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ORIGINAL ARTICLE

Evaluation of bladder capacity in Korean children younger than 24 months: a nationwide multicenter study

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Abstract
Purpose Bladder capacity is an important factor in the diagnosis and treatment of children with voiding dysfunction. The purpose of this study was to define the normal maximal voided volume formula in Korean children younger than 2 years.

Methods We measured the bladder capacities of 151 Korean children between 0 and 24 months of age (83 boys and 68 girls) who did not have clinical voiding dysfunction. The maximal voided volume was determined in all subjects using a 2-day frequency volume chart with a four-hour voiding observation. The largest voided volume for each patient was considered to be the maximal voided volume. Statistical analyses were carried out using linear regression analysis.

Results The maximal voided volume increased with age and weight ($P = 0.0001$). There was no significant difference between males and females ($P = 0.771$). A formula that approximates bladder capacity with respect to age is the following: bladder capacity (ml) = [1.6 × age (months)] + 45 ($t = 8.757$, $P = 0.0001$). A formula that approximates bladder capacity with respect to weight is the following: bladder capacity (ml) = [4.1 × weight (kg)] + 28 ($t = 10.152$, $P = 0.0001$).

Conclusions These formulas may be useful for the diagnosis of abnormal bladder capacity and the evaluation of voiding dysfunction in Korean children younger than 24 months.

Keywords Formularies · Urinary bladder · Children · Korea

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Introduction

The increase in bladder capacity with growth is a crucial step in the development of bladder function. Bladder capacity is an important factor in the diagnosis and treatment of children with voiding dysfunction [1–4]. In parallel to the increase in bladder capacity, the mean voided volume of each micturition increases with age.

In the literature, several studies have demonstrated that maximal voided volume can be accurately estimated and expressed as a function of age with no differences between the sexes. Most prior studies have been performed using cystographic or urodynamic evaluation in older children.

For young infants, this relationship can be expressed as follows [5]: bladder capacity (mL) = 38 + 2.5 × age (months). For older children, Koff's formula is the most widely accepted formula [6]: bladder capacity (ml) = [age (years) + 2] × 30, followed by the similar Hjalmas formula [7]: bladder capacity (mL) = 30 + [age (years) × 30].

Our understanding of voiding patterns and the development of bladder control in healthy Asian infants is still limited. In an attempt to develop a practical formula for the prediction of normal maximal voided volume in Korean children less than 24 months of age who were not yet toilet trained, we performed this study with a four-hour voiding observation in an East Asian sample.

Methods

We observed, followed, and described voiding pattern development in healthy Korean children up to the age where they gained bladder control, focusing mainly on bladder capacity and post-void residual urine volume during the first 2 years of life. Analysis began in 2008 and by 2009 all subjects had reached 24 months of age. The study is part of a larger project that was started in 2008 and was approved by the ethics committees at each participating university.

A total of 151 children, aged 0–24 months (83 boys and 68 girls), without clinical voiding dysfunction, were volunteered for the present study by their parents. Informed consent was obtained from the parents of all children.

Maximal voided volume was determined for all subjects with a 2-day frequency volume chart that used a "four-hour voiding observation" [5]. Each child was observed for 4 h by the parents under the surveillance of an urologist. The normal daily routine adhered to as much as possible, including diaper use. All observations were made during the day. We used a dry weighed diaper that develops a blue line when wetted by urine. Parents checked the diapers every 5–15 min. When voiding occurred, the urine volume was measured by weighing the diaper and the post-void residual urine was determined by ultrasound. Ultrasound was performed by urologists using a 7.5-MHz linear scan probe. In determining the post-void residual urine volume, the bladder was considered to be a rectangular box with all 3 dimensions variable [8].

In this manner, we obtained information regarding the number of voiding episodes, the voided volume, and the post-void residual urine during the 4-hour observation period. Bladder capacity was defined as the maximal sum of the voided volume plus post-void residual urine volume. Interrupted voiding was defined as 2 or 3 voiding episodes at an interval of less than 10 min apart and with the lowest amount of post-void residual urine after the final episode. This phenomenon was considered a single voiding episode, and the volume of urine remaining in the bladder after the final voiding episode was considered the post-void residual urine. The largest voided volume for each patient was considered to be the maximal voided volume. Results were recorded along with information on sleeping and eating. When stool was passed, no attempt was made to measure the concomitant voiding volume. Parents were asked whether the infant strained at voiding and about the quality of the stream. To analyze the voiding pattern and possible changes with time, parents were interviewed regarding physiological, psychological, and social factors and incidents.

Linear regression analysis was used to create the formula. Statistical analysis was carried out using SPSS software (version 13.0; SPSS Inc., Chicago, IL, USA).

Results

Data were obtained from 151 children (83 boys and 68 girls; mean age, 9.9 months; range, 0–24 months). The paired variables of age and bladder capacity are presented in Table 1.

The maximal voided volume increased with age and weight ($P = 0.0001$), and there was no significant difference according to sex ($P = 0.771$).

Linear regression analysis demonstrated the exact relationship between age and bladder capacity. A formula that approximates bladder capacity with respect to age is the following: bladder capacity (ml) = [1.6 × age (months)] + 45 ($t = 8.757$, $P = 0.0001$; Fig. 1). The following formula describes the relationship between bladder capacity and weight: bladder capacity (ml) = [4.1 × weight (kg)] + 28 ($t = 10.152$, $P = 0.0001$; Fig. 2).

Discussion

As opposed to voiding in those with mature bladder function, voiding during infancy is assumed to be an automatic event that is initiated whenever the bladder distention reaches a constant volume. It is mediated via the micturition reflex to the brainstem and back to the bladder without activation of cortical centers [9]. Diagnosis of small, normal, or large bladder capacity is based on suggestive details in the medical history and is confirmed only by comparing the measured capacity with the age-specific normal capacity.

Table 1 Bladder capacity in 151 healthy children without clinical voiding pattern abnormalities

Age (months)	No. Children (boy/girl)	Weight (kg)				Bladder capacity (ml)			
		Mean	Median	SD	Range	Mean	Median	SD	Range
0–3	33 (22:11)	3.8	3.6	1.0	2.5–6.3	45.1	40.1	16.4	20.0–87.0
4–6	19 (12:7)	6.3	5.9	1.9	4.3–10.3	53.1	46.8	19.5	30.4–90.0
7–9	18 (7:11)	7.8	7.7	1.2	5.4–10.2	58.2	58.0	16.7	36.2–93.0
10–12	25 (14:11)	8.8	9.1	2.1	4.1–14.0	63.1	60.0	17.9	33.4–90.0
13–15	19 (5:14)	9.6	9.9	1.3	5.9–11.3	66.9	69.3	15.2	36.0–85.0
16–18	11 (6:5)	10.4	10.5	1.6	8.2–13.0	71.5	67.5	13.9	50.0–90.0
19–21	18 (13:5)	11.4	11.0	1.2	9.5–14.0	76.3	76.0	14.1	50.0–100.0
22–24	8 (4:4)	11.6	11.0	1.1	10.8–14.0	81.3	79.5	17.6	50.0–108.6
Total	151 (83:68)								

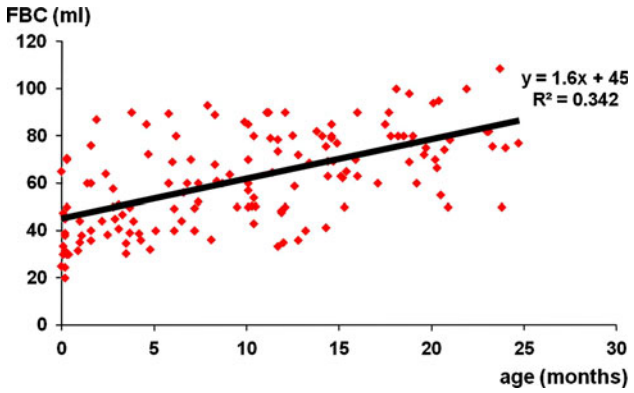

Fig. 1 Age compared with maximal voided volume in Korean children without voiding pattern abnormalities; the maximal voided volume increased with age. Bladder capacity (ml) = [1.6 × age (months)] + 45 (t = 8.757, P = 0.0001)

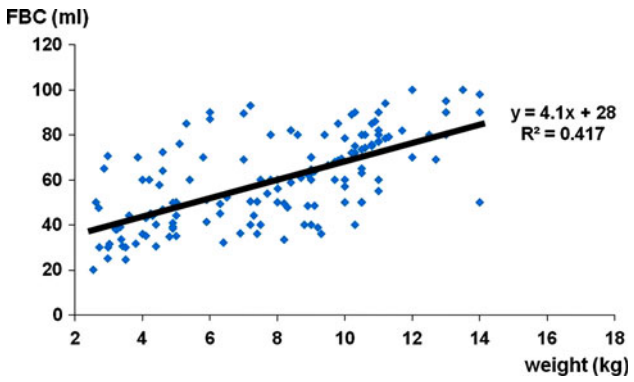

Fig. 2 Weight compared with maximal voided volume in Korean children without voiding pattern abnormalities; the maximal voided volume increased with weight. Bladder capacity (ml) = [4.1 × weight (kg)] + 28 (t = 10.152, P = 0.0001)

Many authors have described various indicators of bladder function in children, such as the number of voiding episodes [5, 7, 9–12], voided volume, bladder capacity [7, 13], post-void residual urine volume [14–18], and arousal state [10, 19]. However, the methods used to measure bladder function such as fluoroscopy [9], suprapubic catheterization [20], and other unnatural circumstances [10] carry the risk of artifactual measurements.

To obtain a more comprehensive picture of the voiding pattern in healthy infants and children of various ages, Jansson et al. [21] used a 4-hour voiding observation that was noninvasive. In the current study, we used a 4-hour voiding observation that was modified to evaluate subjects noninvasively and in as normal a setting as possible. Moreover, the measurement of multiple voided volumes is thought to more closely represent natural conditions with fewer measurement artifacts.

In the current study, we defined the largest volume of urine voided spontaneously during a consecutive 2-day period as the maximal voided volume because the mean voided volume is thought to be influenced by uneven protocol compliance.

Lee et al. [22] previously reported on the normal voiding pattern in healthy Korean children between 0 and 3 years of age. They concluded that the 4-hour voiding observation is an easy, noninvasive method of characterizing the voiding patterns in infants and nontoilet-trained children in Korea. During the first 3 years of life, the number of voiding episodes and residual urine decreased, while the voiding volume and bladder capacity increased. However, the authors did not express this relationship with a mathematical formula. However, the formulas derived in the current study may be a useful guide for the prediction of maximal voided volume in Korean infants.

Hamano et al. [23] reported that Japanese children have somewhat smaller bladder capacities than American children. They suggested the following new formula for Japanese children: bladder capacity (ml) = [25 × (age (years)] + 2. However, they measured the bladder capacities of Japanese children aged 5–15 years.

For young infants, we used the following formula [5]: bladder capacity (ml) = 38 + [2.5 × age (months)]. Although this formula appears useful, it should not be used unquestioningly for children across populations. The formulas derived in the current study, bladder capacity (ml) = [1.6 × age (months)] + 45 and bladder capacity (ml) = [4.1 × weight (kg)] + 28, may be more accurate for Korean children. However, the average maximal voided volume of Korean children is thought to be somewhat different from that of American children. At age 0, our model predicts a bladder capacity of 45 ml, which is larger than the bladder capacity of infants based on a previously reported formula (38 ml) [5]. Moreover, at 24 months, our model predicts a bladder capacity of 83.4 ml, which is smaller than the bladder capacity of infants based on the previously reported formula (98 ml) [5].

In other words, although the bladder capacity of Korean infants increased with age in our study, as in other reports, the rate of increase seems slower when compared to results for American infants. However, we thought this difference was quite small (7–15 ml).

This is the first study to investigate bladder capacity in East Asian children younger than 24 months via four-hour voiding observation. The advantage of our formulas is that they are based on both infant age (months) and weight (kilograms).

The limitation of this study was the relatively small number of participants. However, we collected all of our samples from normal infants and used the four-hour voiding observation, which represents a real-life setting. An additional study with more participants is needed to validate our derived formulas.

In conclusions, the formulas derived in the current study, bladder capacity (ml) = [1.6 × age (months)] + 45 and bladder capacity (mL) = [4.1 × weight (kg)] + 28, may be useful for the diagnosis of abnormal bladder capacity and the evaluation of voiding dysfunction in Korean and Asian children younger than 24 months of age.

Conflict of interest The authors do not have any pertinent commercial relationships, including consultancies, stock ownership or other equity interests, and patents received and/or pending.

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