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Fifteen Years of Experience in Ambulatory Blood Pressure Monitoring in Children at a Single Center

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ABSTRACT

Objective: This study was conducted at a tertiary medical center in a region where similar studies had not been previously conducted. It aimed to analyze 15 years of data obtained from the ambulatory blood pressure monitoring (ABPM) program and to address the challenges associated with diagnosing hypertension (HT).

Materials and Methods: This study included 1,859 children aged 5-18 years who were admitted between 2005 and 2020 and diagnosed with HT according to clinical measurements. All necessary demographic and clinical data were collected retrospectively. Measurements were performed using the Mobil-O-Graph device.

Results: A total of 1,859 cases, comprising 1,098 (59.1%) boys and 761 (40.9%) girls, were included in the study. Of these cases, 327 (17.6%) were obese, and 1,532 (82.4%) were of normal weight. According to ABPM data, 30.7% of all cases were normotensive. Additionally, the rate of HT in obese subjects (79.2%) was significantly higher than in non-obese subjects (67.2%). Logistic regression analysis of the study showed that older age, obesity, and being in the diastolic non-dipper group were associated with a higher risk of invalid measurement.

Conclusion: This study emphasizes the high prevalence of white coat HT in children in our region, despite the difficulties related to measurement adequacy, and thus highlights the importance of using ABPM in the diagnosis and follow-up of hypertension.

Keywords: Ambulatory blood pressure monitoring, childhood, hypertension, measuring adequacy, white coat.

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INTRODUCTION

Hypertension (HT) remains a significant cause of illness and death in all age groups globally.[1] Although HT is common in children, it often develops due to an underlying cause, and there is still a lack of consensus regarding its diagnosis and monitoring.[2]

The fluctuations in blood pressure (BP) can be influenced by various factors, such as circadian rhythm, physical activity, stress, and medications.[3,4] Ambulatory blood pressure monitoring (ABPM) is the preferred method for evaluating short-term and mid-term BP fluctuations, while office BP readings are utilized for assessing long-term BP.[5,6] Published guidelines on this sub-

ject recommend the widespread use of ABPM to identify conditions such as white coat hypertension (WCHT), resistant HT, masked HT, and other clinically significant conditions.[7,8] The increasing availability of ABPM has enabled the collection of a greater amount of clinical data, particularly in children and adolescents. Using ABPM to assess HT in this population may yield more accurate results than traditional measurement methods.

This study aims to retrospectively evaluate the indications, applications, and results of ABPM in children at a tertiary medical center over a 15-year period. It also seeks to investigate ABPM usage in a region that has not previously been studied, providing new insights and information on the use of ABPM in the pediatric population.

MATERIALS AND METHODS

Study Population

All patients between the ages of 5 and 18 who were hospitalized and received outpatient treatment at a pediatric nephrology clinic in Türkiye from 2005 to 2020, underwent ABPM, and were diagnosed with HT based on office measurements, were included in the study. Generally, patients' initial ABPM measurements were used, while repeat measurements, patients on medication, and those with masked hypertension were excluded from the study. Additionally, patients with other anomalies and/or comorbidities were not excluded. The study's design complied with the Helsinki Declaration and was approved by the University Ethics Committee under number 2021-1174.

Data Collection and Ambulatory Blood Pressure Monitoring

The demographic data, including age, gender, height, weight, Body Mass Index (BMI), and clinical presentation for all participants in the study, were collected retrospectively. Percentiles and Standard Deviation Scores (SDS) were documented for these measurements. Patients' BMIs were assessed based on their SDS, with individuals having an SDS value exceeding +2 classified as obese.

In this study, ABPM was performed using the Mobil-O-Graph device (IEM, Stolberg, Germany).[9] Participants were instructed to take their medication regularly and continue their usual activities. The device was programmed to measure BP every 20 minutes (from 07:00 in the morning until 23:00 at night) during the day and every 30 minutes (from 23:00 at night to 07:00 in the morning) at night. Measurements were considered sufficient if more than 70% of the records were valid, or at least two measurements were taken in two non-consecutive hours during the day and at least one measurement in two non-consecutive hours at night. Systolic and diastolic blood pressure variability (BPV) indices were evaluated based on data from the Mobil-O-Graph recordings and reported for the total 24-hour, daytime, and nighttime periods. The 24-hours, day, and night averages of systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and pulse measurements were recorded, along with their percentile and SDS values.

In addition to the 24-hour, daytime, and nighttime averages, the validity percentages of BP measurements, the percentages of measurements exceeding the limits, and the decreases in systolic and diastolic BPs were recorded for these time periods. The study also noted whether these decreases were over 10%.

The software provided by the company was used to calculate all measurements, ensuring compatibility with the ABPM device. The criteria for determining BP patterns were defined as follows: a decrease of less than 10% in BP values during sleep, compared to waking hours, was classified as 'non-dipping'. Conversely, a decrease of 10% or more was classified as 'dipping'. To determine the SBP and DBP loads, the number of measurements exceeding the 95th percentile for HT was divided by the total number of measurements, considering the individual's sex, chronological age, and height. According to the 2022 American Heart Association (AHA) criteria, HT, based on mean ambulatory SBP or DBP values, was defined as follows: (1) values exceeding the 95th percentile in individuals under 13 years of age; (2) for individuals aged 13 years and over, values ≥125/75 mmHg for a 24-hour period, ≥130/80 mmHg during daytime, and ≥110/65 mmHg at nighttime (6).

The definitions of ambulatory pre-HT (mean BP <95th percentile, but BP loads ≥25%) and severe HT (mean BP ≥95th percentile and BP loads >50%) from the 2014 AHA pediatric classification[10] were not evaluated in this study. WCHT was defined in patients whose office BP was in the hypertensive range but with normal ABPM.

Statistical Analysis

Analyses were performed using the Statistical Package for the Social Sciences (SPSS) software (SPSS Inc., Chicago, IL). The normality of continuous variables was assessed using the Kolmogorov-Smirnov test. Normally distributed variables were presented as mean±standard deviation (mean±SD), while non-normally distributed variables were expressed as the median (25–75% interquartile range). Categorical data are reported as numbers and percentages (%). The Chi-square or Pearson tests were used to compare categorical variables as appropriate. Paired groups were compared using either Student's t-test or the Mann-Whitney U test. Binary logistic regression analysis was performed to identify potential risk factors affecting the adequacy of blood pressure measurement. A significance level of $p<0.05$ was adopted for all analyses.

Table 1. Demographic and baseline ABPM data of patients

Parameter	n	%
Gender		
Boy	1,098	59.1
Girl	761	40.9
Obesity		
Obese	327	17.6
Non-obese	1,532	82.4
ABPM results		
Normotensive	571	30.7
Hypertensive	1,288	69.3
BP dipping status		
Systolic dipper HT	718	38.6
Systolic non-dipper HT	1,141	61.4

*: ABPM: Ambulatory blood pressure monitoring; BP: Blood pressure; HT: Hypertension. Data are presented as numbers and percentages.

RESULTS

The study included a total of 1,859 cases, with 1,098 (59.1%) boys and 761 (40.9%) girls. Out of these cases, 327 (17.6%) were obese, and 1,532 (82.4%) were not obese. The demographic and baseline ABPM data of the patients are provided in Table 1. When evaluated according to 24-hour, night, and day systolic and diastolic BP measurement percentages, it was found that the percentages exceeding the nighttime systolic and diastolic values were higher than during the day. Table 2 shows the patients' mean SBP and DBP measurements, both 24-hour and day and night, as well as the SDS of these values and some additional clinical parameters.

In the study, when evaluating the average valid measurement percentages of patients over 24 hours, day, and night, it was found that the validity of 24-hour and daytime measurements was marginal, while the validity of nighttime measurements was more adequate. The average age of normotensive patients was 12.8±3.0, compared to 12.6±3.1 for hypertensive patients, with no significant age difference between the groups (p=0.230). HT was detected in 774 (70.5%) of the boys and 514 (67.5%) of the girls participating in the study. No relationship was found between these BP results and gender (p=0.175). The study also found a significantly higher rate of HT (79.2%) among obese individuals compared to non-obese individuals (67.2%). Additionally, the mean age of those with sufficient measurements was significantly higher than those with insufficient measurements (p=0.001). Adequate measurements were observed in 86.6% of boys and 86.5% of girls, with no significant difference between the genders (p=0.927). The adequate measurement rate in obese individuals (81.3%) was significantly lower than in non-obese individuals (87.7%) (p=0.002). According to the ABPM results, BP was normal in 571 (30.7%) patients, and HT was observed in 1,288 (69.3%) patients. Table 3 presents a comparison of gender, obesity status, adequacy of 24-hour ABPM measurements, and dipping status, according to whether the patients are hypertensive or normotensive.

Table 2. Mean systolic and diastolic blood pressure measurements (24-hour, daytime, and nighttime) with SDS and additional clinical parameters

Parameter	Value
Age (years)	12.7±3.1
Weight (kg)	54.6±21.5
Height (cm)	154.6±16.9
BMI (kg/m^2)	22.0±5.8
BMI Percentile	59.2±35.5
BMI-SDS	0.4±1.6
24-hour MAP (mmHg)	88.0 (83.0–93.0)
24-hour MAP SDS	1.05 (0.31–1.93)
Daytime MAP (mmHg)	91.0 (85.0–96.0)
Daytime MAP SDS	0.62 (-0.06–1.51)
Nighttime MAP (mmHg)	81.0 (76.0–86.0)
Nighttime MAP SDS	1.53 (0.85–2.34)
24-hour SBP (mmHg)	114.0 (107.0–121.0)
24-hour SBP SDS	0.18 (-0.61–1.03)
Daytime SBP (mmHg)	116.0 (110.0–124.0)
Daytime SBP SDS	-0.14 (-0.86–0.72)
Nighttime SBP (mmHg)	107.0 (101.0–113.0)
Nighttime SBP SDS	0.61 (-0.07–1.39)
24-hour DBP (mmHg)	66.0 (62.0–71.0)
24-hour DBP SDS	-0.10 (-0.93–0.73)
Daytime DBP (mmHg)	69.0 (64.0–74.0)
Daytime DBP SDS	-0.53 (-1.29–0.28)
Nighttime DBP (mmHg)	59.0 (55.0–64.0)
Nighttime DBP SDS	0.61 (-0.19–1.44)

*: BMI: Body mass index; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; SBP: Systolic blood pressure; SDS: Standard deviation score. Data are presented as mean±SD (normally distributed) and median (25–75% interquartile range) (non-normally distributed).

The binary logistic regression analysis indicated that advanced age, obesity, and being in the diastolic non-dipper group are associated with a higher risk of invalid measurement. Table 4 shows the analysis of factors affecting the validity of ABPM measurements.

Table 3. Comparison of demographic and ABPM parameters of patients according to their blood pressure level

Parameters	Normotensive		Hypertensive		p*
	n	%	n	%	
Age (years, mean±SD)	12.8 ± 3.0		12.6 ± 3.1		0.230
Gender					0.175
Boy	324	29.5	774	70.5	
Girl	247	32.5	514	67.5	
Obesity					<**0.001**
Obese	68	20.8	259	79.2	
Non-obese	503	32.8	1,029	67.2	
Successful readings					0.251
Sufficient	502	87.9	1,107	85.9	
Insufficient	69	12.1	181	14.1	
Dipping					**0.005**
Systolic dipper HT	248	43.4	470	36.5	
Systolic non-dipper HT	323	56.6	818	63.5	
Diastolic dipper HT	456	79.9	871	67.6	<**0.001**
Diastolic non-dipper HT	115	20.1	417	32.4	

SD: Standard deviation; HT: Hypertension. Data are presented as numbers and percentages. p-value is for comparison between normotensive and hypertensive patients; p<0.05 is considered significant; *: Chi-square test or, when appropriate, Fisher's exact test used.

Table 4. Binary logistic regression analysis of factors affecting the validity of measurements in ABPM

Predictor	B	SE	Wald	p*	OR	(95% CI)	
						Lower	Upper
Age	-0.085	0.025	11.261	**0.001**	0.918	0.874	0.965
Gender	-0.145	0.166	0.762	0.383	0.865	0.624	1.198
Obesity	0.419	0.190	4.854	**0.028**	1.520	1.047	2.205
Hypertension	-0.257	0.171	2.244	0.134	0.774	0.553	1.082
Systolic dipper	0.173	0.197	0.767	0.381	1.189	0.808	1.749
Diastolic dipper	0.823	0.188	19.238	<**0.001**	2.277	1.576	3.289

B: Beta coefficient; CI: Confidence interval; OR: Odds ratio; SE: Standard error; *: Binary logistic regression analysis.

DISCUSSION

The prevalence of hypertension (HT) in childhood is lower compared to adults, and the diagnostic process is more difficult for children. Studies have shown that HT-related complications may occur in childhood.[11–13] All cases included in this study were referred to our unit after HT was detected by BP measurements during clinic visits. Our study revealed that approximately 30% of all patients who underwent ABPM had normotensive results. This finding indicates that the prevalence of WCHT is high in our region. In conclusion, ABPM is recommended for children with suspected HT to reduce the risk of overdiagnosis and unnecessary treatment.

The 2014 AHA pediatric classification of the ABPM phenotype is complex and includes two additional BP stages: ambulatory pre-hypertension (mean BP, <95th percentile, but BP burden ≥25%) and severe ambulatory hypertension (mean BP, ≥95th percentile and BP burden >50%).[10] This finding is significant as it highlights that evaluating HT based on BP burden in ABPM may lack specificity. Utilizing the AHA 2014 categories could

potentially result in the misclassification of certain patients with elevated BP burden but normal mean ambulatory BP and/or normal office BP, or those who are hypertensive. Furthermore, the importance of pre-hypertension in predicting diagnosis, clinical outcome, or subclinical target organ damage remains unclear.[6] Effective and accurate use of ABPM may prevent missed diagnosis and overtreatment in children.

As emphasized in many studies, an optimal ABPM should have a monitoring period of at least 18–20 hours (ideally 24 hours) and should ensure that sleep time is also recorded with at least 70% successful measurements during the monitoring period.[14] Usually, this will result in a minimum of 40 to 50 successful readings over the monitoring period. Suboptimal studies can provide clinically useful information but ideally should be repeated. In addition, at least one BP reading should be taken at non-consecutive hours, including during sleep.[15,16] In our study, it was found that 86.6% of the total number of patients had measurements above 70% and this was deemed sufficient, while 13.4% had insufficient measurements. Furthermore, the average valid measurement percentages of 24-hour, daytime, and nighttime periods were investigated. It was found that nighttime measurements were more sufficient than those taken over 24 hours and during the day. It can be concluded that this high rate of measurement sufficiency is likely due to longer sleep time at night, decreased activity of patients during these hours, and increased compliance with the device. When comparing measurement sufficiency in patients with different stages of HT, it was observed that patients with mild HT had a significantly higher rate of adequate measurements (88.5%) compared to those with severe HT (83.8%). As the stage of HT increases, it is plausible to suggest that the reason for this situation may be insufficient measurements due to stress, anxiety, restlessness, and headaches that can develop in patients with increased HT.

Childhood obesity is closely linked to high BP, as there is a clear connection between body weight and HT. Studies conducted both in our country and globally have reported an increase in HT with rising rates of childhood obesity. Using ABPM to monitor these patients is believed to have significant clinical benefits.[17] In a study by Lurbe et al.,[18] BP was found to be significantly higher in the obese group. Another study with 20,263 children in India found that HT prevalence was 10.1% in the normal weight group, 17.4% in the overweight group, and 18.32% in the obese group.[19] In our study, when the obesity status of the subjects was compared with their hypertensive status, it was found that the rate of being hypertensive in the obese group (79.2%) was significantly higher than that in the non-obese group (67.2%). In a study by Yegül Gülnar et al.[20] from Türkiye, it was reported that only 11 of 118 patients had insufficient measurements, and these were more common in the obese group. This study also evaluated the percentages of validity of the measurements and their relationship with factors such as age and obesity. It was found that younger age groups and obese patients had higher rates of insufficient measurements.

CONCLUSION

As a result, this study revealed that a significant number of children initially diagnosed with HT during outpatient clinic measurements actually had normal BP when assessed using ABPM. These findings allowed us to highlight the prevalence of WCHT in the Eastern Anatolia Region of Türkiye. We believe that the outcomes of our study should be corroborated by research involving a larger and more homogenous patient cohort.

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Ethics Committee Approval: The İnönü University Clinical Research Ethics Committee granted approval for this study (date: 08.02.2022, number: 2021-1174).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Author Contributions: Concept – YT, MŞ; Design – MŞ; Supervision – YT; Resource – YT, MŞ, ŞZS, ATE; Materials – ŞZS, ATE; Data Collection and/or Processing – MŞ; Analysis and/or Interpretation – YT, MŞ; Literature Search – MŞ; Writing – YT, MŞ; Critical Reviews – YT.

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