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Ambulatory Blood Pressure of Adults in Ohasama, Japan

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We performed a cross-sectional study in a small town in northern Japan to evaluate the distribution, reference values, and daily variation in ambulatory blood pressure. A total of 705 subjects (229 men aged 61.3±13.4 years [mean±SD] and 476 women aged 57.5±13.3 years; 41.1% of the regional adult population, n=1716), including those treated with antihypertensive drugs (n=231, 66.5±9.5 years) as well as untreated subjects (n=474, 55.0±13.5 years), participated in the study. Both ambulatory and screening blood pressures were measured in 659 subjects. Ambulatory blood pressure was measured with an automatic device (Colin ABPM-630). The 24-hour ambulatory blood pressure in the total population was 121.7±13.0/71.1±7.6 mm Hg (95th percentile value [95%]=146/85 mm Hg). The corresponding value in the untreated subjects was 119.4±12.5/70.1±7.4 mm Hg (95%=144/83 mm Hg). The 24-hour average ambulatory blood pressure was 118.0±11.1/69.4±6.8 mm Hg (95%=139/81 mm Hg) in subjects identified as normotensive by their screening blood pressure (n=448, 57.2±13.1 years) and 133.6±14.2/78.9±8.8 mm Hg in those identified as hypertensive by their screening blood pressure (n=73, 63.1±10.6 years). Based on the mean+SD of the 24-hour ambulatory blood pressure in the normotensive subjects by their screening blood pressure (129/76 mm Hg), the 24-hour ambulatory blood pressures in 25 (34.2%) of these 73 hypertensive subjects by screening blood pressure were below this level. Nine (2%) of 448 normotensive subjects by screening blood pressure were above the mean+2 SDs (140/83 mm Hg) of the 24-hour ambulatory blood pressure in the normotensive group by screening blood pressure. Ambulatory and screening blood pressures increased with age. The age-dependent increase in ambulatory blood pressure was less apparent in men. The 24-hour average pulse rate decreased with age. The daily variation in ambulatory blood pressure (standard deviation) increased with age, whereas that of pulse rate decreased with age. Increases in blood pressure variation were observed in nighttime and daytime blood pressure values. The differences between day versus night ambulatory blood pressures decreased with age in men but not in women. We arbitrarily cited the reference values of the 24-hour ambulatory blood pressure as mean+SD (135/79 mm Hg), mean+2 SDs (148/86 mm Hg), and 95% (146/85 mm Hg) of the ambulatory blood pressure in the total population and as mean+SD (129/76 mm Hg), mean+2 SDs (140/83 mm Hg), and 95% (139/81 mm Hg) of the ambulatory blood pressure in the normotensive subjects by screening blood pressure. Ambulatory blood pressure values above mean+2 SDs or 95% values are considered significantly elevated, and those above mean+SD values and below mean+2 SDs values are considered marginally elevated. Our results showed that the screening blood pressure values usually overestimated the prevalence of hypertension but were occasionally misleadingly lower than the ambulatory blood pressure. (*Hypertension*. 1993;22:900-912.)

KEY WORDS • **ambulatory blood pressure • casual blood pressure • epidemiology • community • age • gender • reference value**

The diagnosis and treatment of hypertension are classically based on casual readings of blood pressure (BP). This approach provides limited information on the circadian variation of BP; also, a single reading can be erroneous. The development of noninvasive techniques for measuring ambulatory BP makes it possible to study changes in BP over time and thus offers advantages over isolated sporadic measurements.[1] Ambulatory BP reportedly can predict the prognosis of hypertension and provide clues to the development of hypertensive cardiovascular complications with greater accuracy.[2-9] However, few studies have reported the detailed characteristics of ambulatory BP in a representative sample; thus, it becomes difficult to apply ambulatory BP data in clinical practice.

Bättig et al[10] have proposed two principal ways of creating reference values for BP information other than casual BP: one is to screen a large representative population and derive reference values from the obtained data, called the distribution criteria; the other is

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TABLE 1. Total Number of Subjects by Age Category in Uchikawame Region, Ohasama, Japan

	Age Category, y							
	<20	20-29	30-39	40-49	50-59	60-69	70-79	≥80
Men	272	116	153	140	161	152	83	28
Women	260	103	132	137	181	169	108	53

to derive a reference value for ambulatory BP from the corresponding casual BP, called the correspondence criteria.[11] Thus far, most of the reference values for ambulatory BP have come from studies based on correspondence criteria.[12] In the present community survey of ambulatory BP, reference values were derived from the analysis of ambulatory BP based on both correspondence criteria and distribution criteria. In addition, we collected data on age-dependent changes in ambulatory BP and pulse rate (PR) and their daily variation in a large number of adults in a wide range of ages living in a community in northern Japan. Although the data provide comprehensive information on ambulatory BP, we emphasize that the findings reflect this specific population. Preliminary results on distribution criteria in a limited number of subjects have been reported previously.[13]

Methods

Population Background

The study was conducted between 1987 and 1989 in the Uchikawame region in the rural community of Ohasama, Iwate Prefecture. Ohasama, a typical modern Japanese rural town, is 100 km north of Sendai, the central city of the northern part of Japan. The total population of 2248 in the Uchikawame region consists of 1105 men and 1143 women. The number of subjects in each age category is cited in Table 1. Most of the adult population engage in fruit growing, and the remainder work in offices or factories in Ohasama or Morioka. Body weight and height in men and women in whom ambulatory BP was measured were as follows: men: weight, 58.0±8.3 kg; height, 159.4±6.4 cm (n=229, mean±SD); women: weight, 52.0±7.9 kg; height, 147.9±6.1 cm (n=476).

Study Design

In November and December of 1987, health education classes were held by a physician and public health nurses at each of nine health care units of the Uchikawame region to inform the people of the significance of ambulatory BP monitoring. These classes were attended by 363 (78.1%) of the people in 465 households in the Uchikawame region. Adults aged 20 years or older were asked to participate in the study and to measure their ambulatory BP over a 24-hour period. Such measurements were then conducted between 1988 and 1989. No specific inclusion or exclusion criteria were applied except for exclusion of those subjects in whom the ambulatory BP could not be measured; eg, they worked in cities away from home, were in the hospital, were aged and bedridden, or worked outside Ohasama throughout the week. A small percentage of the subjects refused our offer to measure ambulatory BP. A total of 705 adults (41.1% of the 1716 population aged 20 years or older) gave their informed consent and participated in the ambulatory BP monitoring program. This study was approved by the institutional review board of Tohoku University School of Medicine. Public health nurses visited each participant on a weekday morning to attach the ambulatory BP monitoring device and detached it the next morning. Participants were asked to keep a diary in which they reported behavior, including the time they went to bed and when they arose.

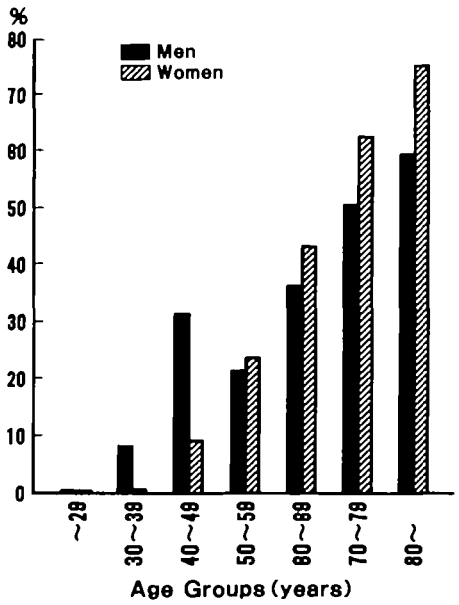

FIG 1. Bar graph shows sex distribution of treated subjects in each age group. Vertical axis is percentage of treated subjects.

Screening Blood Pressure Measurements

Each participant received a medical examination in July or August of either 1988 or 1989. Nurses or technicians measured the subject's BP twice consecutively with the subject in the sitting position after at least a 2-minute rest using a fully automatic BP measuring device (USM 700F, UEDA, Tokyo, Japan). The average of two readings was used for analysis and was defined as the screening BP. The screening BP was measured in 1402 people. Both the screening and ambulatory BP values were determined in 659 people (204 men, 62.4±12.1 years, and 455 women, 57.9±12.7 years).

Information on any antihypertensive medications being taken by these subjects was obtained from questionnaires given to each household, as well as from patient's medical records at the Ohasama prefectural hospital. Subjects who said they had been treated at a hospital or clinic elsewhere, even though their antihypertensive medications were unclear, were classified as treated. Fig 1 shows the classification of these treated subjects by age and sex.

Devices

The ABPM 630 (Nippon Colin, Komaki, Japan), a fully automatic device, was used to monitor ambulatory BP.[14] Cuff pressure is provided by a CO_2 cartridge, and because 60 to 70 measurements can be made with one

TABLE 2. Average Screening and Ambulatory Blood Pressure in Participants Subdivided by Treatment and Sex

		Men				Women			
Blood Pressure	**Subjects**	**n**	**Age, y**	**SBP, mm Hg**	**DBP, mm Hg**	**n**	**Age, y**	**SBP, mm Hg**	**DBP, mm Hg**
Screening BP	Total	614	49.1 (20.2)	131.1 (19.1)*	74.3 (12.8)	788	52.2 (19.7)†	129.1 (20.7)†‡	72.7 (11.8)†
	Untreated	500	45.3 (20.2)	128.6 (17.7)	73.2 (12.3)	583	47.1 (19.7)	125.2 (18.5)§	71.3 (11.3)§
	Treated	114	66.1 (10.7)	141.9 (20.9)‡	79.1 (14.0)‡	205	66.7 (10.1)	140.1 (22.5)‡	76.7 (12.5)‡
ABP: 24-hour average	Total	229	61.2 (13.1)	123.7 (12.6)	72.5 (7.3)	476	57.6 (13.4)§	120.7 (13.1)*§	70.4 (7.6)§
	Untreated	153	58.5 (13.6)	121.8 (12.3)	71.9 (7.2)	321	53.3 (13.1)§	118.2 (12.5)§	69.2 (7.3)§
	Treated	76	66.9 (10.1)	127.5 (12.5)‡	73.7 (7.5)	155	66.4 (9.2)	125.9 (12.8)‡	72.8 (7.7)‡
ABP: Daytime average	Total	229	61.2 (13.1)	128.2 (13.5)	76.0 (8.0)	476	57.6 (13.4)†	126.2 (14.0)*	74.5 (8.3)†
	Untreated	153	58.5 (13.6)	126.1 (13.3)	75.3 (7.9)	321	53.3 (13.1)†	123.8 (13.5)	73.3 (8.0)
	Treated	76	66.9 (10.1)	132.1 (13.2)‖	77.5 (8.1)	155	66.4 (9.2)	131.1 (13.7)‡	76.9 (8.4)
ABP: Nighttime average	Total	229	61.2 (13.1)	115.7 (14.3)	66.3 (7.9)	476	57.6 (13.4)†	109.7 (14.4)§‖	62.2 (7.9)*§
	Untreated	153	58.5 (13.6)	113.7 (13.2)	65.6 (7.5)	321	53.3 (13.1)†	106.7 (13.2)§	60.7 (7.2)§
	Treated	76	66.9 (10.1)	119.9 (15.6)‖	67.6 (8.7)	155	66.4 (9.2)	116.1 (14.7)‡§	65.1 (8.5)‡§

SBP indicates systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure; and ABP, ambulatory blood pressure. Values are mean (SD).

*$P<.05$ vs untreated subjects.

†$P<.05$ vs men.

‡$P<.001$ vs untreated subjects.

§$P<.01$ vs men.

‖$P<.01$ vs untreated subjects.

cartridge, the device was preset to measure BP every 30 minutes. Although systolic BP (SBP) and diastolic BP (DBP) are measured by means of the cuff-oscillometric method concurrently with the microphone method, we used only the former. A fully automatic BP measuring device based on a microphone method, the USM 700F (UEDA), was used for screening BP measurements.[15]

The circumference of the arm was less than 32 cm in most cases, so we used a standard arm cuff for measuring ambulatory and screening BP. The BP measuring devices used in the present study were validated as reported previously.[14] The measurements obtained satisfied the criteria of the Association for the Advancement of Medical Instrumentation[16]; ie, the mean difference between the average of two physicians' auscultation and the ABPM 630 determination (cuff-oscillometric method) was -1.8 ± 6.1 mm Hg for SBP and 3.1 ± 6.9 mm Hg ($n=297$, mean±SD) for DBP, whereas that between the physicians' auscultation and the USM 700F determination was 0.8 ± 5.2 mm Hg for SBP and -0.5 ± 7.3 mm Hg ($n=321$) for DBP.

Analysis of Data

For a subject's ambulatory BP data to be included in the analysis, a monitoring period of more than 8 hours during waking hours (daytime) and more than 4 hours during the time the subject was in bed (nighttime) was required as estimated from the subject's diary. Mean monitoring time was 23.3 ± 1.6 hours; the mean number of measurements was 45.5 ± 4.8 times ($n=705$). The quality of sleep at night was disregarded in the present analysis.

Artifactual readings during ambulatory BP monitoring were defined according to the criteria mentioned previously and were omitted from the analysis.[17] The average 24-hour, day, and night readings for ambulatory BP and PR were calculated for each subject. If the 24-hour ambulatory BP monitoring was not completed, the 24-hour average ambulatory BP or PR was calculated as follows: 24-hour average ambulatory BP=(Daytime Average×Waking Hours+Nighttime Average×Sleeping Hours)/24, where "Sleeping Hours" were those spent in bed. The standard deviations of mean SBP, mean DBP, and mean PR for the 24 hours, daytime, and nighttime were also obtained. These were estimated as the 24-hour, daytime, and nighttime variation of BP and PR, respectively, for each individual. Data were then classified by age and sex. Data on screening BP were also classified by age and sex.

Distribution criteria. We calculated mean±SD of 24-hour, daytime, and nighttime averages of the ambulatory BP obtained in the total subjects and separately in the untreated subjects who measured their ambulatory BP. As distribution criteria for ambulatory BP, BP levels of mean+SD, mean+2 SDs, and 95th percentile values are cited in "Results."

Correspondence criteria. Individuals were classified by their screening BP levels according to World Health Organization (WHO) criteria (1976) as definitely hypertensive (SBP≥160 and/or DBP≥95 mm Hg), normotensive (SBP≤140 and DBP≤90 mm Hg), and borderline hypertensive (SBP<160 and DBP<95; SBP>140 and/or DBP>90 mm Hg). The ambulatory BP level was calculated for each of three groups. As correspondence criteria for the ambulatory BP, BP levels of mean+SD, mean+2 SDs, and 95th percentile values of the ambulatory BP in those subjects identified as normotensive by the screening BP are cited in "Results." Classifications and calculations were done on the total population and separately for the untreated population only.

We also examined the correlation between the two BP measures. Values are expressed as mean±SD. The

TABLE 2. Continued

Men and Women			
n	Age, y	SBP, mm Hg	DBP, mm Hg
1402	50.8 (20.1)	130.0 (20.0)‡	73.4 (12.3)*
1083	46.2 (19.9)	126.8 (18.2)	72.2 (11.8)
319	66.5 (10.3)	140.7 (21.9)‡	77.6 (13.1)‡
705	58.8 (13.4)	121.7 (13.0)‖	71.1 (7.6)*
474	55.0 (13.5)	119.4 (12.5)	70.1 (7.4)
231	66.5 (9.5)	126.4 (12.7)‡	73.1 (7.6)*
705	58.8 (13.4)	126.9 (13.9)‖	75.0 (8.3)
474	55.0 (13.4)	124.6 (13.5)	74.0 (8.0)
231	66.6 (9.5)	131.5 (13.6)‡	77.1 (8.3)‡
705	58.8 (13.4)	111.7 (14.6)‖	63.5 (8.1)*
474	55.0 (13.5)	109.0 (13.6)	62.4 (7.6)
231	66.5 (9.5)	117.3 (15.1)‡	65.9 (8.6)‡

significance of the difference between groups was obtained by analysis of variance for equality of regression (ANOVA-ER) and analysis of covariance (ANCOVA) using the statistical package NAP, version 2 (Igaku Shoin, Tokyo, Japan). Student's *t* test was used for paired or unpaired comparisons unless otherwise stated.

Results

Screening and Ambulatory Blood Pressure

Distribution criteria. Screening and ambulatory BPs were analyzed in the total group of subjects evaluated including the treated and untreated individuals (Table 2). The reference values of ambulatory BP according to distribution criteria are shown in Table 3. The screening BP of the total 1402 subjects including the treated and untreated individuals significantly exceeded that of the 1083 untreated subjects (Table 2; SBP, $P<.001$, and DBP, $P<.005$). The 24-hour ambulatory BP of the 705 subjects so tested significantly exceeded that of the 474 untreated subjects (Table 2). Ambulatory BP obtained during the day and night in the total subjects significantly exceeded that of the untreated group (Table 2).

TABLE 3. Reference Values of 24-Hour, Daytime, and Nighttime Ambulatory Blood Pressure According to Distribution Criteria

		24-Hour		Daytime		Nighttime	
Subjects	Age, y	SBP, mm Hg	DBP, mm Hg	SBP, mm Hg	DBP, mm Hg	SBP, mm Hg	DBP, mm Hg
Total (n=705)							
Mean±SD	58.8±14.4	121.7±13.0	71.1±7.6	126.9±13.9	75.0±8.3	111.7±14.6	63.5±8.1
Mean+SD		135	79	141	83	126	72
Mean+2SDs		148	86	155	92	141	80
95%		146	85	153	90	141	79
Untreated (n=474)							
Mean±SD	55.0±13.5	119.4±12.5	70.1±7.4	124.6±13.5	74.0±8.0	109.0±13.6	62.4±7.6
Mean+SD		132	78	138	82	123	70
Mean+2SDs		144	85	152	90	136	78
95%		144	83	150	88	137	77
Young (n=68)							
Mean±SD	31.8±5.5	111.6±8.4	65.5±5.8	116.6±9.5	69.2±6.5	100.6±8.0	57.1±5.6
Mean+SD		120	71	126	76	109	63
Mean+2SDs		128	77	136	82	117	68
95%		126	75	132	81	114	67
Middle-aged (n=273)							
Mean±SD	51.8±5.3	119.3±11.8	71.1±7.7	124.8±12.7	75.0±8.2	107.6±12.3	62.7±7.7
Mean+SD		131	79	138	83	120	70
Mean+2SDs		143	87	150	91	132	78
95%		140	85	148	90	129	77
Elderly (n=364)							
Mean±SD	69.1±6.7	125.4±13.2	72.1±7.4	130.3±14.1	76.0±8.1	116.8±15.0	65.4±8.2
Mean+SD		137	80	144	84	132	74
Mean+2SDs		152	87	159	92	147	82
95%		149	85	155	90	144	80

SBP indicates systolic blood pressure; DBP, diastolic blood pressure; and 95%, 95th percentile value.

TABLE 4. Average Screening Blood Pressure by Age and Sex in Untreated and Total Subjects (Treated and Untreated Groups)

	Total Subjects by Age Group, y						
	20-29	30-39	40-49	50-59	60-69	70-79	80+
Men							
n	20	71	83	131	130	69	22
SBP, mm Hg	121.9 (11.3)*	124.0 (13.3)†	133.1 (18.5)†	132.4 (17.2)	138.5 (19.2)	138.0 (17.0)	144.5 (20.5)
DBP, mm Hg	68.8 (8.4)*	70.5 (10.7)	77.8 (14.5)*	78.0 (11.2)*	78.0 (11.7)	74.4 (10.9)	77.7 (13.6)
Women							
n	28	85	111	172	165	104	45
SBP, mm Hg	110.5 (13.2)	116.6 (12.0)	125.6 (16.5)	130.7 (19.3)	135.3 (22.4)	140.8 (18.6)	143.9 (24.2)
DBP, mm Hg	62.5 (12.2)	68.2 (9.0)	74.2 (11.4)	75.2 (11.1)	75.8 (12.5)	73.5 (10.5)	74.9 (13.9)

SBP indicates systolic blood pressure; and DBP, diastolic blood pressure. Values are mean (SD).
*$P<.05$, †$P<.001$, ‡$P<.01$ vs women.

Because the age of the total subjects versus that of the untreated subjects differed significantly, ANCOVA or ANOVA-ER was performed. Such analysis also demonstrated that ambulatory BP in the total subjects significantly exceeded that of the untreated subjects (24-hour ambulatory SBP: $F=12.0$, $P<.001$; ambulatory DBP: $F=19.6$, $P<.001$). Therefore, to identify the characteristics of the ambulatory BP in the population, we mainly analyzed the data obtained from the total subjects.

Age-dependent changes in ambulatory BP. The 659 subjects who had measurements of both screening and ambulatory BP were classified by age and sex (Figs 2 and 3; actual values of screening and ambulatory BP and regression equations appear in Tables 4 through 7). Screening and ambulatory BP rose gradually with age in both men and women. After age 60, DBP tended to fall in men but remained at the same level in women, resulting in a wider pulse pressure in the older age groups.

The total subjects (n=705) in whom ambulatory BP was tested were also classified into three subgroups: young (20 to 39 years, n=68, 31.8±5.5 years), middle-aged (40 to 59 years, n=273, 51.8±5.3 years), and elderly (60 or more years, n=364, 69.1±6.7 years). Reference values of ambulatory BP in each age group according to the distribution criteria are shown in Table 3.

The rise in ambulatory BP seen with age in men was significantly smaller than that in women (actual values of screening and ambulatory BP and regression equations appear in Tables 4 through 7) (24-hour ambulatory SBP: $F=10.7$, $P<.001$; 24-hour ambulatory DBP: $F=11.7$, $P<.001$, see Table 7). In men in their 80s, the mean 24-hour ambulatory SBP/ambulatory DBP was 8.8/1.5 mm Hg higher than that seen in men in their 20s. In women, the mean difference between those two age categories was 25.9/10.8 mm Hg. Considering the total subjects, the ambulatory BP of men exceeded that of women (Table 2). In the total subjects the screening BP significantly exceeded the 24-hour ambulatory BP (Tables 2 and 7; SBP in men: $F=6.34$, $P=.01$; DBP in men: $F=12.2$, $P<.001$; SBP in women: $F=129.8$, $P<.001$; DBP in women: $F=29.9$, $P<.001$). The screening BP was also significantly higher than the nighttime ambulatory BP ($F=134.5$, $P<.001$). The screening SBP was slightly but significantly higher than the daytime ambulatory SBP (men: $F=8.9$, $P<.002$; women: $F=30.9$, $P<.001$). The screening DBP did not differ significantly from the daytime ambulatory DBP.

TABLE 5. Average Ambulatory Blood Pressure by Sex and Age in Total Subjects (Treated and Untreated Groups)

	Men: Age Group, y						
Blood Pressure	≤29 (n=6)	30-39 (n=12)	40-49 (n=18)	50-59 (n=49)	60-69 (n=80)	70-79 (n=54)	80+ (n=10)
24-Hour average ABP							
SBP, mm Hg	120.0 (5.3)	116.3 (6.9)	122.6 (9.5)*	122.1 (13.5)	124.4 (11.8)	125.5 (13.5)	128.8 (19.1)
DBP, mm Hg	68.6 (4.3)	69.2 (4.0)*	74.1 (5.6)*	73.5 (8.9)	73.5 (6.6)	71.4 (6.9)	70.1 (11.2)
Daytime average ABP							
SBP, mm Hg	126.0 (7.0)	121.2 (7.8)	127.8 (11.3)†	127.0 (14.6)	128.7 (12.6)	130.0 (14.8)	131.8 (19.3)
DBP, mm Hg	73.6 (5.3)	72.9 (4.7)	78.0 (6.6)*	77.0 (9.4)	76.8 (7.4)	75.0 (7.7)	72.4 (11.9)
Nighttime average ABP							
SBP, mm Hg	107.9 (4.2)	105.4 (7.2)†	112.0 (7.9)‡	112.7 (14.3)	116.7 (13.6)	120.0 (15.4)	123.4 (20.7)
DBP, mm Hg	58.3 (3.8)	61.1 (4.2)†	66.2 (4.9)‡	66.6 (9.2)*	67.5 (7.4)*	66.3 (7.8)	66.1 (11.7)

ABP indicates ambulatory blood pressure; SBP, systolic blood pressure; and DBP, diastolic blood pressure. Values are mean (SD).
*$P<.01$, †$P<.05$, ‡$P<.001$ vs women.

TABLE 4. Continued

Untreated Subjects by Age Group, y						
20-29	30-39	40-49	50-59	60-69	70-79	80+
20	69	75	112	91	30	15
121.9 (11.3)‡	124.2 (13.4)†	130.2 (13.7)‡	131.8 (17.1)	136.4 (17.2)‡	134.5 (18.0)*	145.5 (21.2)
68.8 (8.4)*	70.3 (10.4)	76.1 (11.8)	77.9 (11.1)†	77.0 (11.0)‡	72.3 (10.7)	79.7 (13.8)
28	84	101	133	98	38	23
110.5 (13.2)	116.5 (12.0)	124.8 (15.4)	129.2 (19.6)	130.3 (18.3)	142.9 (16.7)	143.2 (21.5)
62.5 (12.2)	68.0 (9.0)	74.0 (11.6)	74.0 (10.7)	73.0 (11.5)	75.9 (9.8)	74.4 (11.6)

The PR decreased gradually with age in both women and men, although the decrease was less evident in the latter (Figs 2 and 3, Table 7).

Interindividual and intraindividual variation of ambulatory BP. The SD of screening and ambulatory BP in each age group, which shows interindividual variation, gradually increased with age, indicating that the BP was distributed more widely in the elderly than the younger subjects (Figs 2 and 3, Tables 4 through 6).

The SD of 24-hour daytime and nighttime ambulatory BP in individuals, the intraindividual variation, increased gradually with age in both men and women (Figs 2 and 3, Table 7). This trend was also significant for the nighttime ambulatory BP. The intraindividual daily variation of ambulatory SBP was significantly higher than that of the ambulatory DBP (Figs 2 and 3, Table 7).

The intraindividual daily variation in PR decreased gradually with age in men and also in women, although it was less marked in the latter (Figs 2 and 3, Table 7).

Day-night variation of ambulatory BP. The characteristics of the age-dependent change in daytime versus nighttime ambulatory BP also differed between men and women. The increase in daytime ambulatory BP in men in their 20s and 80s (ΔSBP/ΔDBP=5.8/−1.2 mm Hg) was less than that in women (ΔSBP/ΔDBP=27.9/12.9 mm Hg, Table 7), whereas there was not much difference in the age-dependent increase in nighttime BP between sexes (men, ΔSBP/ΔDBP=15.5/7.8 mm Hg; women, ΔSBP/ΔDBP=27.5/10.7 mm Hg; Table 7). This finding indicates that the day versus night difference, or the nocturnal fall in BP, gradually decreased in men with age. Actually, the amplitude of the nocturnal fall in BP in elderly men (those in their 80s, ΔSBP/ΔDBP=8.4/6.3 mm Hg) was less marked than that in young men (those in their 20s, ΔSBP/ΔDBP=18.1/15.3 mm Hg). This tendency was not observed in women. Such analyses conducted in the untreated subjects gave results similar to those obtained in the total subjects.

Ambulatory Blood Pressure Levels in Groups Whose Screening Blood Pressure was Classified by WHO Criteria

Correspondence criteria. In subjects in whom both screening and ambulatory BP were measured, the screening BP readings were classified into three groups according to WHO criteria (1976). The ambulatory BP in each group is shown according to normotensive, borderline, and hypertensive groupings in Table 8. The 95th percentile value of the 24-hour ambulatory BP in the normotensive subgroup was 139/81 mm Hg. Critical

TABLE 5. Continued

Women: Age Group, y						
≤29 (n=13)	30-39 (n=37)	40-49 (n=70)	50-59 (n=136)	60-69 (n=126)	70-79 (n=76)	80+ (n=18)
107.0 (7.5)	110.4 (8.2)	114.9 (9.2)	120.1 (12.0)	123.6 (13.2)	126.9 (11.6)	132.9 (17.8)
61.9 (6.2)	65.0 (5.6)	68.4 (6.6)	71.2 (7.5)	71.7 (7.6)	72.0 (6.5)	72.7 (11.4)
110.8 (8.2)	115.6 (9.4)	120.3 (9.6)	125.9 (13.1)	129.7 (14.2)	131.3 (13.5)	138.7 (16.9)
64.7 (6.8)	68.9 (6.1)	72.2 (6.9)	75.4 (8.3)	76.2 (8.1)	75.5 (8.0)	77.6 (10.7)
97.9 (5.6)	98.9 (8.4)	103.1 (9.7)	107.5 (12.3)	112.7 (14.4)	118.5 (13.6)	125.4 (20.5)
55.3 (5.7)	56.2 (5.9)	60.1 (6.8)	62.3 (7.1)	63.5 (8.1)	65.3 (6.9)	66.0 (13.3)

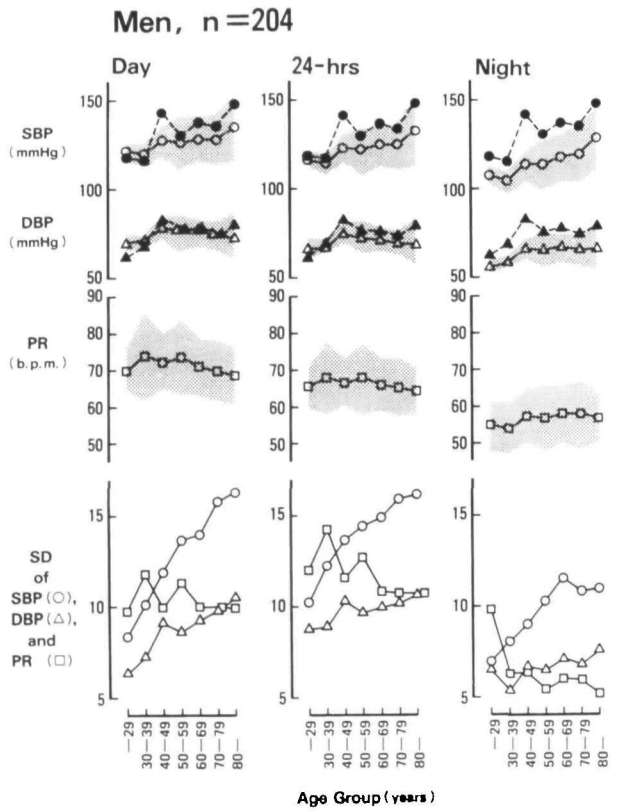

FIG 2. Line graphs show age-dependent change in screening blood pressure (BP, solid symbols), ambulatory BP (open symbols), and pulse rate (PR), with intraindividual variation of ambulatory BP and PR (SD) in men. Shaded area shows mean±SD of ambulatory BP and PR in each age group. SBP and DBP, systolic and diastolic BP; b.p.m., beats per minute.

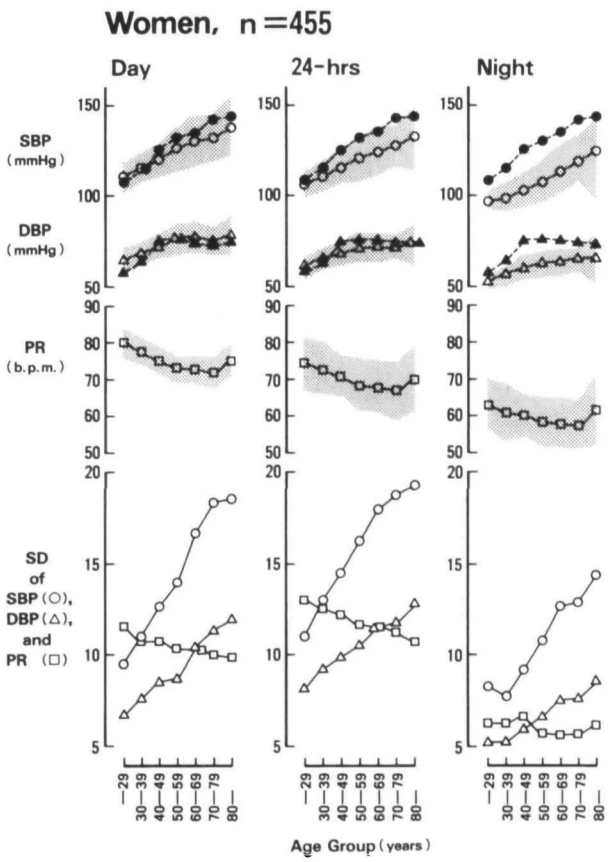

FIG 3. Line graphs show age-dependent change in screening blood pressure (BP, solid symbols), ambulatory BP (open symbols), and pulse rate (PR), with intraindividual variation of ambulatory BP and PR (SD) in women. Shaded area shows mean±SD of ambulatory BP and PR in each age group. SBP and DBP, systolic and diastolic BP; b.p.m., beats per minute.

BP levels were arbitrarily set at the BP levels of mean+SD (24-hour average: 129/76 mm Hg; daytime average: 135/80 mm Hg) and mean+2 SDs (24-hour average: 140/83 mm Hg; daytime average: 147/88 mm Hg) of ambulatory BP in the subjects identified as normotensive by the screening BP (correspondence criteria).

Evaluation of ambulatory BP by correspondence criteria. The 24-hour average BP in the total subjects (n=705) in whom ambulatory BP was measured was evaluated by the correspondence criteria in terms of mean+2 SDs (140/83 mm Hg) of the 24-hour ambulatory BP in the subjects identified as normotensive by screening BP. Of the 705 subjects, 628 (89.1%) were below this level. When subjects were evaluated by the

TABLE 6. Average Ambulatory Blood Pressure by Sex and Age In Untreated Subjects

	Men: Age Group, y						
Blood Pressure	**≤29 (n=6)**	**30-39 (n=11)**	**40-49 (n=12)**	**50-59 (n=40)**	**60-69 (n=54)**	**70-79 (n=25)**	**80+ (n=5)**
24-Hour average ABP							
SBP, mm Hg	120.0 (5.3)	116.9 (6.9)*	124.3 (9.4)†	120.2 (12.3)	122.3 (11.8)	122.7 (14.2)	131.9 (23.2)
DBP, mm Hg	68.6 (4.3)	69.4 (4.1)*	74.7 (5.3)†	72.1 (8.1)	72.6 (6.7)	70.4 (7.0)	73.4 (14.7)
Daytime average ABP							
SBP, mm Hg	126.0 (7.0)	122.0 (7.5)	129.8 (11.1)*	124.8 (13.1)	126.7 (12.9)	125.4 (15.9)	135.1 (23.1)
DBP, mm Hg	73.6 (5.3)	73.3 (4.7)	78.8 (6.5)†	75.5 (8.4)	75.9 (7.6)	73.3 (8.3)	75.9 (14.8)
Nighttime average ABP							
SBP, mm Hg	107.9 (4.2)	105.5 (7.6)	112.6 (8.7)†	110.6 (11.9)	114.7 (13.1)	119.2 (14.4)	126.3 (23.7)
DBP, mm Hg	58.3 (3.8)	61.1 (4.4)*	65.9 (4.2)‡	65.2 (7.9)*	66.9 (7.3)	66.4 (6.9)	69.2 (15.4)

ABP indicates ambulatory blood pressure; SBP, systolic blood pressure; and DBP, diastolic blood pressure. Values are mean (SD). *$P<.05$, †$P<.01$, ‡$P<.001$ vs women.

correspondence criteria in terms of mean+SD of ambulatory BP (129/76 mm Hg), 484 of the 705 subjects (68.7%) were judged to be below this level.

Based on the mean+SD of the correspondence criteria (129/76 mm Hg), the 24-hour ambulatory BP in 25 (34.2%) of the 73 subjects identified as hypertensive by the screening BP were below this level, even though they had been diagnosed as hypertensive by the screening BP (SBP≥160 and/or DBP≥95 mm Hg). Nine (2%) of 448 subjects identified as normotensive by the screening BP were above the mean+2 SDs of the correspondence criteria of the 24-hour ambulatory BP (140/83 mm Hg).

The 24-hour ambulatory BP in the 474 untreated subjects was evaluated according to the correspondence criteria obtained in the untreated normotensive subjects identified by screening BP. Of the 474, 342 had an ambulatory BP that was equal to or below the mean+SD of 127/75 mm Hg observed in the normotensive subjects.

The distribution of ambulatory BP values in the subjects identified as hypertensive by the screening BP widely overlapped that of the subjects identified as normotensive by the screening BP (Fig 4).

Evaluation of ambulatory BP by WHO criteria. The daytime ambulatory BP values in 53% of the subjects identified as hypertensive by the screening BP (WHO criteria) were equal to or lower than 140/90 mm Hg, whereas in 14% they were equal to or higher than 160 mm Hg systole and/or 95 mm Hg diastole. In 0.2% of the subjects identified as normotensive by screening BP, these values were equal to or higher than 160 mm Hg systole and/or 95 mm Hg diastole. In 4% of the subjects who were identified as borderline hypertensive by screening BP, these values were equal to or higher than 160 mm Hg systole and/or 95 mm Hg diastole.

Correlation Between Casual and Ambulatory Blood Pressure

A significant positive correlation was observed between the screening and 24-hour ambulatory BP (Fig 5). However, these scatterplots indicate a wide distribution of the points around the linear regression lines for both SBP and DBP, suggesting the difficulty in inferring the ambulatory from the screening BP or vice versa. This relation resembled that observed between the casual BP and the daytime or nighttime ambulatory BP. The correlation between the screening and ambulatory BP in the untreated subjects tended to be higher than that in the total population (correlation between the screening and 24-hour ambulatory BP in the untreated subjects: SBP, r=.49; DBP, r=.47; n=628).

Discussion

Reference Values of Ambulatory Blood Pressure

Most of the information on reference values for the ambulatory BP level obtained during 24-hour monitoring comes from studies of selected subjects designated as normotensive by conventional BP measurements (correspondence criteria). Battistella et al[18] studied more than 100 subjects in a wide age range, measuring ambulatory BP in 394 normotensive subjects from 20 to 75 years old; they reported that the 24-hour ambulatory BP mean+2 SDs was 141/89 mm Hg. Zachariah et al[19] also evaluated this parameter in 126 normotensive subjects from 20 to 79 years old and set the mean+2 SDs at 138/88 mm Hg. Concerning the distribution criteria, O'Brien et al[20] evaluated the mean ambulatory BP in 815 untreated subjects (17 to 79 years old) at the Allied Irish Bank and reported the mean 24-hour ambulatory BP value as 118/72 mm Hg (mean+2 SDs: 140/86 mm Hg in the population). More recently, Staessen et al[21] reported that 24-hour ambulatory BP averaged 118/71 mm Hg in 328 untreated subjects randomly sampled in a small town in Europe. The mean ambulatory SBP values obtained in those population studies were slightly lower than found in the present study. However, the DBP values were very similar to those determined in the present study, even though we studied Japanese people whereas the other investigators studied Caucasians.

Correspondence Criteria

Some authors emphasize that the evaluation of information on BP, other than the casual BP, should be indirectly based on cardiovascular risk by defining reference data in terms of the corresponding casual BP, because the cardiovascular risk of casual BP is well established.[10,11] However, for valid analysis, the values

TABLE 6. Continued

Women: Age Group, y						
≤29 (n=13)	30-39 (n=37)	40-49 (n=64)	50-59 (n=104)	60-69 (n=72)	70-79 (n=26)	80+ (n=5)
107.0 (7.5)	110.4 (8.2)	114.0 (8.5)	118.1 (11.8)	123.2 (13.4)	130.5 (10.6)	123.7 (17.6)
61.9 (6.2)	65.0 (5.6)	67.8 (6.3)	70.3 (7.6)	71.0 (7.0)	73.4 (6.3)	65.7 (9.2)
110.8 (8.2)	115.6 (9.4)	119.3 (9.0)	123.9 (13.0)	129.5 (14.5)	135.7 (13.3)	131.6 (14.6)
64.7 (6.8)	68.9 (6.1)	71.6 (6.7)	74.4 (8.5)	75.5 (7.6)	77.8 (7.4)	71.5 (7.8)
97.9 (5.6)	98.9 (8.4)	102.1 (8.7)	105.6 (11.1)	112.0 (14.4)	121.5 (15.4)	114.1 (21.9)
55.3 (5.7)	56.2 (5.9)	59.5 (6.2)	61.5 (6.8)	62.9 (7.3)	66.1 (7.1)	58.6 (12.0)

TABLE 7. Regression Analysis of Age-Dependent Change in Blood Pressure and Pulse Rate

Objective of Analysis	Age, y	Regression Equation	r	P
Casual BP				
Men (n=614)	69.4±20.2			
SBP		$y=0.41x+110.6$	.43	<.001
DBP		$y=0.19x+65.2$	.31	<.001
Women (n=788)	51.9±19.6			
SBP		$y=0.48x+104.2$	.46	<.001
DBP		$y=0.17x+63.9$	.28	<.001
24-Hour ABP and PR				
Men (n=229)	61.3±13.4			
SBP		$y=0.18x+112.8$	.18	<.05
DBP		$y=0.002x+72.4$	.004	NS
PR		$y=-0.09x+72.4$	−.15	<.05
Women (n=476)	57.5±13.3			
SBP		$y=0.42x+96.7$	.43	<.001
DBP		$y=0.15x+61.4$	.27	<.001
PR		$y=-0.12x+76.3$	−.23	<.001
SD of 24-hour ABP and PR				
Men (n=229)	61.3±13.4			
SBP		$y=0.07x+10.6$	.24	<.001
DBP		$y=0.02x+9.2$	.08	NS
PR		$y=-0.06x+15.6$	−.21	<.001
Women (n=476)	57.5±13.3			
SBP		$y=0.15x+8.2$	.46	<.001
DBP		$y=0.07x+6.9$	.36	<.001
PR		$y=-0.03x+13.6$	−.13	<.001

BP indicates blood pressure; SBP, systolic BP; DBP, diastolic BP; ABP, ambulatory BP; and PR, pulse rate. In the regression equation, where $y=ax+b$, y is BP or PR and x is age.

TABLE 8. Ambulatory Blood Pressure in Subjects Identified as Normotensive, Borderline Hypertensive, or Hypertensive by Screening Blood Pressure in Total Subjects (Treated and Untreated) and Untreated Subjects

		Corresponding ABP				Corresponding ABP		
Subjects	Screening BP, NT	24-Hour Average	Daytime Average	Nighttime Average	Screening BP, BHT	24-Hour Average	Daytime Average	Nighttime Average
Total								
n	448				138			
Age, y (mean±SD)	57.2±13.1				65.0±10.2			
SBP, mm Hg	122.3 (12.0)	118.0 (11.1)*	122.9 (11.9)	108.2 (12.6)*	147.6 (6.3)	127.4 (12.1)*	133.2 (12.9)*	117.3 (15.0)*
DBP, mm Hg	70.3 (9.6)	69.4 (6.8)	73.0 (7.4)*	62.0 (7.4)*	80.4 (10.2)	73.5 (7.4)*	77.9 (8.2)*	65.7 (8.0)*
Untreated								
n	335				71			
Age, y (mean±SD)	54.0±12.7				62.2±10.6			
SBP, mm Hg	121.1 (12.4)	116.1 (10.4)*	121.1 (11.4)	105.8 (11.4)*	146.7 (6.2)	126.7 (11.6)*	132.2 (12.7)*	116.5 (14.2)*
DBP, mm Hg	69.9 (9.6)	68.5 (6.6)	72.2 (7.2)†	60.9 (6.8)*	81.8 (9.7)	73.5 (7.4)*	77.6 (8.3)†	66.1 (7.8)*

ABP indicates ambulatory blood pressure; BP, blood pressure; NT, normotensive; BHT, borderline hypertensive; HT, hypertensive; SBP, systolic blood pressure; and DBP, diastolic blood pressure. Values are mean (SD).
*$P<.001$, †$P<.01$ vs screening BP.

for ambulatory and casual BP must be comparable. Furthermore, there must be a constant relation between the ambulatory and casual BP with respect to age, sex, and BP levels. If these conditions are satisfied, information other than the casual BP, including the ambulatory BP, may not be required. BP information other than casual BP has already been used clinically to overcome the shortcomings of the casual BP, ie, unreliability due to natural diurnal and random variation. The reference ambulatory BP value, if derived from such variable BP information, would also include a wide range of error. In contrast, averaging a large number of BP values obtained by ambulatory BP eliminates the factor of BP variation.

Although we observed a highly significant correlation between the ambulatory and screening BP, the scatterplots (Fig 5) showed a wide distribution of the points around the linear regression line. The distribution of ambulatory BPs in the subjects identified as hypertensive by the screening BP overlapped that of those classified as normotensive by the screening BP (Fig 4), again indicating the difficulty in predicting the ambulatory BP from screening BP or vice versa. It is also well known that the difference between the casual and ambulatory BP increases with the elevation of casual BP levels.[22-24] Therefore, subjects identified as hypertensive by their casual (screening) BP were not necessarily hypertensive in terms of their ambulatory BP.

Distribution Criteria

One must consider population characteristics in obtaining a reference value for the ambulatory BP from the distribution criteria. The natural history of hypertension in people living in industrialized countries is not known; hence, it is impossible to examine a population without encountering the influence of antihypertensive treatment. If we chose to monitor untreated subjects, their mean BP might be below that of the total population of untreated and treated subjects. In the present study, we demonstrated that the mean BP of the untreated group was significantly lower than that of either the treated or the total group.

TABLE 8. Continued

	Corresponding ABP		
Screening BP, HT	24-Hour Average	Daytime Average	Nighttime Average
73			
63.1±10.6			
171.2 (19.7)	133.6 (14.2)*	139.0 (15.2)*	123.3 (15.7)*
91.0 (12.2)	78.9 (8.8)*	81.1 (9.4)*	68.9 (9.2)*
30			
61.2±10.3			
171.4 (15.1)	135.7 (13.7)*	141.4 (15.0)*	124.1 (14.0)*
90.3 (11.8)	77.8 (7.8)*	82.1 (8.8)*	69.3 (7.4)*

Rowland and Roberts[25] stated in the National Health and Nutritional Survey II (1976 to 1980) that 66% of the hypertensive population was either uncontrolled or untreated. Sawai,[26] who analyzed the data from the Ministry of Health and Welfare, Japan, 1980, reported that more than 60% of the treated hypertensive individuals still exhibited a high BP according to the WHO criteria. In the present study, 18.6% of the treated subjects were definitely hypertensive, and 30.5% were borderline hypertensive, based on screening BP measurements. Accordingly, we analyzed the data from the total population including the treated subjects. This analysis may provide a representative distribution of BP values in a population in a modern industrialized country. Data on the untreated subjects were analyzed separately.

Age-Dependent Changes in Ambulatory Blood Pressure Levels

It is clear that BP becomes elevated with age. Most cross-sectional studies performed worldwide indicate that casual SBP increases with age until the 70s in men and the 80s in women.[27] DBP ceases to increase around the age of 50 to 60 years and even decreases somewhat.[27,28] It is reported that SBP rises at a rate of approximately 0.8 mm Hg per year throughout adult life.[28] There is a difference of 25 mm Hg in the casual SBP of Japanese men in their 20s versus their 80s.[29] The present study also confirmed such age- and sex-specific characteristics of screening BP. Although the age- and sex-specific characteristics of ambulatory BP in the present study resembled those of screening BP, the age-dependent increase in ambulatory SBP was extremely small, especially in men. Screening SBP in men rose by 23 mm Hg from their 20s to their 80s, whereas ambulatory SBP rose by only 9 mm Hg. The smaller age-dependent rise in ambulatory SBP in men (9 mm Hg) than in women (26 mm Hg) reflects the higher ambulatory SBP in men versus those women younger than age 50, as well as a minimal rise in ambulatory SBP in men over age 60.

Difference Between Screening and Ambulatory Blood Pressure Levels

A difference between the casual and ambulatory BP value was previously observed.[30] We found that the 24-hour and even the daytime averages of the ambulatory SBP tended to be lower than those of the screening SBP. This difference between ambulatory and screening SBP was not attributable to differences in BP measuring devices in that the mean differences in SBP between the 24-hour ambulatory BP and the screening BP in the subjects identified as normotensive and those identified as hypertensive were 4.3 and 37.6 mm Hg, respectively, whereas the estimated maximal difference between the devices was 2.6 mm Hg (see "Methods"). The difference between the casual and ambulatory BP is known to increase with age as well as with the elevation of casual BP levels.[22-25,30] We also observed that this difference increased with elevation of screening BP levels (see Table 8). The present study also confirmed that the difference was greater in the elderly than in the young. This observation is supported by the lesser age-dependent increase in the ambulatory SBP with the apparent age-dependent increase in screening BP.

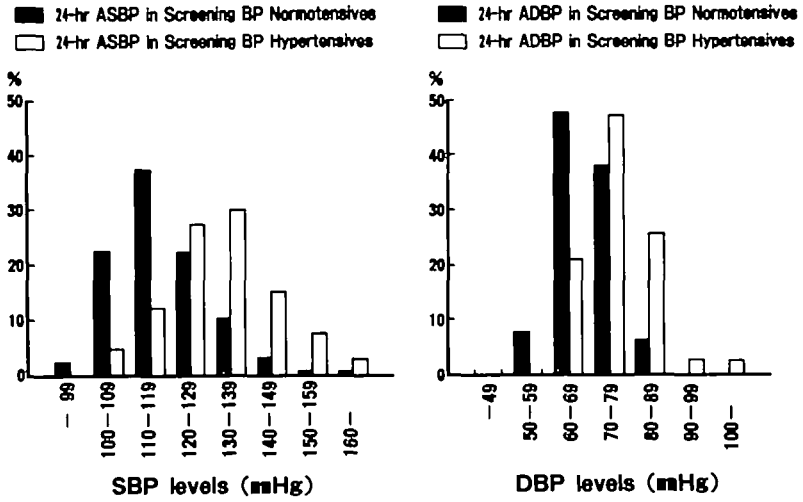

FIG 4. Bar graphs show distribution of values for ambulatory blood pressure (BP) obtained in subjects identified as normotensive by the screening BP and in subjects identified as hypertensive by the screening BP. ASBP and ADBP, ambulatory systolic and diastolic BP; SBP and DBP, systolic and diastolic BP.

Blood Pressure Variability

We measured the ambulatory BP every 30 minutes in the present study. DiRienzo et al[31] reported that the SD for 24-hour intermittent ambulatory BP with a monitoring interval of 30 or 60 minutes does not necessarily offer a precise measurement of BP variability. Although BP variability was determined under such a limited condition, the present investigation as well as several previous studies demonstrated that BP variation (SD of ambulatory BP, daily variation) is greater in the elderly than in the young,[22,32-34] indicating that in the elderly each ambulatory BP value is unexpectedly high on one occasion and low on another. Furthermore, the casual BP is influenced by the so-called white coat effect, which produces a BP that exceeds the "true" BP for an individual.[35,36] The SBP response to mental and physical stimuli may be potentiated in elderly subjects who have a marked decrease in vascular compliance and a diminished baroreceptor reflex function.[22,37-39] A disturbed baroreceptor reflex function in the elderly is suggested by the present findings of an age-dependent decrease in PR variation. However, the average of multiple readings of ambulatory BP is susceptible to the effect of regression to the mean. Such factors could produce a difference between the screening and ambulatory BP.

The variation in SBP exceeds that in DBP.[30] This is true of the 24-hour, daytime, and nighttime variations of the ambulatory BP measurement. We found that the day-night difference in ambulatory BP decreased gradually in men with age. This reflects a lesser age-dependent increase in the daytime BP, as well as an apparent age-dependent increase in the nighttime BP (Fig 2). The physical and mental activities of elderly subjects are decreased during waking hours, and their sleep is easily disturbed. These are not the only factors responsible for the age-specific nature of daytime and nighttime BP, because such an age-dependent decrease has not been observed in women. Although in men the age-dependent increase in nighttime BP exceeded that of the daytime BP, their age-dependent increase in nighttime BP was rather less than seen in women. Therefore, the lesser age-dependent increase in daytime BP in men contributes to a lesser day-night difference of BP in elderly men. Why the reduction in the day-night difference in BP is observed only in men remains to be clarified but could have clinical significance; ie, the hypertensive cardiovascular and cerebrovascular organ damage would be accerelated in patients with a minimal nocturnal fall in BP.[40-42]

Evaluation of Ambulatory Blood Pressure Values

Because the 24-hour and even the daytime average ambulatory BP is less than the screening (casual) BP, ambulatory BP values should not be considered as either normal or abnormal on the WHO criteria for screening BP. However, in subjects identified as normotensive by the screening BP and the WHO criteria, hypertension accounted for 1% and borderline hypertension for 7% based on the daytime average ambulatory BP. That the screening (casual) measurement of BP occasionally provides misleadingly low readings has prognostic importance for hypertensive patients. That is, individuals whose average ambulatory BP exceeds their "casual" values obtained in the clinic are at higher risk for serious cardiovascular complications than those whose average ambulatory BP is below their "casual"

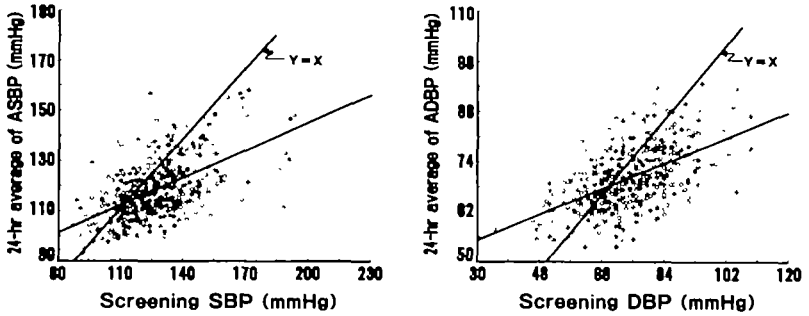

FIG 5. Scatterplots show correlation between screening and ambulatory blood pressure (BP). ASBP and ADBP, ambulatory systolic and diastolic BP; SBP and DBP, systolic and diastolic BP. Correlation equation for SBP was $y=71.9+0.37x$ ($r=.56$) and for DBP, $y=45.1+0.34x$ ($r=.45$), where y is ambulatory BP and x is screening BP.

readings.[6] The major problem in the diagnosis and treatment of hypertension is the variation in casual readings, so those people who demonstrate hypertension in ambulatory BP monitoring but not on "casual" BP determination should be regarded as definitely hypertensive. However, one should not denigrate the utility of the casual (screening) BP, because valuable epidemiologic information concerning the predictive value of BP for disease and mortality has come from studies that used a single casual (screening) BP determination.[37]

Conclusion

We have demonstrated the characteristics of the ambulatory and screening BP in a population in a rural town in northern Japan. The results indicate only the reference values for the ambulatory BP obtained in this specific population. However, the results also illustrate the characteristic ambulatory BP of people living in an industrialized country. We are presently conducting follow-up studies to evaluate the predictive significance of different values in the BP distribution to determine the utility of ambulatory BP monitoring.

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