from direct intra-arterial measurement of

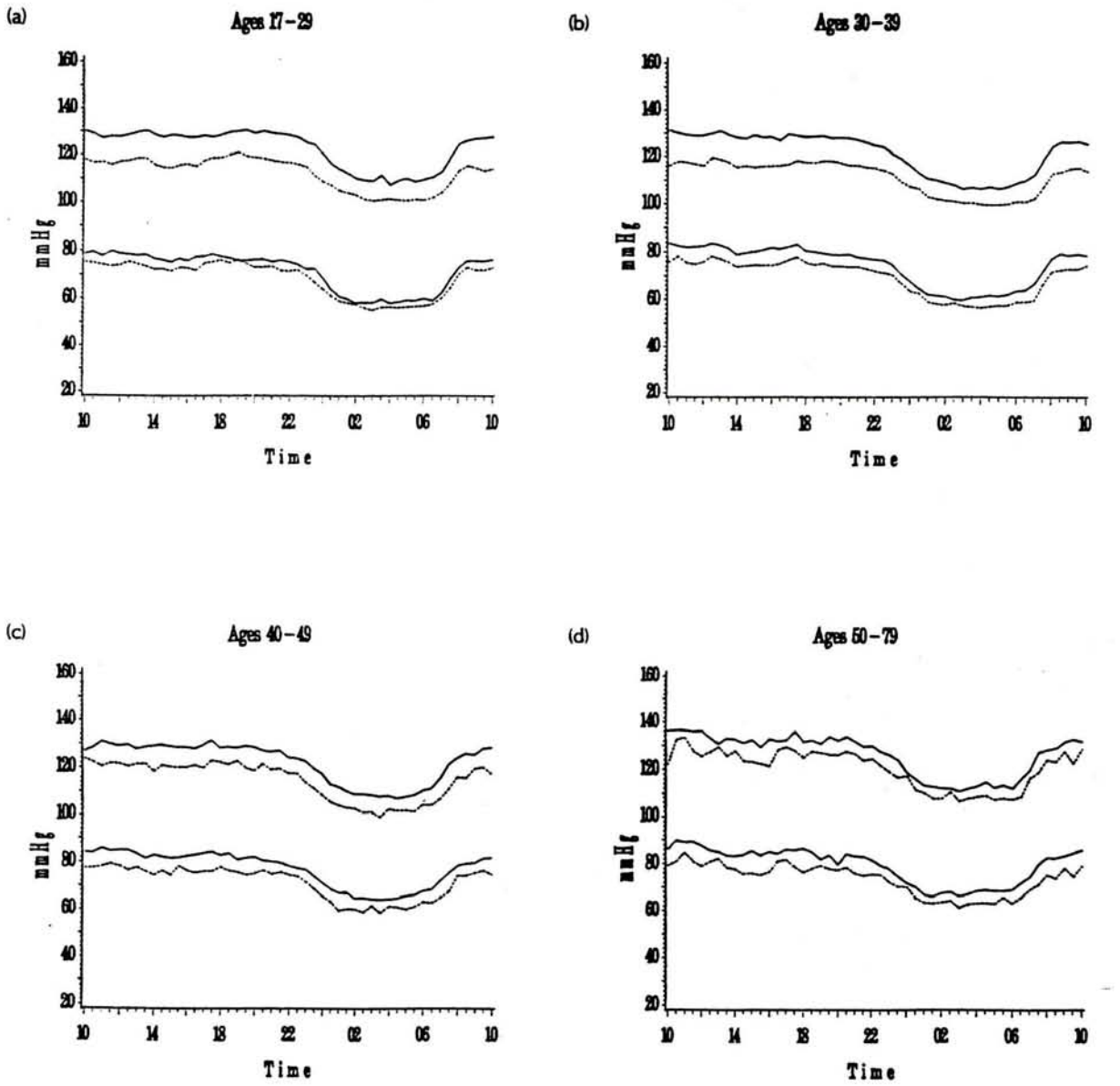

Fig. 1. Mean 24-h systolic and diastolic blood pressure in men (–) and women (···) aged (a) 17–29 years, (b) 30–39 years, (c) 40–49 years and (d) 50–79 years.

24-h blood pressure [26–30], but these studies were performed on patients who had been referred for assessment because of previous blood pressure elevation and they cannot, therefore, be taken as being representative of the 'normal' population. Direct intra-arterial measurement provides different blood pressure levels than the non-invasive techniques used in clinical practice and measurements obtained by the two techniques, although capable of determining 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-h blood pressure, larger studies have been performed in an attempt to determine the normal reference values for 24-h blood pressure [9,10,31–41]. 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 blood pressure which subsequently settles to normal and cannot, therefore, be regarded as representative of the normal population. Recent studies have sought to redress these deficiencies [42].

The 24-h ambulatory data in our study were obtained from healthy individuals during a working day. Only those undergoing drug treatment for hypertension were excluded from analysis. Quite definite differences in relation to age and sex were observed. For all age groups, men had higher 24-h daytime and night-time pressures. The

differences tended to lessen with advancing years for systolic but not for diastolic pressure. Both men and women over 40 years old had higher office and daytime pressures than the younger age groups and this tendency was also seen at night-time, but more so for diastolic than systolic pressure. Office blood pressures were lower than daytime ambulatory blood pressures in subjects less than 50 years old; the difference was greatest for the 17–29-year-old men and women (8/4 and 7/3 mmHg, respectively) and the 30–39-year-old men (7/3 mmHg) and, by the age of 40 years in women and 50 years in men, this trend was reversed with office pressures being higher than daytime pressure for both men and women. The differences between office and daytime ambulatory blood pressures are small, probably reflecting the low mean blood pressure levels of the subjects, although it is also possible that the relationship between office and ambulatory pressure is modified as blood pressure rises in hypertensive subjects. Interindividual variability, as reflected by the standard deviation and coefficient of variation of each age group, increased with age for both males and females.

The mean 24-h ambulatory blood pressure for the entire group was 118/72 mmHg. If the mean + 2 s.d. is chosen as the upper limit of normal, our data yield values of 139/87 mmHg. The corresponding values for daytime and night-time blood pressure are 147/94 mmHg and 127/76 mmHg. The 95th centile values were 134/84 mmHg for 24-h pressures, 143/91 mmHg for daytime and 123/75 mmHg for night-time pressures.

As there are substantial independent effects of age and sex on ambulatory blood pressure and there are large numbers of subjects in each category, we are in a position to give values for the upper limits of normal in relation to both these variables. For example, the overall 24-h mean + 2 s.d. for women was 131/82 mmHg compared with 142/89 mmHg for men. The lowest values were found in young females aged 17–29 years (127/79 mmHg) and the highest values in older males aged 50–79 years (149/96 mmHg) and older females (150/88 mmHg).

We present these data from the AIB study as reference values for non-invasive ambulatory blood pressure, while bearing in mind that the relevance of such data to end-organ effects, morbidity and mortality awaits elucidation.

Acknowledgement

This study was made possible through the participation of the employees of the Allied Irish Bank to whom we express gratitude.

References

1. O'Brien E, O'Malley K: Overdiagnosing hypertension. *Br Med J* 1988, 297:1211–1212.
2. White WB: Assessment of patients with office hypertension by 24-hour non-invasive ambulatory blood pressure monitoring. *Arch Intern Med* 1986, 146:2196–2199.
3. Mancia G: Clinical use of ambulatory blood pressure monitoring. *Am J Hypertens* 1989, 2:50S–54S.
4. Petrie JC, O'Brien ET, Littler WAW, de Swiet M: Recommendations of blood pressure measurement. British Hypertension Society. *Br Med J* 1986, 293:611–615.
5. O'Brien E, Atkins N, Mee F, O'Malley K: Inaccuracy of the Hawksley random zero sphygmomanometer. *Lancet* 1990, 336:1465–1468.
6. O'Brien E, Sheridan J, Browne T, Conroy R, O'Malley K: Validation of the SpaceLabs 90202 ambulatory blood pressure recorder. *J Hypertens* 1989, 7 (suppl 6):S388–S389.
7. Simpson JA, Jamieson G, Dickhaus DW, Grover RF: Effect of size of cuff bladder on accuracy of measurement of indirect blood pressure. *Am Heart J* 1965, 70:208–215.
8. SAS Institute Inc, Carey, North Carolina.
9. Horan JM, Kennedy HL, Padgett NE: Do borderline hypertensive patients have labile blood pressure? *Ann Intern Med* 1981, 94:466–468.
10. White WB, Schulman P, McCabe EJ, Dey HM: Average daily blood pressure, not office blood pressure determines cardiac function in patients with hypertension. *JAMA* 1989, 261:873–877.
11. Garrett BN, Kaplan N: Ambulatory blood pressure monitoring: a question for now and the future. *J Clin Hypertens* 1987, 3:378–380.
12. O'Brien E, Cox J, O'Malley K: Ambulatory blood pressure measurement in the evaluation of blood pressure lowering drugs [editorial review]. *J Hypertens* 1989, 7:243–247.
13. Pickering TG, James GD, Boddie C, *et al.*: How common is white coat hypertension? *JAMA* 1988, 259:225–228.
14. Clark IA, 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.
15. Harshfield GA, Pickering TG, Kleinert HD, Blank S, Laragh JH: Situational variations of blood pressure in ambulatory hypertensive patients. *Psychosom Med* 1982, 3:237–245.
16. Pickering TG, Harshfield GA, Kleinert HD, Blank S, Laragh JH: Blood pressure during normal daily activities, sleep and exercise. *JAMA* 1982, 247:992–996.
17. O'Brien E, Sheridan J, O'Malley K: Dippers and non-dippers [letter]. *Lancet* 1988, ii:397.
18. Kenny RA, Brennan M, O'Malley K, O'Brien E: Blood pressure measurements in borderline hypertension. *J Hypertens* 1987, 5 (suppl 5):S483–S485.
19. O'Brien E, Fitzgerald D, O'Malley K: Comparison of clinic, home and ambulatory blood pressure measurement. *J Ambulatory Monitoring* 1988, 1:285–291.
20. Pickering TG, James GD: Some implications of the differences between home, clinic and ambulatory blood pressure in normotensive and hypertensive patients. *J Hypertens* 1989, 7 (suppl 3):S65–S72.
21. Perloff D, Sokolow M, Cowan R: The prognostic value of ambulatory blood pressures. *JAMA* 1983, 249:2792–2798.
22. Pickering TG, Devereux RB: Ambulatory monitoring of blood pressure as a predictor of cardiovascular risk. *Am Heart J* 1987, 114:925–928.
23. Perloff D, Sokolow M, Cowan RM, Juster RP: Prognostic value of ambulatory blood pressure measurements: further analyses. *J Hypertens* 1989, 7 (suppl 3):S3–S10.
24. Devereux RB, Pickering TG: Relationship between ambulatory and exercise blood pressure and cardiac structure. *Am Heart J* 1988, 116:1124–1133.
25. Mancia G, Zanchetti A: Value of echocardiographic and ambulatory blood pressure monitoring in hypertension. *Clin Exp Hypertens [A]* 1989, 11:869–886.
26. Littler WA, Honour J, Pugsley DJ, Sleight P: Continuous recording of direct arterial pressure in unrestricted patients, its role in the diagnosis and management of high blood pressure. *Circulation* 1975, 51:1101–1106.
27. Millar-Craig MW, Bishop CN, Raftery EB: Circadian variation of blood pressure. *Lancet* 1978, i:795–797.
28. Mancia G, Ferrari A, Gregorini L, *et al.*: Blood pressure variability in man: its relation to high blood pressure, age and baroreflex sensitivity. *Clin Sci* 1980, 59:401s–404s.

29. MANCIA G, FERRARI A, GREGORINI L, *ET AL*.: Blood pressure and heart rate variabilities in normotensive and hypertensive human beings. *Circ Res* 1983, 53:96–104..
30. TURJANMAA V, KALLI S, MAJAHALME S, SARANUMMI N, UUSITALO A: Diurnal blood pressure profiles and variability in normotensive subjects. *Clin Physiol* 1987, 7:389–401.
31. KENNEDY HL, HORAN MJ, SPRAGUE MK, PADGETT NE, SHRIVER KK: Ambulatory blood pressure in healthy normotensive males. *Am Heart J* 1983, 106:717–722.
32. WEBER MA, DRAYER JIM, NAKAMURA DK, WYLE FA: The circadian blood pressure in ambulatory normal subjects. *Am J Cardiol* 1984, 54:115–119.
33. DRAYER JIM, WEBER MA: Definition of normalcy in whole-day ambulatory blood pressure monitoring. *Clin Exp Hypertens [A]* 1985, 7:195–204.
34. PAGNY JY, DELVA R, AOUIZERATE M *ET AL*.: Ambulatory blood pressure in normotensive subjects: determination of reference values according to age, using the Spacelabs instrument. *Presse Med* 1987, 16:1621–1624.
35. EGGER M, BIANCHETTI MG, GNADINGER M, KOBELT R, OETLIKER O: Twenty four hour intermittent, ambulatory blood pressure monitoring. *Arch Dis Child* 1987, 62:1130–1135.
36. DE GAUDEMARIS R, MALLION JM, BATTISTELLA P *ET AL*.: Ambulatory blood pressure and variability by age and sex in 200 normotensive subjects: reference population values. *J Hypertens* 1987, 5 (suppl 5):S429–S430.
37. SUNDBERG S: Non-invasive, automatic 24 h ambulatory blood pressure monitoring in normotensive subjects. *Eur J Appl Physiol* 1987, 56:381–383.
38. CHAU NP, CHANUDET X, LARROQUE P: A method to define reference profiles for ambulatory blood pressure, with application to blood pressure profiles in 158 young subjects. *Clin Exp Hypertens [A]* 1988, 10:951–969.
39. WARLING X, CARLIER PG, KREZESINSKI JM, RORIVE GL: Does ambulatory blood pressure improve the definition of hypertension? *Arch Mal Coeur* 1988, 81 (suppl HTA):225–230.
40. CHANUDET X, CHAU NP, LARROQUE P: Evaluation of borderline arterial hypertension in young adults by ambulatory blood pressure measurement. *Arch Mal Coeur* 1989, 82:365–372.
41. WEBER MA, DRAYER JIM: Role of blood pressure monitoring in the diagnosis of hypertension. *J Hypertens* 1986, 4 (suppl 5):S325–S327.
42. BATTISTELLA P, DE GAUDEMARIS R, FRANCOIS G, *ET AL*.; Reference population values of ambulatory blood pressure by age and sex in 394 normotensive subjects during normal daily activities. *Arch Mal Coeur* 1989, 82:1019–1022.