[J Tokyo Wom Med Univ
77 (Extra) E46～E53 (2007)]

24-hour Blood Pressure Monitoring in Children and Adolescents with Relevant to Age, Gender and Growth Parameters

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(Accepted Mar. 12, 2007)

Ambulatory blood pressure monitoring (ABPM) was performed in 68 children with normal blood pressure. There were 14 boys (junior boys) and 24 girls (junior girls) in primary school and 17 boys (senior boys) and 13 girls (senior girls) in junior high school or senior high school. A significant daily fluctuation in ABPM values in systolic and diastolic blood pressure was observed in all four groups. Only some of the average blood pressure values in three periods (24 hr, daytime from 09 : 00 to 20 : 00, and nighttime from 00 : 00 to 06 : 00) were positively correlated with anthropometrical values. The average blood pressure values at nighttime were significantly higher in the senior boys than in the junior boys. When the blood pressure values were rearranged in ascending order and the lowest 12 and highest 12 of all 48 values measured every 30 min for 24 hr were used, in contrast to the time series data, significant differences in the bottom and top quartile groups of blood pressure values were found between the junior and senior age groups and between boys and girls. In conclusion, the method that used rearranged blood pressure values appeared to be useful for evaluating ambulatory blood pressure in children and adolescents.

Key words: blood pressure, children, adolescents, ambulatory blood pressure monitoring

Introduction

A small, lightweight, mobile automatic sphygmomanometer has recently become available for a clinical use. Although ambulatory blood pressure monitoring (ABPM) with this mobile sphygmomanometer has been used to diagnose hypertension in children[1)~3)], no method of evaluating ambulatory blood pressure (ABP) data from children and adolescents has yet been established. In this study we analyzed the characteristics of the ABP values of healthy children and obtained some interesting results regarding the evaluation of ABP.

Subjects and Methods

Sixty-eight children (31 boys, 37 girls) whose blood pressure (BP) was assessed to be within the normal range based on the diagnostic criteria for hypertension at any age and either gender were enrolled in this study. Informed consent was obtained from the subjects and/or their guardians. The subjects were divided into four groups according to age and gender. There were 14 boys (junior boys) and 24 girls (junior girls) in primary school and 17 boys (senior boys) and 13 girls (senior girls) in junior high school or senior high school.

The diagnostic criteria used for hypertension[4)] were: primary school children: 135/80 mmHg; junior high school boys: 140/80 mmHg; junior high school girls: 135/80 mmHg; senior high school boys: 145/85 mmHg; and senior high school girls: 140/85 mmHg. ABP was measured with a model ABPM 630 (Nihon Colin, Japan).

The cuff size was set at approximately 40% of the upper arm circumference of each subject. After 4 to 6 trial BP measurements to acclimate the subjects to the system, ABP measurements were made every 30 min for 24 hr, i.e., a total 48 times. The average BP values in three periods (24 hr, daytime from 09 : 00 to 20 : 00, and nighttime from 00 : 00 to

06 : 00) were calculated.

The measurements of ABP were analyzed by the following approach.

1) Correlations between average BP values in 3 periods (24 hr, daytime from 09:00 to 20:00, and nighttime from 00 : 00 to 06 : 00) and the anthropometrical data, including height, weight, percent overweight, body surface area, and age were calculated.

2) Daily fluctuations in ABP values were measured. The rate of decrease in systolic BP at night was calculated as follows: average daytime systolic BP−average nighttime systolic BP/average daytime systolic BP × 100 (%). The rate of decrease in diastolic BP at night was calculated in the same way: average daytime diastolic BP−average nighttime diastolic BP/average daytime diastolic BP × 100 (%).

3) Correlations between average BP values in each period and age groups of different gender were calculated. The rate of increase in BP with age was calculated as follows: average BP in the senior group−average BP in the junior group/average BP in junior group × 100 (%).

4) Average BP values obtained each time measured (48 times) were rearranged in ascending order and divided at the quartile points.

Each group consists of averages of BP data obtained at each of 12 times. We focused on the highest 12 values (the top quartile group, above the 75 percentile) and the lowest 12 values (the bottom quartile group, below the 25 percentile) of the 48 values obtained by measuring BP every 30 min for 24 hr. The rate of increase in BP with age was calculated as follows: average BP in each quartile group in the senior group − average BP in each quartile group in the junior group/average BP in each quartile group in junior group × 100 (%). Correlations between BP values after rearrangement and age groups of different gender were calculated.

A single regression analysis was performed for the correlation between average BP values of each period and the anthropometrical data. Mann−Whitney's U test was used for the other statistical analyses.

Results

1. Correlation between average BP in the three periods and the anthropometrical data

Only some of the average BP values in three periods were positively correlated with anthropometrical values (Table 1).

2. Daily fluctuations in ABP values

Daily fluctuations in ABP values were examined in four groups: 14 junior boys, 24 junior girls, 17 senior boys, and 13 senior girls (Table 2). The rate of decrease in systolic BP of the junior boys, junior girls, senior boys, and senior girls was 8.4, 9.2, 6.2 and 6.6%, respectively. The rate of decrease in diastolic BP in the junior boys, junior girls, senior boys, and senior girls was 12.1, 10.4, 7.9 and 9.2%, respectively. The rate of decrease in heart rate of the junior boys, junior girls, senior boys, and senior girls was 26.9, 25.0, 20.9 and 19.5%, respectively. A significant daily fluctuation in ABP values and heart rate was observed in all four groups ($p<0.001$). The rate of decrease was higher in the junior groups than in the senior groups in both boys and girls.

3. Correlations between the average BP values in each period and age groups of different gender

Table 3 shows the age difference in systolic and diastolic BP values in each period. The rate of increase in nighttime systolic and diastolic BP with age in the boys was 7.1 and 9.9%, respectively. The rate of increase in nighttime systolic and diastolic BP with age in the girls was 2.2 and 4.8%, respectively. Both the average systolic and diastolic BP values at nighttime were significantly higher in the senior boys than in the junior boys ($p<0.05$). The increase of the average BP values with age was not significant in the girls. These results show higher rate of increase in BP at night with age in the boys than in the girls.

Table 4 shows the gender difference in systolic and diastolic BP values in each period. Comparisons between average systolic and diastolic BP in each period showed no significant gender difference between junior boys and junior girls or between senior boys and senior girls in any period.

Table 1 Correlations between average blood pressure in each period and the anthropometrical data

	gender	n	period	systolic blood pressure			diastolic blood pressure		
				correlation coefficient	p value		correlation coefficient	p value	
body length	boys	31	24 hr	0.078	0.126	NS	0.009	0.617	NS
			DT	0.043	0.272		0.021	0.442	
			NT	0.114	0.063		0.007	0.666	
	girls	37	24 hr	0.150	0.017	*	0.082	0.086	
			DT	0.063	0.136	NS	0.018	0.428	
			NT	0.085	0.081		0.005	0.677	
body weight	boys	31	24 hr	0.066	0.249	NS	0.014	0.596	NS
			DT	0.055	0.307		0.000	0.925	
			NT	0.145	0.083		0.003	0.804	
	girls	37	24 hr	0.335	0.001	**	0.271	0.004	**
			DT	0.232	0.008	**	0.120	0.066	NS
			NT	0.212	0.011	*	0.079	0.139	
percent overweight	boys	31	24 hr	0.035	0.426	NS	0.140	0.105	NS
			DT	0.088	0.217		0.086	0.224	
			NT	0.001	0.976		0.085	0.213	
	girls	37	24 hr	0.007	0.669		0.059	0.203	
			DT	0.000	0.925		0.015	0.528	
			NT	0.004	0.736		0.046	0.266	
body surface area	boys	31	24 hr	0.036	0.395	NS	0.068	0.233	NS
			DT	0.028	0.465		0.082	0.696	
			NT	0.107	0.137		0.037	0.391	
	girls	37	24 hr	0.304	0.002	**	0.200	0.015	*
			DT	0.234	0.008	**	0.103	0.089	NS
			NT	0.191	0.018	*	0.039	0.306	
age	boys	31	24 hr	0.070	0.233	NS	0.034	0.409	NS
			DT	0.001	0.881		0.000	0.998	
			NT	0.020	0.037	*	0.117	0.119	
	girls	37	24 hr	0.014	0.482	NS	0.013	0.496	
			DT	0.008	0.593		0.004	0.720	
			NT	0.012	0.527		0.001	0.866	

DT: daytime (09:00-20:00), NT: nighttime (00:00-06:00), NS: not significant, *: $p < 0.05$, **: $p < 0.01$ (single regression analysis).

Table 2 Daily fluctuations in ABPM values

group	gender (n)	DT mean ± SD (mmHg)	NT mean ± SD (mmHg)	difference (mmHg)	rate of decrease (%)	
1. Systolic blood presssure						
junior	boys (14)	109.6 ± 6.6	100.3 ± 6.4	9.2	8.4	***
	girls (24)	110.2 ± 8.7	99.7 ± 7.6	10.5	9.2	***
senior	boys (17)	114.7 ± 9.8	107.4 ± 8.4	7.3	6.2	***
	girls (13)	112.2 ± 7.1	104.8 ± 8.2	7.4	6.6	***
2. Diastolic blood pressure						
junior	boys (14)	65.0 ± 6.1	56.8 ± 4.6	8.1	12.1	***
	girls (24)	65.1 ± 7.1	58.0 ± 5.7	7.1	10.4	***
senior	boys (17)	67.9 ± 8.6	62.4 ± 8.3	5.5	7.9	***
	girls (13)	65.3 ± 6.2	59.3 ± 7.5	5.9	9.2	***
3. Heart rate						
junior	boys (14)	88.3 ± 5.0	64.5 ± 3.4	23.8	26.9	***
	girls (24)	88.4 ± 3.1	66.3 ± 4.2	22.1	25.0	***
senior	boys (17)	80.6 ± 4.5	63.7 ± 2.4	16.8	20.9	***
	girls (13)	87.3 ± 4.4	70.3 ± 5.0	17.0	19.5	***

DT: daytime (09:00-20:00), NT: nighttime (00:00-06:00), difference: average daytime blood pressure (BP) − average nighttime BP, rate of decrease: (difference/average daytime BP) × 100, ***: $p < 0.001$ (Mann − Whitney's U-test).

Table 3 Correlations between the blood pressure values and age group

	period	junior group (n=14) mean ± SD (mmHg)	seinior group (n=17) mean ± SD (mmHg)	difference (mmHg)	rate of increase (%)	
1. Systolic blood pressure						
boys	24 hr	106.2 ± 5.9	112.2 ± 8.6	6.0	5.7	NS
	DT	109.6 ± 6.6	114.7 ± 9.8	5.1	4.7	NS
	NT	100.3 ± 6.4	107.4 ± 8.4	7.0	7.1	*
girls	24 hr	105.6 ± 7.1	109.9 ± 7.3	4.4	4.1	NS
	DT	110.2 ± 8.7	112.2 ± 7.1	2.1	4.5	NS
	NT	99.7 ± 7.6	104.8 ± 8.2	5.2	4.8	NS
2. Diastolic blood pressure						
boys	24 hr	61.6 ± 5.0	65.6 ± 8.3	4.1	6.5	NS
	DT	65.0 ± 6.1	67.9 ± 8.6	3.0	1.4	NS
	NT	56.8 ± 4.6	62.4 ± 8.3	5.6	9.9	*
	24 hr	62.2 ± 6.2	63.7 ± 6.8	1.5	2.4	NS
girls	DT	65.1 ± 7.1	65.3 ± 6.2	0.2	0.3	NS
	NT	58.0 ± 5.7	59.3 ± 7.5	1.3	2.2	NS

DT: daytime (09:00-20:00), NT: nighttime (00:00-06:00), difference: average blood pressure (BP) in seinor group − average BP in junior group, rate of increase: (difference/average BP in junior group) × 100, NS: notsignificant, * : $p < 0.05$ (Mann − Whitney's U-test).

Table 4 The gender difference of average blood pressure values

group	period	boys (n=17) mean ± SD (mmHg)	girls (n=13) mean ± SD (mmHg)	difference (mmHg)	
1. Systolic blood pressure					
junior	24 hr	106.2 ± 5.9	105.6 ± 7.1	0.6	NS
	DT	109.6 ± 6.6	110.2 ± 8.7	− 0.6	NS
	NT	100.3 ± 6.4	99.7 ± 7.6	0.7	NS
senior	24 hr	112.2 ± 8.6	109.9 ± 7.3	2.2	NS
	DT	114.7 ± 9.8	112.2 ± 7.1	2.4	NS
	NT	107.4 ± 8.4	104.8 ± 8.2	2.5	NS
2. Diastolic blood pressure					
junior	24 hr	61.6 ± 5.0	62.2 ± 6.2	− 0.6	NS
	DT	65.0 ± 6.1	65.1 ± 7.1	− 0.1	NS
	NT	56.8 ± 4.6	58.0 ± 5.7	− 1.2	NS
senior	24 hr	65.6 ± 8.3	63.7 ± 6.8	2.0	NS
	DT	67.9 ± 8.6	65.3 ± 6.2	2.7	NS
	NT	62.4 ± 8.3	59.3 ± 7.5	3.1	NS

DT: daytime (09:00-20:00), NT: nighttime (00:00-06:00), difference: average BP in boys − average BP in girls, NS: not significant (Mann − Whitney's U-test).

4. Correlations between BP values after rearrangement and age groups of different gender

Figures 1 and 2 clearly show that after rearrangement both systolic and diastolic BP values were higher in the senior group than in the junior group in both boys and girls. Table 5 shows the result of the analysis of age differences in BP values after rearrangement. The rates of increase in BP with age in the boys were: systolic BP in the top quartile group: 4.1%; systolic BP in the bottom quartile: 6.2%, diastolic BP in the top quartile: 3.8%; diastolic BP in the bottom quartile: 7.6%. The rates of increase in BP with age in the girls were systolic BP: 3.7 and 4.1%, respectively and diastolic BP: 2.9 and −0.8%, respectively. There was a significant age difference in systolic BP in all quartile groups ($p<0.001$). There was a significant age difference in diastolic BP only in the boys, both in top ($p<0.05$)

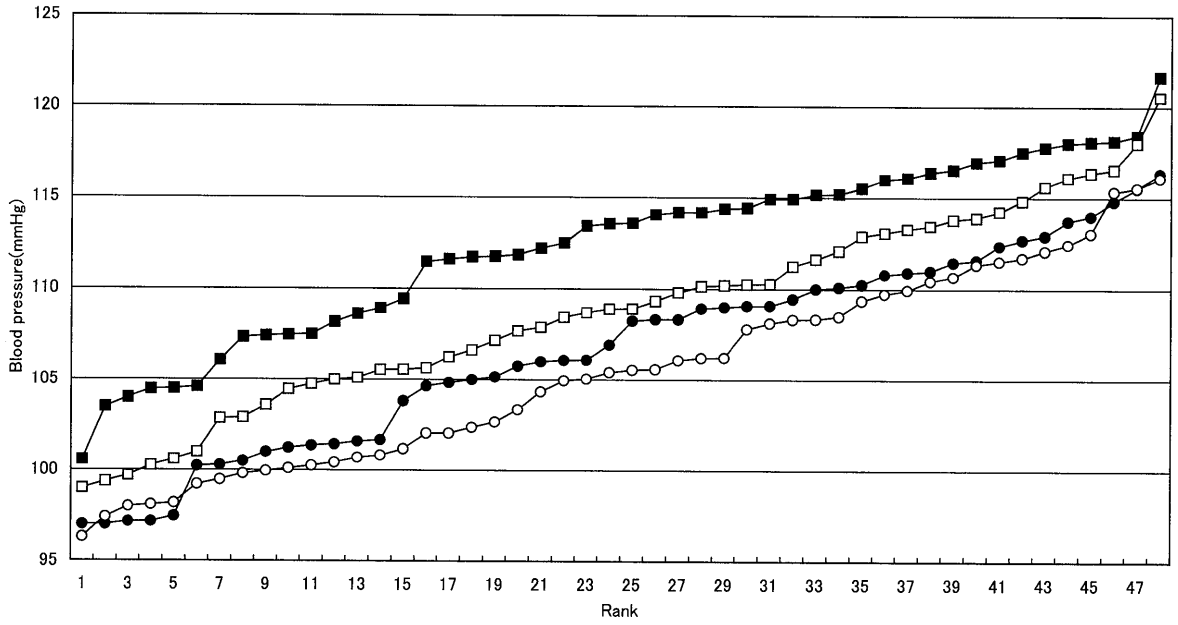

Fig. 1 Systolic BP after rearrangement of the values

Averages of the systolic blood pressure obtained at each time (48 times) were rearranged in ascending order. X-axis shows rank of systolic blood pressure after rearrangement in ascending order. Subjects were divided into 4 groups. Fourteen boys are in primary school (junior boys), 17 boys are in junior high school or senior high school (senior boys), 24 girls are in primary school (junior girls), and 13 girls are in junior high school or senior high school (senior girls).

●: junior boys, ■: senior boys, ○: junior girls, □: senior girls.

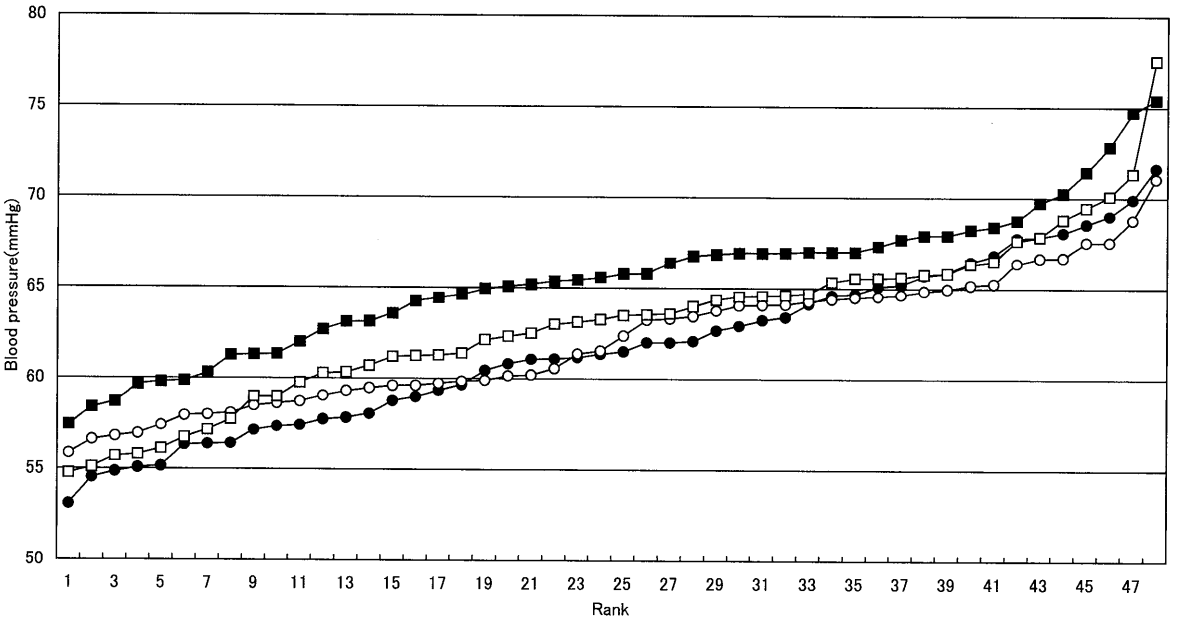

Fig. 2 Diastolic BP after rearrangement of the values

Averages of the diastolic blood pressure obtained at each time (48 times) were rearranged in ascending order. X-axis shows rank of diastolic blood pressure after rearrangement in ascending order. Subjects were divided into 4 groups. Fourteen boys are in primary school (junior boys), 17 boys are in junior high school or senior high school (senior boys), 24 girls are in primary school (junior girls), and 13 girls are in junior high school or senior high school (senior girls).

●: junior boys, ■: senior boys, ○: junior girls, □: senior girls.

Table 5 Correlations between the blood pressure values after rearrangement and age group

	quartile group	junior group (n=14) mean ± SD (mmHg)	senior group (n=17) mean ± SD (mmHg)	difference (mmHg)	rate of increase (%)	
1. Systolic blood pressure						
boys	top	113.1 ± 1.8	117.7 ± 1.5	4.6	4.1	* * *
	bottom	99.3 ± 1.9	105.5 ± 2.3	6.1	6.2	* * *
girls	top	111.9 ± 2.2	116.1 ± 1.8	4.2	3.7	* * *
	bottom	98.4 ± 1.2	102.4 ± 1.4	4.0	4.1	* * *
2. Diastolic blood pressure						
boys	top	67.7 ± 1.9	70.3 ± 2.7	2.5	3.8	*
	bottom	56.0 ± 1.4	60.2 ± 1.6	4.3	7.6	* * *
girls	top	66.6 ± 1.9	68.6 ± 3.4	1.9	2.9	NS
	bottom	57.7 ± 1.0	57.3 ± 1.9	− 0.5	− 0.8	NS

difference: average blood pressure (BP) in seinor group-average BP in junior group , rate of increase: (difference/average BP in junior group) × 100, NS: not significant, *: $p < 0.05$, * * *: $p < 0.001$ (Mann − Whitney's U-test).

Table 6 The gender difference of the blood pressure after rearrangement

group	quartile group	boys (n = 14) mean ± SD (mmHg)	girls (n = 24) mean ± SD (mmHg)	difference (mmHg)	
1. Systolic blood pressure					
junior	top	113.1 ± 1.8	111.9 ± 2.2	1.2	NS
	bottom	99.3 ± 1.9	98.4 ± 1.2	1.0	NS
senior	top	117.7 ± 1.5	116.1 ± 1.8	1.7	*
	bottom	105.5 ± 2.3	102.4 ± 1.4	3.1	*
2. Diastolic blood pressure					
junior	top	67.7 ± 1.9	66.6 ± 1.9	1.1	NS
	bottom	56.0 ± 1.4	57.7 ± 1.0	− 1.8	* *
senior	top	70.3 ± 2.7	68.6 ± 3.4	1.7	NS
	bottom	60.2 ± 1.6	57.3 ± 1.9	3.0	* *

difference: average blood pressure (BP) in boys − average BP in girls, NS: notsignificant, * : $p < 0.05$, * *: $p < 0.01$ (Mann − Whitney's U-test).

and bottom quartile groups ($p < 0.001$).

Figure 1 also shows that after rearrangement the systolic BP values were higher in the boys than in the girls in both junior and senior group. Table 6 shows the result of the analysis of gender differences in BP values after rearrangement. We compared the rearranged BP averages of junior boys and girls and of senior boys and girls. The differences in BP between the boys and girls were as follows: in the junior group, systolic pressure in the top quartile group: 1.2 mmHg, bottom quartile group: 1.0 mmHg; in the senior group, 1.7 and 3.1 mmHg, respectively; in the junior group, diastolic BP in the top quartile group: 1.1 mmHg, and bottom quartile group: −1.8 mmHg, respectively, in the senior group, 1.7 and 3.0 mmHg, respectively. There was a significant gender difference in systolic pressure in both the top and bottom quartile group in senior group ($p < 0.05$). A significant gender difference in diastolic pressure in both the junior and senior group was observed in the bottom quartile group ($p < 0.01$).

Discussion

BP is well known to be affected by a variety of factors, including age, gender, obesity, physical and mental condition, time of day, posture, drugs, and food intake. In this study we first investigated ABP values according to time of day for correlations with anthropometrical data, i.e., height, weight, percent overweight, body surface area, and age, but significant correlations were found with only a few of these factors.

It is also well known that BP increases with growth and maturation in children and adolescents, and a clear gender difference develops during adolescence. Since The Second Task Force on Blood pressure Control in Children stated that age and gender are important factors for evaluation of BP in children and adolescents[5], we divided the subjects into four groups by age and gender. A possible limitation of this study is the relatively small number of subjects with regard to statistical requirements.

Difference in daily life activities is one of the factors that influence the daily fluctuations in BP. Physical activity is usually greater during the daytime than nighttime. Posture, i.e., standing or sitting during the daytime and lying down in the night, is also a critical factor that influences ABP values. In this study we demonstrated that the rate of decrease in systolic and diastolic BP and heart rate at night was greater in the junior groups (both boys and girls) than in the senior groups. This result suggests that the junior subjects may be more greatly influenced by factors that affect BP and heart rate in the daytime, such as mental and physical activity.

Soergel et al[6] and Reichert et al[7] reported that the increase in ABP with age is more marked in boys than in girls. Similar results were obtained in our study, which showed that the rate of increase in ABP was more marked in boys than in girls in every period, and the rates of increase in both systolic and diastolic BP in the boys at night were significantly larger. The physiological increase in BP with age may be concealed during the daytime because BP may be easily affected by physical movement in the daytime by both junior and senior subjects, while it may not change much during asleep at night.

Measured values in evaluations of ABP in adults are usually investigated as time series data[8][9]. Although daily fluctuations were recognized in the time series ABP data in our study, an age difference, which is an important element for evaluation of BP in children and adolescents, was observed only in the nighttime BP values of the boys, and there was no clear gender difference in the ABP values according to our time series data. Our results suggest that the factors that raise BP, such as physical and mental activity, may be more varied in children, even children of the same age and gender and at the same time, than in adults. We therefore concluded that analyzing BP using time series data as is usually done with adult data may have limitations in regard to the analysis and evaluation of the BP data of children and adolescents.

Tochikubo et al[10] pointed out the importance of "base BP" for analysis of a BP distribution. Base BP is the lower limit of BP in an individual, and no other BP values ever falls below the base BP in that individual. Casual BP is the sum of the base BP and the increase produced by elevating factors, such as physical and mental activity. Accordingly, we next examined the bottom quartile group of BP values, which reflects base BP, and the top quartile group, which reflects maximal BP. Significant age and gender differences were revealed when the bottom and top quartile group of data, which are important factors in evaluating BP in children and adolescents, were used while they were not clearly identified by the analysis according to the time series data.

In addition to the conventional method of estimating ABP by time series data, the result of this study suggested that the method using rearranged BP values is useful for the evaluation of ABP in children and adolescents. Our results may be useful as normal reference values for assessing ABP and for diagnosing hypertension in children and adolescents.

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小児の24時間自由行動下血圧に関する研究
—年齢・性・成長との関連—

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正常血圧小児68例（男子31例，女子37例）を対象に，24時間自由行動下血圧測定を行った．対象を小学生男子群（14例），小学生女子群（24例），中・高校生男子群（17例），中・高校生女子群（13例）の4群に分類し検討を行った．24時間，夜間（0～6時），日中（9～20時）の各時間帯の血圧平均値と身体計測値（身長・体重・肥満度・体表面積）および年齢との相関を検討したところ，一部に相関が認められた．血圧日内変動の検討では，全ての群において夜間に有意な血圧低下と心拍数低下が認められた（$p<0.001$）．各時間帯の血圧平均値と年齢群との相関について男女別に比較したところ，男子は，夜間において収縮期・拡張期血圧平均値ともに中・高校生群が小学生群よりも有意に血圧が高かった（$p<0.05$）．各時間帯別の血圧平均値を年齢群別に男子と女子で比較したところ，いずれの時間帯でも有意な男女差は認められなかった．別の手法として，自由行動下血圧値を低い値から高い値の順に再配列し，再配列したデータを四分位階級に分割し，第1四分位（25パーセンタイル値）以下の血圧値を低値群，第3四分位（75パーセンタイル値）以上の血圧値を高値群として検討したところ，収縮期血圧値では，男子，女子ともに年齢差が認められ，低値群，高値群ともに中・高校生群が小学生群よりも有意に血圧が高かった（$p<0.001$）．拡張期血圧値では，男子に年齢差が認められ，中・高校生群が小学生群よりも有意に血圧が高かった（$p<0.05$：低値群，$p<0.001$：高値群）．再配列後の血圧値の男女差についての検討では，収縮期血圧では，中・高校生群において高値群，低値群の双方に男女差が認められ，男子が有意に高かった（$p<0.05$）．拡張期血圧では，低値群に有意な男女差が認められ，小学生群は女子が高く，中・高校生群は男子が高かった（$p<0.01$）．この方法は24時間自由行動下血圧の新しい分析，評価方法として有用と思われた．