Pediatric Nephrology (2021) 36:1833–1841
https://doi.org/10.1007/s00467-020-04896-7

ORIGINAL ARTICLE

Do children with solitary or hypofunctioning kidney have the same prevalence for masked hypertension?

Sibel Yel[1] · Neslihan Günay[1] · Ayşe Seda Pınarbaşı[1] · Aynur Gencer Balaban[1] · Zeynep Caferoğlu[2] · İsmail Dursun[1] · Muammer Hakan Poyrazoğlu[1]

Received: 10 July 2020 / Revised: 12 November 2020 / Accepted: 8 December 2020 / Published online: 18 January 2021
© IPNA 2021

Abstract

Background Having a low nephron number is a well-known risk factor for hypertension. There is an inverse relationship between the filtration surface area and systemic hypertension. A significant percentage of masked hypertension can be detected in children with nephron loss by ambulatory blood pressure monitoring (ABPM).

Methods We prospectively investigated ABPM results of children having reduced kidney mass with normal office blood pressures (BPs) and kidney function. Forty-three children with congenital solitary kidney (group 1), 11 children with acquired solitary kidney (group 2), and 76 children with hypofunctioning kidney (group 3) were compared with age, gender, and BMI-matched healthy control group (group 4). The dietary salt intake of 76 patients was evaluated as salt equivalent (g/day). The primary endpoint was change from baseline in mean 24-h ABPM variables and the proportion of patients with masked hypertension when assessed by ABPM.

Results The masked hypertension ratio of all patients was 12.3% when assessed with ABPM. Night hypertension was significantly higher in all patient groups than in the control group ($p = 0.01$). Diastolic BP loads of groups 1 and 3 were higher than in controls ($p = 0.024$). Systolic BP loads were higher only in group 1 than in the control group ($p = 0.003$). The dietary salt equivalent of patients in group 1 correlated positively with 24-h SBP and mean arterial pressure (MAP) values. Patients with excessive dietary salt intake in group 1 had a significantly higher diastolic BP load than those without excessive salt intake in group 1 ($p = 0.002$).

Conclusions Masked hypertension can be seen in children with a solitary kidney or when one of the kidneys is hypofunctioning. Systolic BP loads are higher in children with congenital solitary kidney, and salt intake correlates with systolic BP profiles especially in those. Our results suggest that being born with a congenital solitary kidney increases predisposition to hypertension and salt sensitivity.

Keywords Hypertension · Children · Ambulatory blood pressure monitoring · Solitary kidney

✉ Sibel Yel
drsibelyel@gmail.com

Neslihan Günay
neslihankosr@hotmail.com

Ayşe Seda Pınarbaşı
drsedacoskun@gmail.com

Aynur Gencer Balaban
aynurgencerbalaban@gmail.com

Zeynep Caferoğlu
zeynepcaferoglu@gmail.com

İsmail Dursun
drdursun@hotmail.com

Muammer Hakan Poyrazoğlu
drpoyrazoglu@yahoo.com

[1] Department of Pediatric Nephrology, Faculty of Medicine, Erciyes University, Kayseri, Turkey

[2] Department of Nutrition and Dietetics, Faculty of Health Sciences, Erciyes University, Kayseri, Turkey

Introduction

Having a low nephron number is a well-known risk factor for hypertension, proteinuria, and glomerulosclerosis [1, 2, 3]. This concern has emerged from findings in experimental animal models of renal mass reduction [1, 2]. A reduction in the number of glomeruli means a reduction in the whole-kidney glomerular surface area resulting in reducedsodium excretory capacity and susceptibility to hypertension [4, 5]. Children with low birth-weight, a surrogate for low nephron number, have increasing blood pressure (BP) from childhood to adulthood [4]. Patients with a solitary kidney are prone to develop hypertension during childhood [6, 7].

Other than a solitary kidney; obstructive uropathy; aplasia, hypoplasia, or renal dysplasia; reflux nephropathy; and other causes of a congenital abnormality of the kidney or urinary tract (CAKUT) may cause nephron loss and chronic kidney disease (CKD) [8]. Hypertension is an independent risk factor for kidney disease progression and should be managed, especially among patients with CAKUT [9].

Ambulatory blood pressure monitoring (ABPM) is a crucial method in diagnosing and managing hypertension in children, especially with kidney disorders [10]. Previous studies using ABPM in children with CAKUT without CKD have been conducted with heterogeneous study designs to determine masked hypertension [6, 7, 11–13], especially in children with an acquired or congenital solitary kidney. There is a lack of information about children with one hypofunctioning kidney and a contralateral normal one without CKD.

In the current study, we investigated the BP profiles of children with a solitary kidney and two kidneys, one of which is hypofunctioning due to CAKUT, using ABPM. Because Na load excretion is diminished in decreased nephron number, an important underlying pathogenetic determinant of hypertension, participants' dietary sodium intake was assessed.

Methods

Patients

Children, between 5 and 18 years, followed in the Pediatric Nephrology Unit of Erciyes University with solitary kidney and one hypofunctioning kidney with another normal functioning one were enrolled in this prospective study. Patients diagnosed with solitary or one hypofunctioning kidney between January 2000 and December 2018 were enrolled. The patient records were examined by December 2018. Eligible patients were selected, and ABPM was performed until March 2020. There were 276 children altogether, and 130 eligible patients were selected according to the following inclusion criteria:

1. Congenital renal agenesis, multicystic renal dysplasia, and acquired solitary kidney (due to nephrectomy) patients who have proven single functioning kidney with a contralateral non-functioning one on Tc^{99m} dimercaptosuccinic acid (DMSA) scintigraphy at any time in the past
2. Hypofunctioning one kidney with a normal functioning one due to CAKUT (vesicoureteral reflux, hypo/dysplasia, obstructive uropathy) or urolithiasis seckel
3. Hypofunctioning kidney was determined as the split kidney function < 30% shown on DMSA in the last 2 years [14]
4. Being normotensive during previous and last clinical visits by office measurements. Office measurements were taken by the auscultatory method. If the patient is normotensive according to the European Society of Hypertension criteria, only one measurement is taken [15]
5. Having records with a minimum 70% of valid readings at ABPM.

The exclusion criteria were: low birth weight and/or body mass index (BMI) above 25 and estimated glomerular filtration rate (GFR) < 90 ml/min/1.73 m^2 using the Schwartz formula [16].

Patients were categorized as congenital solitary kidney (group 1), acquired solitary kidney (group 2), and hypofunctioning kidney (group 3) and compared with age-, gender-, and BMI-matched healthy control group (group 4). Patient distribution of groups with final analyzed numbers according to underlying kidney disease is shown in Table 1. The two children with Wilms' tumor were not treated with chemotherapy.

Ambulatory blood pressure monitoring was performed on patients who met inclusion criteria and controls. Twenty-four-hour urine collection and 24-h dietary recall for salt intake were performed at the same time as ABPM. Seventy-six of the 130 patients (30 of 76 in group 1; 9 of 76 in group 2; 37 of 76 in group 3) agreed to complete 24-h urine collection.

Clinical characteristics, laboratory findings, office and ambulatory systolic BP (SBP), diastolic BP (DBP), mean arterial pressure (MAP), heart rate, and SBP and DBP load of all patients were recorded. Twenty-four-hour urine collection and 24-h dietary recall were done to assess the salt intake of participants.

The study protocol was approved by the local Institutional Ethics Committee (reference number: 2018/255, date: 9.05.2018). All procedures were in accordance with the Declaration of Helsinki, and a signed consent form was obtained from parents of all patients before participating in the study.

Study design

Ambulatory blood pressure monitoring was performed with Mobil-O-Graph oscillometric devices (Mobil-O-Graph, I.E.M., Stolberg Germany). According to the European Society of Hypertension criteria, the Mobil-O-Graph has

Table 1 Patient distribution according to underlying kidney disease

Group	Number	Underlying disease	Number
Congenital solitary kidney (Group 1)	43	Renal agenesis	25
		Multicystic dysplastic kidney	18
Acquired solitary kidney (Group 2)	11	Nephrectomy for Wilms' tumor	2
		Nephrectomy for infection	9
Hypofunctioning kidney (Group 3)	76	Vesicoureteral reflux	41
		Hypo/dysplasia	19
		Obstructive uropathy	10
		Atrophy secondary to urolithiasis	6

already been validated for the measurement of 24-h ABPM [17]. The appropriately-sized cuff was placed on the non-dominant arm of the patient. BP was measured every 30 min during the day and every 60 min during the night. Records with a minimum 70% valid readings (minimum 1 valid reading per hour with at least 40 readings) at ABPM were included for analysis [10]. We performed a second ABPM in the case of unexpected or invalid results, and previous invalid readings were not included. Profiles of ABPM were calculated according to the 2016 European Society of Hypertension guidelines for the management of high blood pressure in children and adolescents [15].

Appropriate ABPM standard deviation score (SDS) values of each subject were calculated. The SDS of mean SBP, DBP, and MAP for gender and height was calculated by using reference data of healthy children [18]. Hypertension was defined as a mean office SBP and/or DBP or 24-h ABPM SDS ≥ 1.96 (95th percentile). Prehypertension (high-normal) was considered as a mean office SBP and/or DBP or 24-h ABPM SDS ≥ 1.64 (90th percentile) but < 1.96 (95th percentile). Also, isolated daytime and nocturnal hypertension and prehypertension were noted (ABPM SD scores ≥ 1.96 and ≥ 1.64 for day and night reference values, respectively).

Systolic and diastolic BP load, the percentage of measurements above the 95th percentile, was determined for each subject. The dipping status was calculated by subtracting the mean nighttime BP from the mean daytime BP, then dividing this value by the mean daytime BP. A greater than 10% drop in mean SBP and DBP between the daytime and nighttime was defined as dipping [19].

Dietary salt intake of the 76 patients is evaluated as salt equivalent (g/day) in two ways: according to the (1) 24-h urinary sodium excretion values and (2) dietary recall.

The 24-h urine collection was completed using a standardized procedure outlined by the WHO (WHO 2018) [20]. When collection time was not exactly 24 h but within 20–28 h, total urine volume and urinary electrolytes were standardized to a 24-h period as published previously [21]. Urine samples were considered valid if collection time was > 20 h and < 28 h, the participant reported missing ≤ 1 collection, and urinary volume was > 300 ml/24 h [21]. The participants were asked to follow their habitual diet and make no daily salt intake changes during the urine collection time. Upon completing the collection, the total urine volume was recorded, and all samples were analyzed by the central laboratory at Erciyes University. For each individual, the sodium excretion in 24 h (mmol/day) was calculated as urinary sodium concentration (mmol/L) × total urine volume (L/day) [22]. These sodium excretion values were then used to estimate dietary salt intake by the following conversion factor: 87 mmol of sodium is equal to 5 g of salt [20]. Moreover, an additional analysis was performed using estimated 24-h sodium excretion based on Tanaka's formulas [23] to use all urine samples regardless of the collection accuracy [24].

Twenty-four-hour dietary recall: Participants' dietary intake was assessed by a face-to-face multiple-pass 24-h dietary recall method by using a photographic atlas of food portion sizes to quantify the data on the day of the urine collection [25]. Diet composition was analyzed by the BeBiS Nutrition Information System software version 8.2. Intakes of energy (kJ/day), sodium (mg/day), and salt (g/day) are reported, and daily sodium density (mg/1000 kJ) was also calculated to correct for differences in participants' energy intake [26].

The effect of salt intake on the blood pressure between patient groups was investigated. We used the upper limits of the Turkey Dietary Guidelines (TUBER) [27] for considering the sodium intake as excessive: (1) > 1900 mg/day (salt equivalent 4.75 g/day) for 5- to 8-year-olds, (2) > 2200 mg/day (salt equivalent 5.5 g/day) for 9- to 13-year-olds, and (3) > 2300 mg/day (salt equivalent 5.75 g/day) for 14- to 18-year-olds.

The primary endpoint was change from baseline in mean 24 h ABPM variables (SBP, DBP, and BP loads) and the proportion of patients with masked hypertension when assessed by ABPM. The study's primary outcome was to investigate whether there is masked hypertension in children with solitary and hypofunctioning kidney. If so, to find out the differences of masked hypertension prevalence between these groups. The secondary outcome was to detect how excessive salt intake affects these patients' BP profiles on ABPM.

Statistics

All tests were performed using IBM SPSS 22 (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL, USA). First, the distributions of all parameters were determined using the Shapiro–Wilk test. Parameters with non-normal distribution were expressed as median (25th–75th percentile), and parameters with normal distribution were expressed as mean ± standard deviation (SD).

The comparisons between the groups for the parameters with normal distribution were conducted using analysis of variance (ANOVA) with Tukey's post hoc procedure. The parameters with non-normal distribution were compared using the Kruskal–Wallis H-test. Then, when statistical significance was found using the Kruskal–Wallis H-test, Dunn's procedure was conducted. Spearman's test was used to calculate the correlations. Categorical variables were analyzed using Pearson and Fisher's exact test. The comparisons between the two groups were conducted using Wilcoxon and paired *t* tests. A *p* value of < 0.05 was accepted as statistically significant.

Results

Patient characteristics

One hundred-thirty of 276 children, with a mean age of 11 years, met inclusion criteria. A flow diagram of patient selection is shown in Fig. 1.

Finally, a total of 150 children, 43 in group 1, 11 in group 2, 76 in group 3, and 20 in group 4, are analyzed. The demographic data and kidney functional parameters of the study groups and controls are shown in Table 2. Age, BMI, serum creatinine, and GFR are not different between each patient group and the controls ($p > 0.05$). All patients had normal kidney function with estimated GFR > 90 ml/min/1.73 m^2 using the Schwartz formula [16].

Blood pressure profiles with ABPM and hypertension status

The office BP measurements were within normal ranges in all patient groups by selection because detection of white coat hypertension was not a goal of the study. No differences were found in systolic and diastolic office BP values between the patient and control groups ($p > 0.05$) (Table 3).

Standard deviation scores for daytime SBP of 24-h ABPM were higher in children with congenital solitary kidney than in healthy controls ($p = 0.031$) (Fig. 2a). No significant difference was found between the groups for nocturnal ABPM SD scores and daytime DBP SD scores ($p > 0.05$)

Data about BP load and dipping status are shown in Table 4. Twenty-four-hour and night BP loads for SBP and DBP were higher in group 1 than in the control group ($p < 0.05$). Furthermore, 24-h and night BP loads for DBP were higher in also group 3 than in the control group ($p < 0.05$).

ABPM identified 24-h hypertension in 16 (12.3 %) of 130 children and high-normal tension in two children. There were no differences in the proportions of 24-h hypertension and high-normal tension between the patient groups ($p > 0.05$).

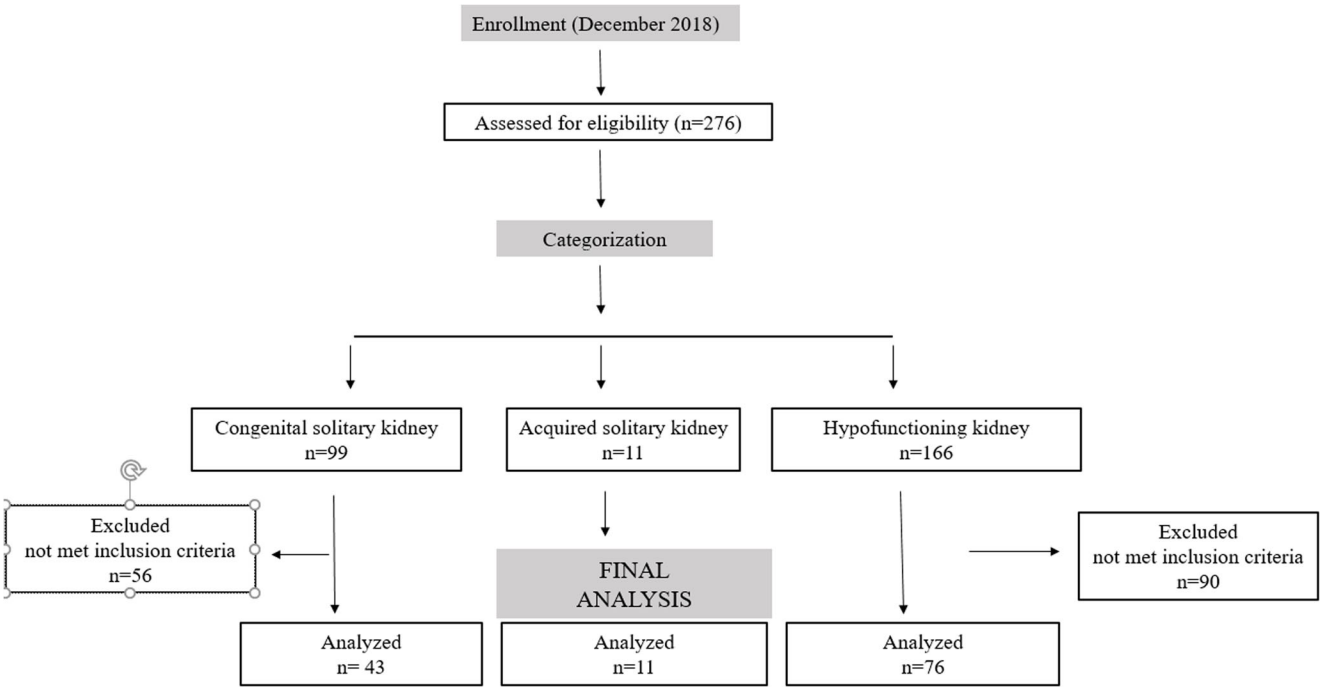

Fig 1 Flow diagram of patient selection

Table 2 Patient and control group characteristics

	Group 1 (congenital solitary kidney) $n = 43$	Group 2 (acquired solitary kidney) $n = 11$	Group 3 (one hypofunctioning kidney with other normal) $n = 76$	Group 4 (control) $n = 20$
Female (n) (%)	18 (41.8)	5 (45.4)	39 (51.3)	12 (60.0)
Age (years)	11.00 ± 3.01	11.09 ± 3.91	12.29 ± 3.83	12.85 ± 3.37
Serum creatinine	0.58 (0.48–0.68)	0.57 ± 0.12	0.61 ± 0.14	0.60 ± 0.14
GFR	141.33 ± 24.07	143.29 ± 21.75	142.49 ± 26.87	148.07 ± 26.32

The parameters with normal distribution are expressed as mean ± SD, and the parameters with non-normal distribution are expressed as median (25th–75th percentile)

BMI body mass index, *GFR* glomerular filtration rate

Night hypertension proportions of patient groups were different from those in the control group ($p = 0.01$) (Table 5).

Dietary salt intake status and blood pressure correlations:

The median levels of salt intake were 6.20 g/day, 5.32 g/day, and 7.05 g/day in groups 1, 2, and 3, respectively. The percentage of patients with excessive salt intake in each group was determined (Table 6). No statistically significant differences in the rate of patients with excessive salt intake were observed between groups ($p > 0.05$).

Univariate analysis between the salt intake of the patients and BP profiles was performed. No significant correlation was found between the patients' BP profiles and dietary salt intake calculated according to dietary recall ($p > 0.05$). Significant univariate positive correlations were detected between BP profiles and dietary salt equivalent calculated from 24-h urinary sodium excretion values ($p < 0.05$). The dietary salt equivalent of patients correlated positively with 24-h SBP and 24-h DBP only in group 1. No significant correlation was found in the multivariate analysis of groups.

In patients with congenital solitary kidney (group 1), the excessive salt intake subgroup had a significantly higher 24-h DBP load than those without excessive salt intake ($p = 0.002$) (Fig. 2b). Subgroup differences were not significant for excessive salt intake in groups 2 and 3 ($p = 0.051$ and 0.590, respectively).

Discussion

This study demonstrates that 12% of children with a congenital solitary kidney and hypofunctioning kidney who are normotensive on office measurements, are hypertensive when assessed with ABPM. Night hypertension is especially detected. While systolic and diastolic BP loads of patients with congenital solitary kidney are higher than in healthy children, only DBP loads of patients with one hypofunctioning kidney

Table 3 Blood pressure SDS profiles

	Group 1 $n = 43$	Group 2 $n = 11$	Group 3 $n = 76$	Group 4 (control) $n = 20$	p
Mean 24-h SBP SDS	− 0.16 ± 0.94	− 0.31 ± 0.98	− 0.40 ± 0.99	− 0.90 ± 0.91	0.053
Mean 24-h DBP SDS	− 0.39 1.34	− 0.23 0.57	− 0.29 ± 1.28	− 0.79 ± 1.02	0.438
24-h MAP SDS	0.78 ± 1.06	0.77 ± 0.71	0.75 ± 1.12	0.20 ± 0.87	0.183
Day SBP SDS	− 0.49 ± 0.89[a]	− 0.50 ± 1.03	− 0.71 ± 1.05	− 1.28 ± 0.92	0.031
Day DBP SDS	− 0.83 ± 1.32	− 0.89 ± 0.49	− 0.76 ± 1.12	− 1.18 ± 0.092	0.559
Day MAP SDS	0.30 ± 1.11	0.24 ± 0.64	0.20 ± 1.01	− 0.27 ± 0.73	0.181
Night SBP SDS	0.64 ± 0.91	0.53 ± 0.87	0.32 ± 0.97	− 0.01 ± 0.80	0.062
Night DBP SDS	0.91 (− 0.4–1.40)	0.87 (− 0.69–1.57)	0.45 (− 0.31–1.39)	− 0.05 (− 0.47–0.93)	0.131
Night MAP SDS	1.51 ± 1.00	1.51 ± 0.67	1.33 ± 1.00	0.94 ± 0.71	0.165

The parameters with normal distribution are expressed as mean ± SD, and the parameters with non-normal distribution are expressed as median (25th–75th percentile)

SBP systolic blood pressure, *DBP* diastolic blood pressure, *MAP* mean arterial pressure

[a] Different from controls

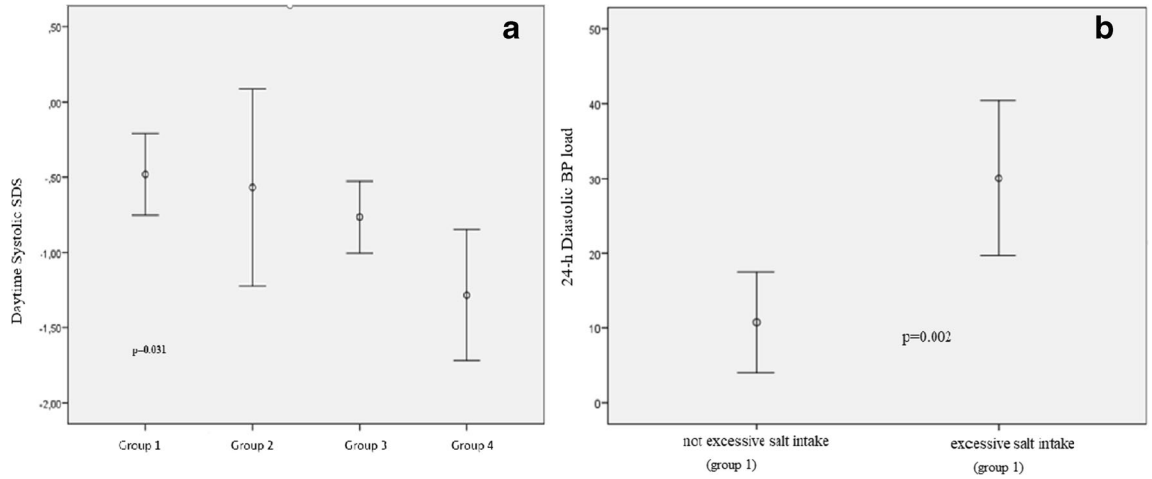

Fig. 2 Error bar graphic of daytime SBP (SDS) and 24-h DBP load of the patient groups

are higher than in healthy children. Salt intake is positively correlated with systolic blood pressure profiles. Patients with excessive salt intake seem to have higher DBP loads.

Traditionally, BP readings taken in the office or home have been used to evaluate children for hypertension. The white coat effect or physiologic variability of BP can be confusing, and masked hypertension cannot be identified by this way. Masked hypertension is defined as office and home BPs below the 95th percentile, when ambulatory BPs > 95th percentile with ≥ 25% BP load on ABPM [28]. Because of the well-known risk of transition from masked to sustained hypertension in healthy youths, the detection of masked hypertension is essential to prevent complications [15]. Patients with solitary and hypofunctioning kidneys had the same prevalence of masked hypertension in the current study. Though when BP loads are evaluated, some differences were detected.

ABPM is a useful tool for the evaluation of day and night hypertension status separately. Rather than hypertension status, BP load profiles of patients can be detected by ABPM. The ratio of patients with night hypertension was higher than in controls, but not different between subgroups of patients. In a recent study, kidney disease has been determined as the underlying cause in one-third of cases of masked isolated nocturnal hypertension [29].

Based on experimental studies, hyperfiltration injury due to reduced kidney mass is associated directly with hypertension. There is an inverse relationship between the filtration surface area and systemic hypertension [5, 30]. In this context, investigators have reported an increased prevalence of hypertension in children with a solitary kidney. Moreover, when ABPM was performed, a high percentage of masked hypertension was detected in these children [6, 7, 11, 12]. Those studies have been conducted in different and heterogeneous designs. Some [12, 31, 32] have compared the results of BP readings of children having solitary kidney with healthy controls, some [6, 13, 20] compared among the results of children having

Table 4 Blood pressure load profiles

	Group 1 $n = 43$	Group 2 $n = 11$	Group 3 $n = 76$	Group 4 (control) $n = 20$	p
24-h SBP load (%)	18[a] (7–32)	17 (5–38)	10.5 (5–21)	5 (2–10.5)	0.003
24-h DBP load (%)	19[a] (6–37)	18 (10–33)	16[a] (5.25–32)	8.5 (3.5–9.75)	0.024
Night SBP load (%)	12[a] (0–33)	9 (0–33)	11 (0–22)	0 (0–9.25)	0.005
Night DBP load (%)	29[a] (4.3–43)	25 (0–33)	14[a] (0–38)	0 (0–11.75)	0.005
Day SBP load (%)	8 (3–14)	8 (0–12)	5 (0–11)	1.5 (0.4.75)	0.063
Day DBP load (%)	8 (0–26)	4 (0–14)	5 (0–17)	4 (0–6.75)	0.428
Systolic dipping (%)	6.59 ± 5.46	7.15 ± 4.39	7.29 ± 5.04	6.85 ± 4.10	0.91
Diastolic dipping (%)	10.11 ± 9.20	11.69 ± 6.46	12.60 ± 6.93	12.11 ± 6.15	0.40

The parameters with normal distribution are expressed as mean ± SD, and the parameters with non-normal distribution are expressed as median (25th–75th percentile)

SBP systolic blood pressure, *DBP* diastolic blood pressure

[a] Different from controls

Table 5 Hypertension and high-normal tension status

	Group 1 $n = 43$	Group 2 $n = 11$	Group 3 $n = 76$	Group 4 (control) $n = 20$	p
24-h hypertension (n) (%)	5 (11.6)	0 (0)	11 (14.5)	0 (0)	0.45
24-h high-normal (n) (%)	1 (2.3)	0	1 (1.3)	0	
Day hypertension (n) (%)	2 (4.7)	0 (0)	4 (5.3)	0 (0)	0.66
Day high-normal (n) (%)	2 (4.7)	0 (0)	1 (1.3)	0 (0)	
Night hypertension (%)	9 (20.9)	4 (36.3)	19 (25.0)	0 (0)	0.01
Night high-normal (n) (%)	6 (14.0)	0 (0)	3 (3.9)	0 (0)	

solitary kidney subgroups (congenital or acquired). The typical result of these studies is that children with solitary kidney are at risk for hypertension. There have been studies performed regarding apparent hypertension in patients with kidney scars. Ahmed et al. reported that kidney scars are present in 21% of children evaluated for newly diagnosed hypertension [33]. In the current study, we not only evaluated masked hypertension of children with solitary kidney but also those with two kidneys, one of which is hypofunctioning. Also, blood pressure loads apart from hypertension status were evaluated. The masked hypertension ratio of our patients with solitary kidney was similar to previous reports [13]. In a recent study, Hooman et al. reported 5% masked hypertension in children with kidney scars [34]. The current study demonstrates that the masked hypertension ratio of children with hypofunctioning kidney is higher than previously reported and as high as in congenital solitary kidney. Therefore, the comparison between these patient groups strengthens the emphasis of masked hypertension in children with solitary kidney and reduced kidney mass due to other reasons.

Compared with children with essential hypertension, children with secondary hypertension are more likely to have increased awake SBP loads and increased awake and asleep DBP loads. These children are at high risk of having end-organ damage [28]. Left ventricular mass index correlation with ambulatory SBP load in children has also been demonstrated [10]. Dursun et al. [11] and Tabel et al. [12] reported higher 24-h diastolic loads in children having single atrophic kidney and in children with multicystic dysplastic kidney than in controls, respectively. Zahav et al. [6] found 24-h DBP load higher than in controls. In the same study, BP loads of the nephrectomy group were similar to those of controls. In the current study, night and 24-h DBP loads were higher in solitary and hypofunctioning kidney groups.

Tabel et al. [12] reported higher 24-h systolic BP loads in patients with solitary kidney. We found night and 24-h systolic BP loads were also higher in only the congenital solitary kidney group compared with controls. The first group consisted of patients who had solitary kidney from birth, so the increased SBP load could result from a long time living with a solitary kidney. It is suggested that renal compensatory mechanisms for nephron loss may be different while nephrons are developing compared with when nephrogenesis is completed [4]. It is known that kidney homeostasis is remarkably maintained in acute renal mass reduction [35]. KIdney of MONofunctional Origin (KIMONO) study investigated kidney injury in children with different origins of solitary kidney. It demonstrated that a congenital solitary kidney may lead to hypertension and albuminuria [36, 37]. In our current study, both systolic and diastolic BP loads of congenital solitary kidney groups were higher, whereas only diastolic loads of children in group 3 were higher than in controls. We speculate that reduced kidney mass might result in increased DBP load previously.

The effect of salt intake on BP profile was another goal of our study. It is well known that salt reduction prevents cardiovascular disease, especially in chronic kidney disease patients [38]. Excessive salt intake leads to volume expansion and arterial hypertension. In a meta-analysis of 966 healthy children and adolescents, median salt intake reduction during 4 weeks was found to be accompanied by reductions in systolic blood pressure [39]. In line with this, Rios Leyvraz et al. found a positive correlation between sodium intake and BP [40]. The present study demonstrated a positive correlation between the dietary salt equivalent of all patients and 24-h SBP and MAP values. When patient groups were evaluated separately, for the same variables, only children with congenital solitary kidney had significant correlations. Furthermore, subgroup analysis of group 1 revealed that 24-h DBP load of the children with excessive salt intake was higher than of those without excessive salt intake.

Table 6 Levels of salt intake and excessive salt intake status of groups

	Salt intake (g/day)	Excessive salt intake n (%)
Group 1 $n = 30$	6.20 (4.96–7.76)	19 (63.3)
Group 2 $n = 9$	5.32 (4.15–10.7)	5 (55.5)
Group 3 $n = 37$	7.05 (4.65–8.61)	23 (62.1)

The parameters with non-normal distribution are expressed as median (25th–75th percentile)

Our study is prospectively designed. We investigated hypertension status in patients with solitary kidneys of different etiologies and also with two kidneys; one of which is hypofunctioning. The estimations of salt intake were done by measuring sodium excretion in 24-h urine samples, which is considered the gold standard [41]. In comparison, salt intake evaluation by dietary recall did not give correct information as it did not demonstrate any significant difference. So, the study design is strong in some ways but has a limitation that the number of patients in the nephrectomy group was small.

Conclusions

Masked hypertension can be seen in children with a solitary kidney or when one of the kidneys is hypofunctioning. Blood pressure screening with ABPM should be used in the evaluation of these patients. Systolic BP loads are higher in children with solitary kidney from birth, and salt intake correlates with systolic BP profiles especially in those patients. Our results suggest that being born with a congenital solitary kidney increases predisposition to hypertension and salt sensitivity. Longitudinal studies on large cohorts are needed.

Funding Funded by scientific research and projects unit of Erciyes University (Project number: (TSA-2018-8312)

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

References

1. Hostetter TH, Olson JL, Rennke HG, Venkatachalam MA, Brenner BM (1981) Hyperfiltration in remnant nephrons: a potentially adverse response to renal ablation. Am J Phys 241:85–93. https://doi.org/10.1152/ajprenal.1981.241.1.F85
2. Brenner BM (1985) Nephron adaptation to renal injury or ablation. Am J Phys 249:324–337. https://doi.org/10.1152/ajprenal.1985.249.3.F324
3. Anderson S, Brenner BM (1986) The role of intraglomerular pressure in the initiation and progression of renal disease. J Hypertens Suppl 4:236–238
4. Luyckx VA, Brenner BM (2010) The clinical importance of nephron mass. J Am Soc Nephrol 21:898–910. https://doi.org/10.1681/ASN.2009121248
5. Brenner BM, Garcia DL, Anderson S (1988) Glomeruli and blood pressure. Less of one, more the other? Am J Hypertens 1:335–347. https://doi.org/10.1093/ajh/1.4.335
6. Mei-Zahav M, Korzets Z, Cohen I, Kessler O, Rathaus V, Wolach B, Pomeranz A (2001) Ambulatory blood pressure monitoring in children with a solitary kidney - a comparison between unilateral renal agenesis and uninephrectomy. Blood Press Monit 6:263–267. https://doi.org/10.1097/00126097-200110000-00007
7. La Scola C, Marra G, Ammenti A, Pasini A, Taroni F, Bertulli C, Morello W, Ceccoli M, Mencarelli F, Guarino S, Puccio G, Montini G (2020) Born with a solitary kidney: at risk of hypertension. Pediatr Nephrol 35:1483–1490. https://doi.org/10.1007/s00467-020-04535-1
8. Fathallah-Shaykh SA, Flynn JT, Pierce CB, Abraham AG, Blydt-Hansen TD, Massengill SF, Moxey-Mims MM, Warady BA, Furth SL, Wong CS (2015) Progression of pediatric CKD of nonglomerular origin in the CKiD cohort. Clin J Am Soc Nephrol 10:571–577. https://doi.org/10.2215/CJN.07480714
9. Gabriele MM, Koch Nogueira PC (2019) Management of hypertension in CAKUT: protective factor for CKD. Front Pediatr 7:222. https://doi.org/10.3389/fped.2019.00222
10. Patel SS, Daniels SR (2019) Ambulatory blood pressure monitoring in pediatrics. Curr Hypertens Rep 21:71. https://doi.org/10.1007/s11906-019-0976-1
11. Dursun H, Bayazit AK, Cengiz N, Seydaoglu G, Buyukcelik M, Soran M, Noyan A, Anarat A (2007) Ambulatory blood pressure monitoring and renal functions in children with a solitary kidney. Pediatr Nephrol 22:559–564. https://doi.org/10.1007/s00467-006-0389-7
12. Tabel Y, Aksoy Ö, Elmas AT, Çelik SF (2015) Evaluation of hypertension by ambulatory blood pressure monitoring in children with solitary kidney. Blood Press 24:119–123. https://doi.org/10.3109/08037051.2014.992194
13. Westland R, Schreuder MF, van der Lof DF, Vermeulen A, Dekker-van der Meer IM, Bökenkamp A, van Wijk JA (2014) Ambulatory blood pressure monitoring is recommended in the clinical management of children with a solitary functioning kidney. Pediatr Nephrol 29:2205–2211
14. Akkaş BE, Vural GU, Akdemir UÖ, Karabacak Nİ (2012) Demonstration of adaptive functional differences seen in kidneys accompanying a nonfunctioning/hypofunctioning partner, using camera based Tc 99m MAG3 clearance measurement technique. Mol Imaging Radionucl Ther 21:56–62. https://doi.org/10.4274/Mirt.309
15. Lurbe E, Agabiti-Rosei E, Cruickshank JK, Dominiczak A, Erdine S, Hirth A, Invitti C, Litwin M, Mancia G, Pall D, Rascher W, Redon J, Schaefer F, Seeman T, Sinha M, Stabouli S, Webb NJ, Wühl E, Zanchetti A (2016) 2016 European Society of Hypertension guidelines for the management of high blood pressure in children and adolescents. J Hypertens 34:1887–1920. https://doi.org/10.1097/HJH.0000000000001039
16. Schwartz GJ, Haycock GB, Edelmann CM Jr, Spitzer A (1976) A simple estimate of glomerular filtration rate in children derived from body length and plasma creatinine. Pediatrics. 58:259–263
17. Franssen PM, Imholz BP (2010) Evaluation of the Mobil-O-Graph new generation ABPM device using the ESH criteria. Blood Press Monit 15:229–231. https://doi.org/10.1097/mbp.0b013e328339be38
18. Wühl E, Witte K, Soergel M, Mehls O, Schaefer F, German Working Group on Pediatric Hypertension (2002) Distribution of 24-h ambulatory blood pressure in children: normalized reference values and role of body dimensions. J Hypertens 20:1995–2007
19. Seeman T, Patzer L, John U, Dusek J, Vondrák K, Janda J, Misselwitz J (2006) Blood pressure, renal function, and proteinuria in children with unilateral renal agenesis. Kidney Blood Press Res 294:210–215. https://doi.org/10.1159/000095735
20. World Health Organization. Regional Office for the Eastern Mediterranean (2018) How to obtain measures of population-level sodium intake in 24-hour urine samples. World Health Organization. Regional Office for the Eastern Mediterranean. https://apps.who.int/iris/handle/10665/272555. License: CC BY-NC-SA 3.0 IGO
21. Grimes CA, Riddell LJ, Campbell KJ, Beckford K, Baxter JR, He FJ, Nowson CA (2017) Dietary intake and sources of sodium and potassium among Australian schoolchildren: results from the cross-sectional Salt and Other Nutrients. in Children (SONIC) study.

BMJ Open 7:e016639. https://doi.org/10.1136/bmjopen-2017-016639
22. Ozkayar N, Dede F, Ates I, Akyel F, Yildirim T, Altun B (2016) The relationship between dietary salt intake and ambulatory blood pressure variability in non-diabetic hypertensive patients. Nefrologia 36:694–700
23. Tanaka T, Okamura T, Miura K, Kadowaki T, Ueshima H, Nakagawa H, Hashimoto T (2002) A simple method to estimate populational 24-h urinary sodium and potassium excretion using a casual urine specimen. J Hum Hypertens 16:97–103. https://doi.org/10.1038/sj.jhh.1001307
24. Beus E, de Jager RL, Beeftink MM, Sanders MF, Spiering W, Vonken EJ, Voskuil M, Bots ML, Blankestijn PJ, SYMPATHY study group (2017) Salt intake and blood pressure response to percutaneous renal denervation in resistant hypertension. J Clin Hypertens 19:1125–1133. https://doi.org/10.1111/jch.13085
25. Moshfegh AJ, Rhodes DG, Baer DJ, Murayi T, Clemens JC, Rumpler WV, Paul DR, Sebastian RS, Kuczynski KJ, Ingwersen LA, Staples RC, Cleveland LE (2008) The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. Am J Clin Nutr 88:324–332. https://doi.org/10.1093/ajcn/88.2.324
26. O'Halloran SA, Grimes CA, Lacy KE, Campbell KJ, Nowson CA (2016) Dietary Intake and sources of potassium and the relationship to dietary sodium in a sample of Australian pre-school children. Nutrients. 8:496. https://doi.org/10.3390/nu8080496
27. Turkey Dietary Guidelines, Head of Department of Obesity, Diabetes and Metabolic Diseases of the Public Health Agency of the Ministry of Health of Turkey, Ankara 2016; Reference Values of Energy and Nutrients for Turkey pp:175
28. Macumber I (2017) Ambulatory blood pressure monitoring in children and adolescents: a review of recent literature and new guidelines. Curr Hypertens Rep 19:96. https://doi.org/10.1007/s11906-017-0791-5
29. Fujita H, Matsuoka S, Awazu M (2018) Masked isolated nocturnal hypertension in children and young adults. Pediatr Cardiol 39:66–70. https://doi.org/10.1007/s00246-017-1728-0
30. Mackenzie HS, Brenner BM (1995) Fewer nephrons at birth: a missing link in the etiology of essential hypertension? Am J Kidney Dis 26:91–98. https://doi.org/10.1016/0272-6386(95)90161-2
31. eco-Antić A, Paripović D, Kotur-Stevuljević J, Stefanović A, Sćekić G, Miloševski-Lomić G (2012) Renal functional reserve in children with apparently normal congenital solitary functioning kidney. Clin Biochem 45:1173–1177. https://doi.org/10.1016/j.clinbiochem.2012.06.018
32. Wasilewska A, Zoch-Zwierz W, Taranta-Janusz K (2009) Urinary transforming growth factor beta1 in children and adolescents with congenital solitary kidney. Pediatr Nephrol 24:753–759. https://doi.org/10.1007/s00467-008-1045-1
33. Ahmed M, Eggleston D, Kapur G, Jain A, Valentini RP, Mattoo TK (2008) Dimercaptosuccinic acid (DMSA) renal scan in the evaluation of hypertension in children. Pediatr Nephrol 23:435–438. https://doi.org/10.1007/s00467-007-0656-2
34. Hooman N, Isa-Tafreshi R, Mostafavi SH, Hallaji F, Tavasoli A, Otukesh H (2017) The prevalence of hypertension in children with renal scars. Minerva Pediatr 69:200–205. https://doi.org/10.23736/S0026-4946.16.04217-1
35. Cochat P, Febvey O, Bacchetta J, Bérard E, Cabrera N, Dubourg L (2019) Towards adulthood with a solitary kidney. Pediatr Nephrol 34:2311–2323. https://doi.org/10.1007/s00467-018-4085-1
36. Schreuder MF, Langemeijer ME, Bökenkamp A, Delemarre-Van de Waal HA, Van Wijk JA (2008) Hypertension and microalbuminuria in children with congenital solitary kidneys. J Paediatr Child Health 44:363–368. https://doi.org/10.1111/j.1440-1754.2008.01315.x
37. Westland R, Schreuder MF, van Goudoever JB, Sanna-Cherchi S, van Wijk JA (2014) Clinical implications of the solitary functioning kidney. Clin J Am Soc Nephrol 9:978–986. https://doi.org/10.2215/CJN.08900813
38. Schreuder MF (2018) Life with one kidney. Pediatr Nephrol 33:595–604. https://doi.org/10.1007/s00467-017-3686-4
39. He FJ, MacGregor GA (2006) Importance of salt in determining blood pressure in children: meta-analysis of controlled trials. Hypertension. 48:861–869. https://doi.org/10.1161/01.HYP.0000245672.27270.4a
40. Rios-Leyvraz M, Bloetzer C, Chatelan A, Bochud M, Burnier M, Santschi V, Paradis G, Tabin R, Bovet P, Chiolero A (2019) Sodium intake and blood pressure in children with clinical conditions: a systematic review with meta-analysis. J Clin Hypertens (Greenwich) 21:118–126. https://doi.org/10.1111/jch.13436
41. World Health Organization (2011) Strategies to monitor and evaluate population sodium consumption and sources of sodium in the diet: report of a joint technical meeting convened byWHO and the Government of Canada. World Health Organization, Geneva Available at: http://apps.who.int/iris/bitstream/10665/44614/1/9789241501699_eng.pdf?ua=1. Accessed 23 July 2015

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.