The Diurnal Blood Pressure Profile

A Population Study

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This population study included 399 subjects, of whom 370 (93%) showed a significant diurnal blood pressure (BP) rhythm. The nocturnal BP fall was normally distributed and averaged 16 ± 9 mm Hg systolic and 14 ± 7 mm Hg diastolic (mean ± SD). The amplitude of the diurnal BP curve followed a positively skewed distribution, with a mean of 16 ± 5 mm Hg for systolic BP and 14 ± 4 mm Hg for diastolic BP. The daily BP maximum occurred at 15:54 ± 4:47 for systolic BP and at 15:11 ± 4:20 for diastolic BP. Thirty-four subjects were reexamined after a median interval of 350 days. The test for the presence of a significant diurnal rhythm was discordant in only two subjects. Repeatability (twice the standard deviation of the differences between paired recordings expressed as a percentage of the mean) varied from 11 to 25% for the 24 h, daytime, and overnight BP, and from 76 to 138% for the parameters describing the diurnal BP rhythm. In nine subjects with an initial night/day ratio of mean BP < 0.78, the nighttime BP was significantly increased at the repeat examination, whereas the opposite tendency was observed in nine subjects with an initial ratio > 0.87. In conclusion, the distribution of the nocturnal BP fall is unimodal. The reproducibility of the ambulatory BP is satisfactory for the level of BP and for the presence of a diurnal BP rhythm, but not for the parameters of the diurnal BP curve. Thus, one 24 h recording is insufficient to fully characterize an individual's diurnal BP profile. Am J Hypertens 1992;5:386-392

KEY WORDS: **Ambulatory blood pressure, diurnal blood pressure profile, nocturnal blood pressure fall.**

The clinical value of ambulatory blood pressure monitoring has not yet been clearly established.[1,2] However, some clinicians advocate the use of ambulatory blood pressure monitoring in day-to-day practice, because ambulatory readings outside the medical environment are free of the so-called white coat effect,[3,4] often seen when the blood pressure is conventionally measured. In addition, ambulatory monitoring provides blood pressure measurements during habitual daily activities and during sleep. Some investigators have speculated that the amplitude of the diurnal blood pressure curve is characteristic for an individual,[5] or that the fall in blood pressure during sleep is correlated with cardiovascular prognosis.[6] However, few studies have examined how consistent the diurnal blood pressure profile and the nocturnal blood pressure fall are when the ambulatory measurement of blood pressure is repeated.

This study describes the diurnal blood pressure curve and the nocturnal blood pressure fall in 399 subjects drawn from the population of a small town.[7] Furthermore, in a subsample of 34 subjects who were investi-

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gated twice, this study investigates the consistency of the diurnal blood pressure curve.

METHODS

Subjects This study is part of an ongoing population survey[7] and reports on the characteristics of the diurnal blood pressure curve in 399 subjects, who represented a random sample of the population of a small town. We measured the ambulatory blood pressure in 58% of the subjects in the sample. These participants, 191 men and 207 women, were on average 49 ± 15 years old (mean ± standard deviation). A trained nurse measured their sitting blood pressure at home. Five consecutive readings were obtained on each of two separate home visits. Based on the readings obtained at the first home visit, the casual blood pressure averaged 123 ± 17 mm Hg systolic and 74 ± 10 mm Hg diastolic with ranges from 89 to 210 mm Hg and from 52 to 121 mm Hg, respectively. Seventeen subjects were on antihypertensive drugs, 117 were smokers (median: 15 cigarettes/day), and 73 reported daily intake of alcohol (median: 24 g/day). Thirty-seven women took a contraceptive pill. Three subjects reported a history of myocardial infarction, three had experienced a transient ischemic attack, and one had a history of both conditions.

After the first year of the field work, 105 subjects had taken part in the population study.[7] These subjects were ranked according to the night/day ratio of their directly measured mean ambulatory blood pressure. The nine subjects with a night/day ratio less than 0.78 (strong dippers), the nine individuals with a ratio greater than 0.87 (nondippers), and 18 randomly selected participants with a ratio ranging from 0.78 to 0.87 (intermediate dippers) were invited to undergo a repeat measurement of their ambulatory blood pressure. However, one subject had left the region and a second person withdrew his consent for the repeat examination, leaving a total of 34 subjects for this part of the study. These subjects, 21 men and 13 women, were 54 ± 15 years old (range: 28 to 81 years).

Ambulatory Blood Pressure Monitoring At the occasion of one of the home visits a 24-h ambulatory blood pressure recording was started with the SpaceLabs 90202 monitor (SpaceLabs Inc., Redmond, WA). This device records the systolic, diastolic, and mean blood pressure with the use of an oscillometric technique.[8] The recorders were programmed to obtain measurements with an interval of 20 min from 8:00 until 21:59 and every 45 min from 22:00 to 7:59. A cuff with an inflatable bladder length of 24 cm and a width of 12 cm was applied, except in 10 obese men, in whom the use of a larger cuff was required.

Analysis of the Ambulatory Blood Pressure Recordings The ambulatory recordings were truncated so that their total duration did not exceed 24 h. The recordings were not edited, ie, measurements were only excluded from analysis when they were labelled as technically erroneous by the software of the monitors. Ambulatory blood pressure means and variances were weighted by the time interval between consecutive readings.

The runs test[9] with a one-sided probability level of 5% was used for detecting a diurnal rhythm, in contrast to pure random variation, in the blood pressure. Subjects showing a significant runs test[9] for their systolic or diastolic blood pressure or for both were classified as having a diurnal blood pressure rhythm. Fourier series with four harmonics were fitted to the blood pressure readings over 24 h by weighted least squares regression.[10] The daytime period was defined as the interval from 10:00 to 19:59 and nighttime as the interval from midnight to 5:59, because previous studies[7,11] had shown that in most subjects the blood pressure changes rapidly and considerably from 6:00 to 9:59 and from 20:00 to 23:59. The nocturnal blood pressure fall was defined as the difference between the average day- and nighttime blood pressure.

Statistical Analysis Data base management and statistical analyses were performed with the Statistical Analysis System.[12] Statistical methods included Student's *t* test and linear regression. Departure from normality was evaluated by the Shapiro-Wilk statistic.[13]

The agreement between paired ambulatory blood pressure recordings was evaluated by the Bland and Altman method.[14] The standard for a parameter was defined as the average of the paired recordings. Changes were assessed by subtracting the first from the repeat measurement keeping the sign of the difference. Consistency was estimated from these differences with omission of the sign. The repeatability coefficient was calculated as twice the standard deviation of the individual differences, assuming a mean difference for all subjects of zero.[14] To allow comparisons between various measurements, the repeatability coefficient was expressed as a percentage of the mean of a given measurement, and as a percentage of nearly maximal variation, ie, four times the standard deviation of the measurement under investigation.

RESULTS

The Blood Pressure Curve in 399 Subjects Most (91%) recordings were performed on weekdays (all without nighttime work) and the remainder (9%) during weekends. The runs test was compatible with a significant diurnal rhythm in 370 subjects (93%).

The night/day ratio averaged 0.87 ± 0.07 (range: 0.63 to 1.20) for systolic pressure and 0.81 ± 0.08 (range: 0.54 to 1.31) for diastolic pressure. The nocturings in the average whole day, daytime, and overnight blood pressures (Table 1) and in the hourly blood pressure means (Figure 2). The repeatability coefficient for the 24 h blood pressure was 14 mm Hg systolic and 11 mm Hg diastolic (Table 1). Expressed as a percentage of the mean, repeatability was 11% for the 24 h systolic pressure and 15% for the 24 h diastolic pressure; expressed as a percentage of maximal variation these percentages were 37 and 47%, respectively.

Repeatability for the daytime and nighttime blood pressure levels was comparable with that of the blood pressure over 24 h, but in general repeatability tended to be less for the parameters describing the nocturnal blood pressure fall and the diurnal blood pressure curve (Table 1).

Agreement Between Paired Recordings According to the Nocturnal Blood Pressure Fall in the Initial Recording In the nine strong dippers the nighttime blood pressure was significantly higher at the repeat than at the initial recording. This was associated with a decrease in the nocturnal blood pressure fall and in the amplitude of the blood pressure curve (Table 2). In the nine nondippers the nighttime diastolic blood pressure fell at the repeat examination (Table 2), but none of the nondippers had a night/day ratio of mean blood pressure < 0.78 at the repeat examination (Table 3).

At the initial examination all 34 subjects, with the exception of one nondipper, showed a significant diurnal blood pressure rhythm. At the repeat examination two subjects with an intermediate nocturnal blood pressure fall did no longer show a significant diurnal blood pressure rhythm. Only in these two subjects was there disagreement between the first and the repeat examination with respect to the presence of a significant diurnal blood pressure rhythm.

DISCUSSION

In the present population study 93% of the subjects showed a diurnal blood pressure rhythm, which significantly differed from random variation. The observation that the nocturnal blood pressure fall follows a unimodal distribution suggests that the distinction between subjects with and without a decrease in their nighttime blood pressure, so-called dippers and nondippers,[6] is arbitrary. The night/day blood pressure ratio in the present population averaged 0.87 for systolic and 0.81 for diastolic pressure. In 18 studies in normotensive subjects the night/day ratio averaged 0.87 for the systolic and 0.83 for the diastolic pressure with ranges across the studies from 0.79 to 0.92 and from 0.75 to 0.90, respectively.[2] However, in these studies various definitions of the day- and nighttime periods were employed, explaining at least part of the differences.

In the present population study the amplitude of the diurnal blood pressure curve followed a positively skewed distribution (Figure 1). Because there was also a

TABLE 1. CHANGE, CONSISTENCY AND REPEATABILITY OF THE DIURNAL BLOOD PRESSURE CURVE IN 34 SUBJECTS

		Standard*	Change†	Consistency‡	Repeatability§
Blood pressure level					
Casual (mm Hg)	SBP	123 ± 13	+3 ± 9	7 ± 6	18 (15, 36)
	DBP	73 ± 6	+2 ± 8	6 ± 5	15 (21, 65)
24 h (mm Hg)	SBP	121 ± 10	+1 ± 7	6 ± 6	14 (11, 37)
	DBP	72 ± 6	+1 ± 6	4 ± 3	11 (15, 47)
Daytime (mm Hg)	SBP	127 ± 10	0 ± 9	7 ± 5	17 (13, 41)
	DBP	77 ± 7	−1 ± 7	6 ± 4	14 (19, 55)
Nighttime (mm Hg)	SBP	111 ± 11	+3 ± 10	9 ± 5	21 (19, 49)
	DBP	64 ± 7	+1 ± 8	6 ± 5	16 (25, 53)
Blood pressure pattern					
Nocturnal fall (mm Hg)	SBP	16 ± 8	+3 ± 11	9 ± 6	22 (138, 66)
	DBP	13 ± 7	+2 ± 8	7 ± 4	16 (120, 59)
Amplitude (mm Hg)	SBP	16 ± 4	−1 ± 6	5 ± 4	12 (76, 83)
	DBP	14 ± 4	−1 ± 6	4 ± 4	12 (87, 83)
Acrophase (hh:mm)	SBP	16:40 ± 3:16	+0:55 ± 7:14	5:23 ± 4:50	14:23 (86, 109)
	DBP	14:42 ± 3:15	−2:02 ± 5:43	4:51 ± 3:43	11:59 (82, 92)

Values are means ± standard deviation. The casual blood pressure is the average of the first three readings obtained at the first home visit.

SBP, DBP = systolic, diastolic blood pressure.

* *Average of first and repeated measurement.*

† *First measurement subtracted from repeated measurement.*

‡ *Difference between first and repeated measurement with omission of the sign.*

§ *Twice the standard deviation of the difference between paired measurements, keeping the sign and assuming zero mean difference. The repeatability coefficient, expressed respectively as a percentage of the mean and maximal variation, is given between parentheses (see Results for further details).*

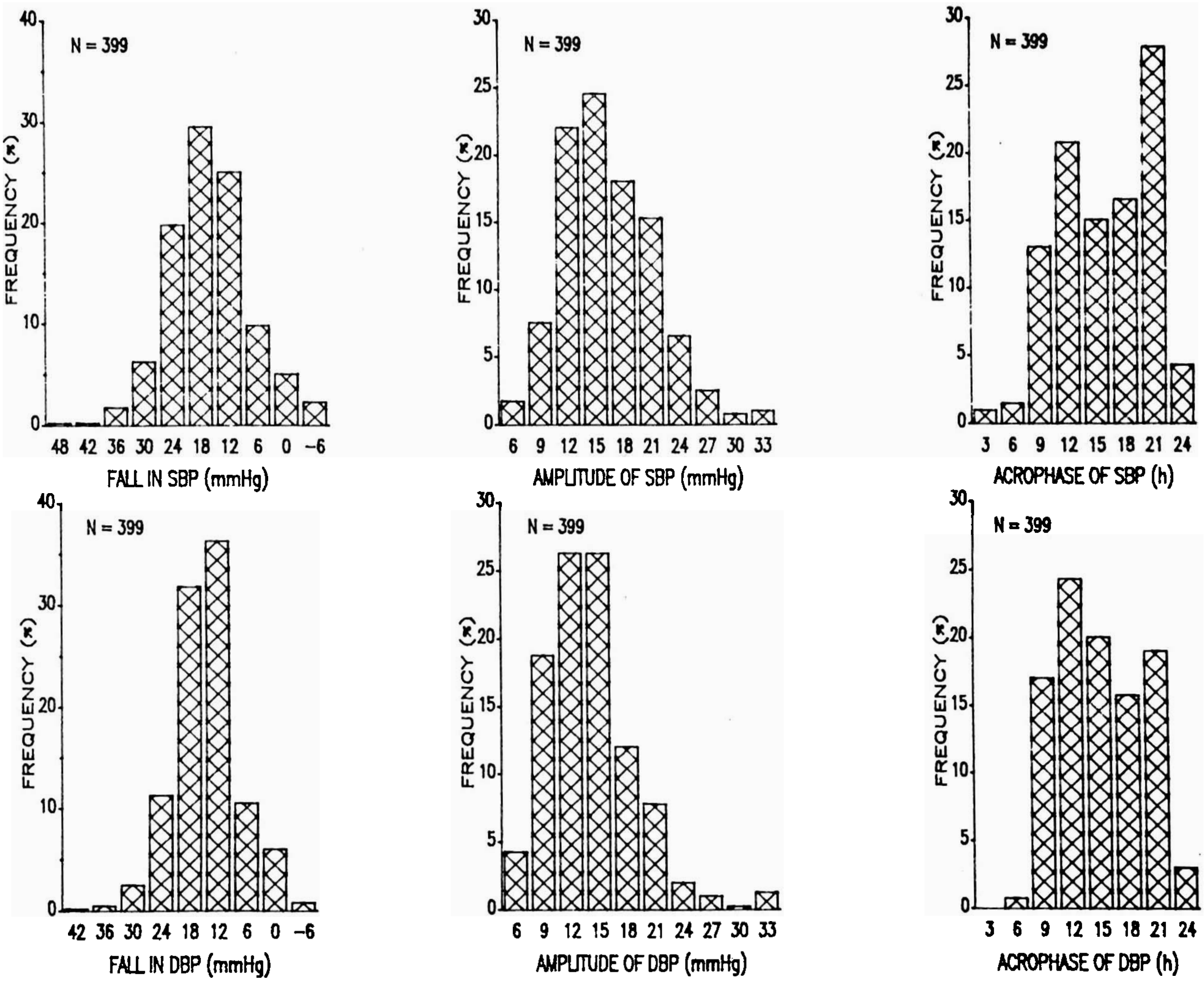

FIGURE 1. *Distribution of the nocturnal blood pressure fall and of the amplitude and acrophase of the diurnal blood pressure curve in 399 subjects drawn from the population.*

nal blood pressure fall was normally distributed (Figure 1), and averaged 16 ± 9 mm Hg systolic and 14 ± 7 mm Hg diastolic. The falls in systolic and diastolic pressure were not correlated with the height of the pressure (derived from the conventional blood pressure measurements at home to have an independent estimate). There was, however, an inverse correlation between the nocturnal fall in diastolic blood pressure and age ($r = -0.14$; $P = .006$), which was not removed by cumulative adjustments for gender and body mass index. The partial regression coefficient was compatible with a 0.7 mm Hg decline in the nocturnal fall in diastolic blood pressure per decade of life.

The distribution of the amplitude of the diurnal blood pressure curve fitted by Fourier analysis, was positively skewed and deviated significantly from normality (Figure 1). The amplitude averaged 16 ± 5 mm Hg systolic and 14 ± 4 mm Hg diastolic. The amplitude of the diurnal blood pressure curve was positively correlated with the height of the blood pressure (estimated from the conventional blood pressure measurements at home): the correlation coefficient was 0.23 ($P < .001$) for systolic and 0.13 ($P < .01$) for diastolic blood pressure. In single regression analysis the amplitude of the 24 h systolic blood pressure curve was positively correlated with age ($r = 0.15$; $P = .003$) and body mass index ($r = 0.12$; $P = .01$). However, these correlations with age and body mass index disappeared after adjusting for the height of the blood pressure.

The acrophase, ie, the time of the blood pressure maximum, occurred in most recordings between 9:00 and 21:00 h (Figure 1). The acrophase in the 399 subjects combined averaged 15:54 ± 4:47 systolic and 15:11 ± 4:20 diastolic.

Agreement Between the Paired Recordings in 34 Subjects The median interval between the first and repeat blood pressure recording in the 34 subjects was 350 days (range: 254 to 430 days).

There was close agreement between the paired record-

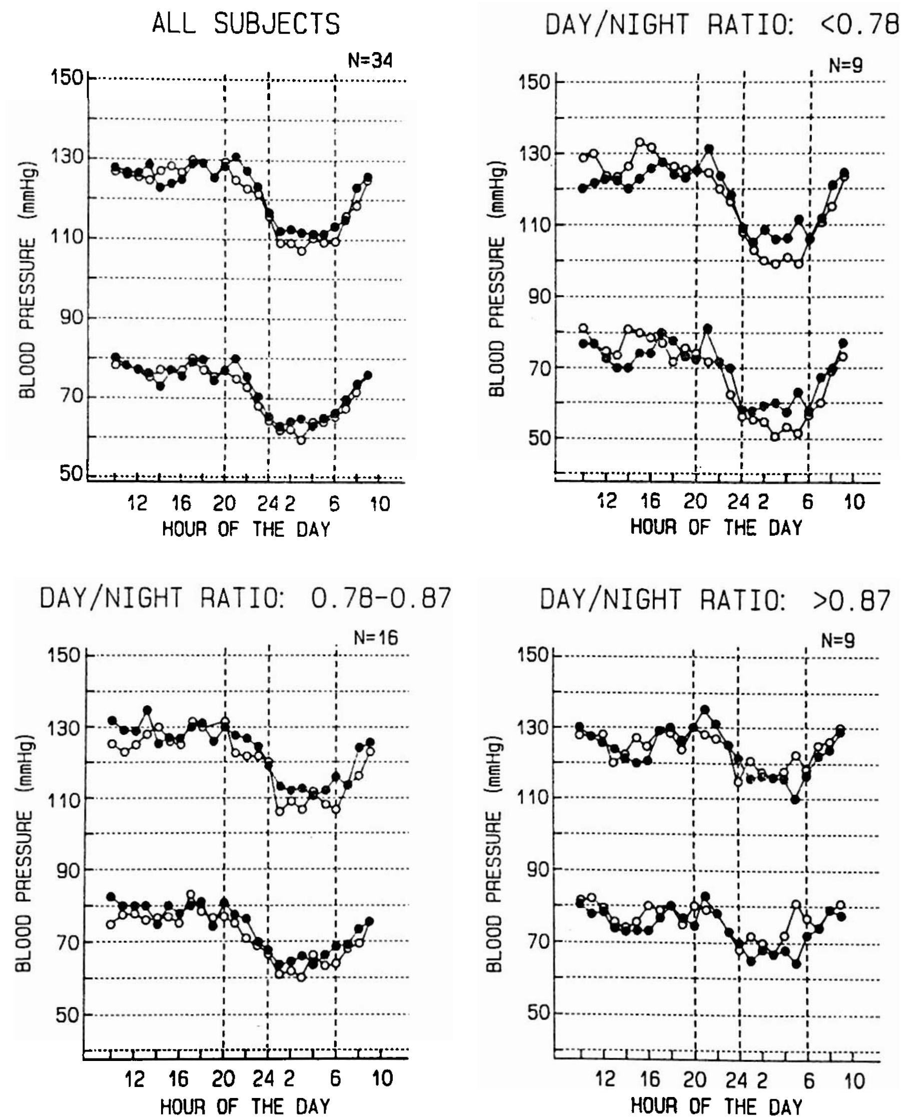

FIGURE 2. *The hourly means of the ambulatory blood pressure in paired recordings performed with a median interval of 350 days. Results are given for nine strong dippers, 16 intermediate dippers and nine nondippers, separately, and for the 34 subjects combined.*

positive relationship between the height of the blood pressure and the amplitude of the diurnal curve, hypertensive patients made up most of the tail area of the distribution. These findings are in agreement with previous reports, which showed a positive relationship between blood pressure variability and the height of the blood pressure[15–17] and a disturbed integration of cardiovascular reflexes in hypertensive patients.[17]

The statistical methods used in the present study for deriving the parameters of the diurnal blood pressure curve do not imply any preconceived idea on the origin of the blood pressure curve and are applicable whatever mechanism drives the blood pressure during the day. It is, for instance, possible that the autonomic nervous system[18,19] and several hormonal mechanisms[20] contribute to the maintenance of the diurnal blood pressure curve, because a diurnal blood pressure rhythm is preserved during bed rest[21] and in patients with a fixed-rate artificial cardiac pacemaker.[21,22] On the other hand, many experts would agree that in ordinary circumstances the diurnal blood pressure rhythm is largely dependent on physical and mental activity.[17,23] The latter hypothesis is corroborated by the observation that in shift laborers the phase of the diurnal blood pressure curve moves within 24 to 48 h following a change in working and sleeping hours.[24–26]

Repeatability in the present study not only reflects the variability inherent to the measurement technique,[14] but also biologic variability. The latter may have been inflated due to the long interval between the recordings, exceeding 1 year in half of the subjects, and due to seasonal and random variation in the pattern of the daily activities. In a review of seven studies,[5] which included a total of 216 subjects, the interval between consecutive measurements ranged from 11 to 350 days. The systolic pressure measured by an observer decreased from the first to the repeat examination by 6 mm Hg ($P < .05$) and the diastolic pressure by 2 mm

TABLE 2. STANDARD, CHANGE, AND CONSISTENCY OF THE BLOOD PRESSURE MEASUREMENTS IN STRONG AND INTERMEDIATE DIPPERS AND IN NONDIPPERS

		Standard*			Change†			Consistency‡		
		SD	IN	ND	SD	IN	ND	SD	IN	ND
Blood pressure level										
24 h (mm Hg)	SBP	118	122	124	+1	+2	−1	6	5	6
	DBP	67	73	75	+1	+2	−2	4	4	5
Daytime (mm Hg)	SBP	125	128	126	−3	+1	0	8	7	7
	DBP	75	78	77	−2	+1	−2	6	6	6
Nighttime (mm Hg)	SBP	105	111	117	+7§	+4	−4	9	8	11
	DBP	56	64	70	+6§	+3	−6§	7	6	6
Blood pressure pattern										
Nocturnal fall (mm Hg)	SBP	20	17	9	−11*	−3	+4	11	8	9
	DBP	19	4	7	−8*	−1	+3	8	6	6
Amplitude (mm Hg)	SBP	18	16	14	−4§	−1	+3	7	4	4
	DBP	16	13	12	−5§	−1	+2	5	4	4
Acrophase (hh:mm)	SBP	17:00	16:35	13:29	+2:59	−1:52	+3:48	5:00	4:23	7:31
	DBP	14:58	14:46	14:19	−1:30	−1:57	−2:42	5:23	4:19	5:14

Values are means.

SD, strong dippers (N = 9); ID, intermediate dippers (N = 16); ND, nondippers (N = 9); SBP, DBP, systolic, diastolic blood pressure.

* *Average of first and repeated measurement.*

† *First measurement subtracted from repeated measurement.*

‡ *Difference between first and repeated measurement with omission of the sign.*

§ $P < .05$.

* $P < .01$.

Hg ($P < .05$), whereas the differences between consecutive measurements of the daytime ambulatory pressure were not statistically significant, as they averaged only 0.5 and 0.1 mm Hg, respectively. The fall in the clinic pressure on repeat measurement is usually explained by habituation of the patient to both clinic environment and the observer and by regression to the mean, when the subjects were selected as having either a high or low pressure. The present data suggest that regression to the mean is also observed for the nighttime blood pressure, when ambulatory blood pressure recordings are repeated in subjects selected for being a strong dipper or nondipper. The alternative explanations that nondippers become accustomed to the recorder and sleep deeper at the repeat examination, and that some dippers may sleep less well must also be considered.

In conclusion, group means for the ambulatory blood pressure parameters can be accurately reproduced. In individual subjects the agreement between paired recordings is satisfactory for the level of blood pressure. This makes ambulatory blood pressure monitoring an attractive tool in clinical and epidemiologic research. By contrast, the parameters related to the diurnal blood pressure rhythm are less reproducible in individual subjects with the exception of the runs test for the presence of a significant diurnal rhythm. Thus, studies based on only one 24 h blood pressure recording are not satisfactory to fully characterize an individual with respect to the diurnal blood pressure profile. Increasing the number of recordings per subject or standardizing activity patterns during the recordings may increase the potential of 24 h ambulatory monitoring to characterize individual subjects with respect to their diurnal blood pressure profile.

TABLE 3. NUMBER OF PATIENTS IN EACH NIGHT/DAY RATIO RANGE OF MEAN BLOOD PRESSURE AT THE FIRST AND REPEAT EXAMINATION

	Initial Examination		
Repeated Examination	<0.78	0.78 to 0.87	>0.87
<0.78	3	3	0
0.78 to 0.87	3	7	4
>0.87	3	6	5
Total	9	16	9

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