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Original Article

Uroflowmetric analysis and derivation of nomograms for normal paediatric Indian population between 5 to 15 years of age

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Abstract *Objective:* We aimed to established normal uroflowmetric values and subsequently derived nomograms of maximum flow rate (Q_{max}) and average flow rate (Q_{avg}) against voided volume (VV) in children aged 5—15 years at our institute.
Methods: A total of 440 children underwent uroflowmetric evaluation with no history of urological, renal, psychiatric, or neurological disorder between 5 and 15 years of age. Each subject data regarding Q_{max}, Q_{avg}, VV, time to Q_{max}, and flow time, as well as age, sex, height, and weight were recorded. Of the 440 children, around 300 (68.18%) children could produce a normal flow rate at VV of more than 50 mL. Of the remaining 140 (31.82%) children, 50.00% voided less than 50 mL, and remaining 50.00% had abnormal voiding pattern, staccato or interrupted (21.43% each) and plateau or tower shaped (3.57% each). Cases were divided into two age groups (5—9 years and 10—15 years), and uroflowmetric analysis was done between boys and girls in both age groups to derive nomograms of Q_{avg} and Q_{max}.
Results: Q_{max} and Q_{avg} flow nomograms were plotted for boys and girls. Mean Q_{max} for boys was 16.68 mL/s and for girls 20.69 mL/s. The mean Q_{avg} values were 11.04 mL/s and 8.60 mL/s for girls and boys, respectively. The Q_{max} and Q_{avg} values were higher in girls. There were significant increases in flow rates with increasing age, body surface area, and VV in both sexes.
Conclusions: Nomograms for Q_{max} and Q_{avg} may be a useful tool in evaluation of lower urinary tract disturbances in children.

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1. Introduction

Uroflowmetry is one of the most commonly used screening outpatient tools used in urology. This test gives an objective assessment of voiding dysfunction and has gained wide acceptance as initial screening test for evaluation of voiding dysfunction because it is simple, non-invasive, and relatively inexpensive [1]. Evaluating symptoms of urinary disorders by non-invasive methods like uroflowmetry is not only helpful in planning a rational therapy, but also useful to evaluate any response to therapy [2].

Urinary flow rates depend on voided volume (VV) in a nonlinear fashion [3]. Nomograms are required to see the change in flow rates at different VVs, and the use of nomograms overcomes the danger of referencing flow rates to single VV [4]. Children have small bladders compared to adults, and both their bladder capacity and flow rates increase with age. Therefore, the nomograms made for adult population cannot be applied to children [5]. Literature present is not profuse in this regard for children, and need for more studies on separate age specific pediatric nomograms is warranted.

Uroflowmetry may be applied to neurologically normal children after toilet training or if they are 5 years old, have lower urinary tract symptoms, or have signs [6].

The aim of this study is to 1) establish normal reference values of uroflow rates in children of both sexes for maximum flow rate (Q_{max}) and average flow rate (Q_{avg}) for a wide range of voiding volumes and 2) derive paediatric nomograms for Indian children.

2. Patients and methods

2.1. Study design

A prospective cross-sectional study was conducted from 1st November, 2017 to 31st May, 2018 among 5–15 years old children at our urology department. The study protocol was approved by ethics committee of our hospital (MGM-ECRHS/2017), and conducted in accordance with principles of the Declaration of Helsinki and International Council for Harmonization-Good Clinical Practice. Children who wanted to take part in the project voluntarily and happily and whose parents filled in an informed consent were included in this study. Prior to uroflowmetry, the children were instructed about the course of the examination. They were properly hydrated and test began as the patients reported urinary urgency. They were asked to void in familiar position. All boys voided in a standing position and girls voided in a sitting position on the uroflowmetry device. Uroflowmeter used was Duet Logic G2 (Mediwatch, Swift Valley, Rugby, UK).

Uroflowmetry was performed on 440 children with no history of renal, urological, psychological, or neurological disorder. Uroflow patterns were classified according to the International Children's Continence Society recommendation into five types—bell-shaped, staccato, interrupted, plateau, and tower shaped. Bell-shaped curves were regarded as normal. Staccato curves were continuous curves with sharp peaks and troughs with fluctuations larger than the square root of the Q_{max}, usually suggestive of sphincter overactivity. Interrupted curves were curves separated by a zero-flow rate, suggestive of underactive detrusor. Plateau curves were low amplitude, even flowmetry curves suggestive of anatomical obstruction. Tower-shaped curves were defined as high amplitude, short duration curves.

For each subject, data regarding Q_{max}, Q_{avg}, VV, time to Q_{max} and flow time, as well as age, sex, height, and weight were recorded. Body surface area (BSA) was calculated using Mosteller formula. Boys and girls were divided in two groups each, one aged 5–9 years and the other 10–15 years. Nomograms were constructed between Q_{max} and VV and between Q_{avg} and VV in boys and girls separately.

2.2. Statistical analysis

Categorical variables were presented in number and percentage (%), and continuous variables were presented as mean±SD. Normality of data was tested by Kolmogorov-Smirnov test. If the normality was rejected, non-parametric test was used. Quantitative variables were compared using Mann-Whitney test (when the data sets were not normally distributed) between the two groups. Spearman rank correlation coefficient was used to assess the correlation of various parameters with Q_{max} and Q_{avg}. The quintile regression method was used to establish the percentile levels (5th, 10th, 25th, 50th, 75th, 90th, and 95th). A *p*-value of <0.05 was considered statistically significant. The data were entered in MS EXCEL (Microsoft Corporation, Redmond, WA, USA) and analysis was done using Statistical Package for Social Sciences version 21.0 (IBM Corp, Armonk, NY, USA).

3. Results

A total of 440 uroflowmetry readings were taken of which around 300 (68.18%) children could produce a normal flow rate at VV of more than 50 mL. Of the remaining 140 (31.82%) children, 50.00% voided less than 50 mL, and 50.00% had abnormal voiding pattern, staccato or interrupted (21.43% each), and plateau or tower shaped (3.57% each) (Table 1). Of the total 140 excluded patients, 70

Table 1 Distribution of uroflow pattern in all the evaluated children.

Uroflow pattern	Frequency, *n*	Percentage (%)
Normal flow rate	300	68.18
Abnormal flow rate	140	31.82
Voided volume <50 mL	70	50.00
Staccato	30	21.43
Interrupted	30	21.43
Plateau	5	3.57
Tower	5	3.57

children had void less than 50 mL (aged 5–9 years: 30 boys and 20 girls; aged 10–15 years: 12 boys and eight girls); 30 had staccato pattern (aged 5–9 years: 14 boys and six girls; aged 10–15 years: Seven boys and three girls); 30 had interrupted (aged 5–9 years: 13 boys and seven girls; aged 10–15 years: Nine boys and one girl); five had plateau (aged 5–9 years: Two boys and one girl; aged 10–15 years: One boy and one girl); and five had tower pattern of voiding (aged 5–9 years: One boy and three girls; aged 10–15 years: No boy and one girl) (Table 2). Of the remaining 300, 179 (59.67%) were boys and 121 (40.33%) were girls. The mean age was 10.44±2.25 years for boys and 9.73±2.17 years for girls. The mean BSA in boys was 1.03±0.28 kg/m^2 and 0.99±0.28 kg/m^2 in girls.

The mean Q_{max} values were 16.68 mL/s in boys and 20.69 mL/s in girls, and mean Q_{avg} values were 8.60 mL/s in boys and 11.04 mL/s in girls. The mean VVs were 137.68 mL in boys and 154.43 mL in girls. The various results are shown in Tables 3 and 4. The girls had significantly higher Q_{max} and Q_{avg} values as compared to boys ($p<0.0001$). The rest of the parameters were not significant when compared according to sex (boys and girls). However, on splitting like we did into two age specific groups, it was seen that boys in the age of 5–9 years had significantly longer time to Q_{max} ($p=0.037$), as well as flow time ($p=0.0169$).

It was seen that there were significant differences in Q_{max} and Q_{avg} beyond 10 years of age between boys and girls ($p<0.0001$). However, in children less than 10 years, most of the parameters like Q_{max}, Q_{avg}, time to Q_{max}, and flow time showed significant differences between boys and girls. Hence, the boys and girls were further divided into age-specific groups of 5–9 years and 10–15 years each. On comparing data between age groups, significant differences were seen in all parameters except time to Q_{max}.

In girls, there were positive correlations of Q_{max} with age ($r=0.609$) and BSA ($r=0.711$). Q_{avg} values were not so strongly related with age ($r=0.096$) and BSA ($r=0.207$). In boys, Q_{avg} and Q_{max} increased with age ($r=0.371$ and 0.524, respectively) and with BSA ($r=0.458$ and 0.584, respectively). Both boys and girls showed strong positive correlations of Q_{max} ($r>0.50$) and not of Q_{avg} ($r<0.50$) with respect to age and BSA (Figs. 1 and 2). There were increases in VVs with age and BSA in both groups. There were also strong positive correlations of Q_{max} and Q_{avg} with VVs ($r>0.50$).

Nomograms were presented in centile form and prepared for both boys and girls for Q_{max} and Q_{avg} against VVs (Figs. 3 and 4).

Table 2 Distribution of excluded children according to sex and age.

Variable	Boy, *n* (%)	Girl, *n* (%)	Total, *n* (%)
Voided volume <50 mL			
5–9 years	30 (71.43)	20 (71.43)	50 (71.43)
10–15 years	12 (28.57)	8 (28.57)	20 (28.57)
Staccato pattern			
5–9 years	14 (66.67)	6 (66.67)	20 (66.67)
10–15 years	7 (33.33)	3 (33.33)	10 (33.33)
Interrupted			
5–9 years	13 (59.09)	7 (87.50)	20 (66.67)
10–15 years	9 (40.91)	1 (12.50)	10 (33.33)
Plateau			
5–9 years	2 (66.67)	1 (50.00)	3 (60.00)
10–15 years	1 (33.33)	1 (50.00)	2 (40.00)
Tower pattern of voiding			
5–9 years	1 (100.00)	3 (75.00)	4 (80.00)
10–15 years	0 (0.00)	1 (25.00)	1 (20.00)

Table 3 Mean uroflowmetry parameters by gender.

Uroflowmetry parameter	Boy	Girl	*p*-Value
Q_{max}[a], mL/s	16.68±4.48	20.69±5.08	<0.0001
Q_{avg}[a], mL/s	8.60±2.29	11.04±2.72	<0.0001
VV[a], mL	137.68±64.66	154.43±97.51	0.55
Time to Q_{max}[a], s	5.78±2.20	5.50±1.88	0.23
Flow time[a], s	13.03±4.38	13.31±7.50	0.062

Q_{max}, maximum flow rate; Q_{avg}, average flow rate; VV, voided volume.
[a] Values are presented as mean±SD.

4. Discussion

We have come a long way since Kaufman [7] first used uroflowmeter in children in 1957. The clinical usefulness of uroflow rate has been attenuated by the lack of absolute values defining normal limits. Among the parameters generated from uroflowmetry, Q_{max} was regarded by the International Children's Continence Society as the most relevant variable when assessing bladder outflow [1]. Farhane et al. [8] clearly stated that uroflowmetry parameters are important, but are difficult to interpret due to the lack of normal data in children.

Our study showed mean Q_{max} of 16.68 mL/s in boys and 20.69 mL/s in girls, and mean Q_{avg} of 8.60 mL/s in boys and 11.04 mL/s in girls. Kaufman in 1957 [7] stated the Q_{max} of children aged 4–13 years to be 13–26 mL/s in VVs greater than 150 mL. Scott and McIlhaney [9] measured Q_{max} of 8–29 mL/s at a VV of over 100 mL. The lower limits of normal Q_{max} and Q_{avg} are still unclear in both sexes.

In our study, there were statistically significant higher values of Q_{max} and Q_{avg} in girls as compared to boys ($p<0.0001$). A statistically similar observation was seen by Sibarani et al. [2], with greater values in favour of girls in both Q_{max} and Q_{avg} as well as VVs. This is because of shorter urethral length offering lesser outlet resistance in females. However, Kajbafzadeh et al. [10] observed significant difference in Q_{max}, and not in Q_{avg}, between boys and girls.

Boys aged 5–9 years, in our study, had significantly greater time to Q_{max} and flow time than girls. In the Gutierrez Segura's study [11], mean values of flow time and time to Q_{max} were higher in boys except in the 7- to 8-year-old group with small volumes. Flow time differences were

Table 4 Mean uroflowmetry parameters according to age groups and sexes.

Uroflowmetry parameter	Aged 5–9 years			Aged 10–15 years		
	Boys	Girls	*p*-Value	Boys	Girls	*p*-Value
Q_{max}[a], mL/s	15.12±4.09	19.34±3.48	<0.0001	19.06±4.01	23.57±4.45	<0.0001
Q_{avg}[a], mL/s	8.05±2.06	10.25±1.52	<0.0001	9.43±2.38	11.64±3.31	<0.0001
VV[a], mL	135.32±70.71	116.21±49.24	0.272	141.27±54.46	187.35±115.6	0.058
Time to Q_{max}[a], s	5.47±2.14	4.88±1.64	0.037	6.25±2.22	6.03±1.92	0.645
Flow time[a], s	13.14±4.59	11.98±4.94	0.017	12.87±4.06	14.45±9.03	0.453

Q_{max}, maximum flow rate; Q_{avg}, average flow rate; VV, voided volume.
[a] Values are presented as mean±SD.

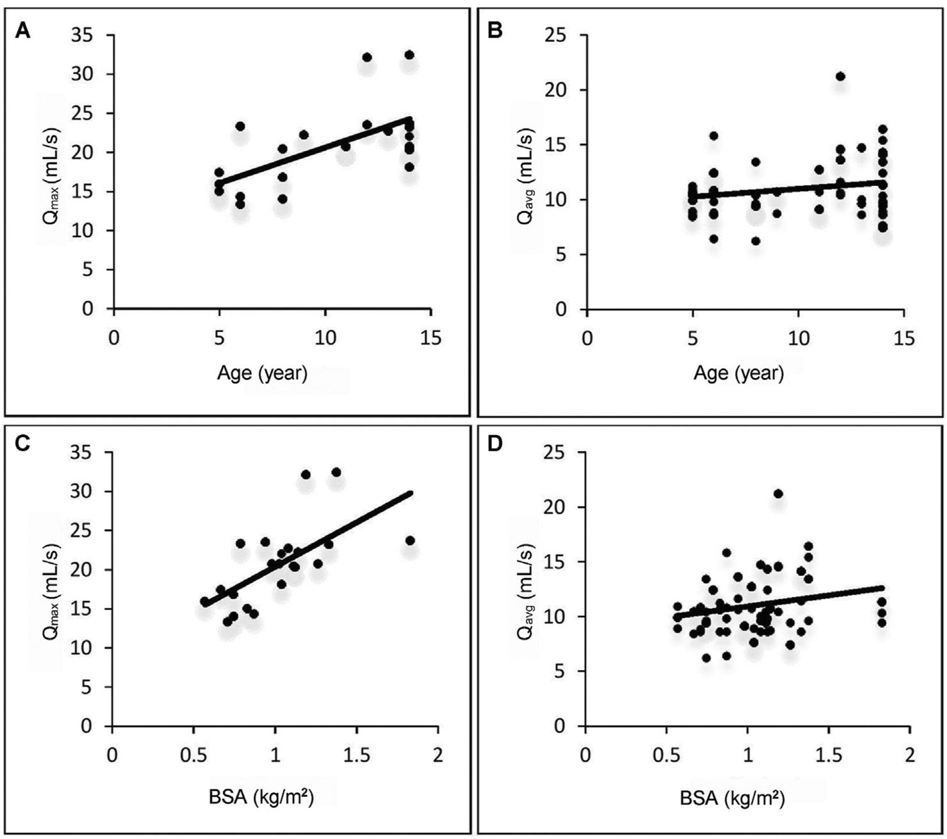

Figure 1 Correlations of Q_{max} and Q_{avg} with age and BSA in girls. (A) Correlation of Q_{max} with age; (B) Correlation of Q_{avg} with age; (C) Correlation of Q_{max} with BSA; (D) Correlation of Q_{avg} with BSA. Q_{max}, maximum flow rate; Q_{avg}, average flow rate; BSA, body surface area.

greater with high volumes. The time to Q_{max} and flow time decreased with age and this may be the reason that similar difference was not seen in older boys. Jensen et al. [12] also inferred that the micturition time was shorter in the girls and decreased with advancing age. As age advances, the Q_{max} of boys and girls matched to that of adults, and girls reached Q_{max} faster than boys.

There was positive correlations with age in all parameters except time to Q_{max} and therefore, it was decided during the course of study that the subjects be divided into two groups of 5–9 years and 10–15 years of age. Gupta et al. [13] in 2013 had similar observations noting significant changes after 11 years of age. They clearly concluded that as age and VV had significant correlation with uroflowmetry parameters, they should be taken into consideration when studying uroflow in children.

Like our study, Kumar et al. [4] concluded that Q_{max} is more significantly correlated with age and VV than Q_{avg}. A strong relationship between Q_{max} and Q_{avg} values with VV was seen. A similar strong correlation was found by

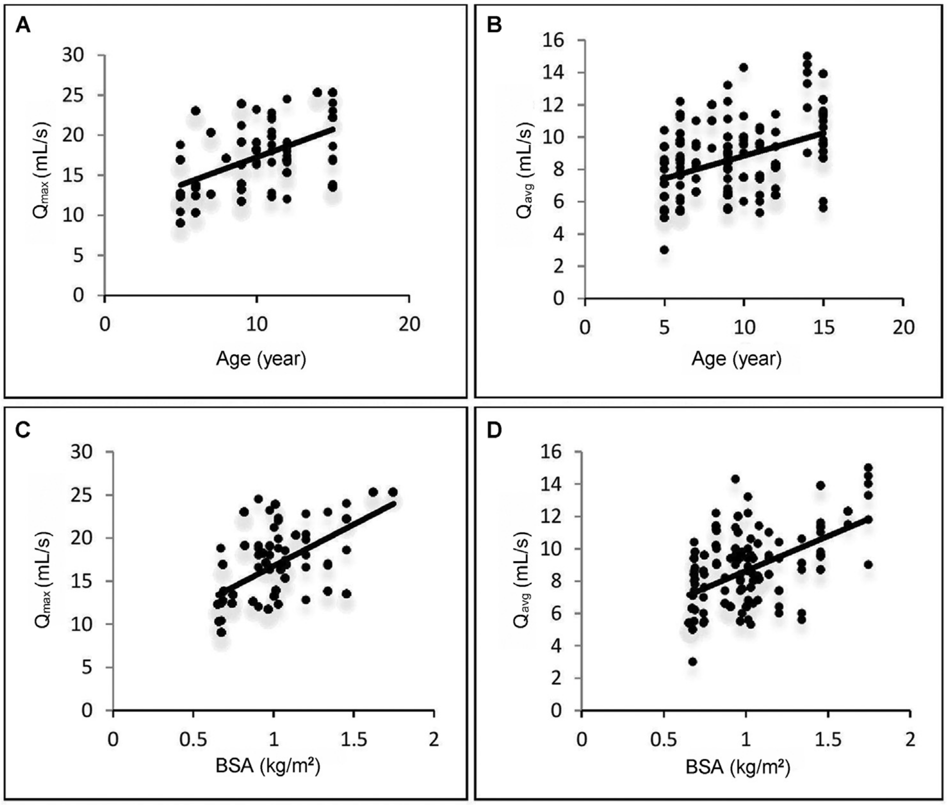

Figure 2 Correlations of Q_{max} and Q_{avg} with age and body surface area in boys. (A) Correlation of Q_{max} with age; (B) Correlation of Q_{avg} with age; (C) Correlation of Q_{max} with BSA; (D) Correlation of Q_{avg} with BSA. Q_{max}, maximum flow rate; Q_{avg}, average flow rate; BSA, body surface area.

Siroky et al. [3]. Uroflowmetry nomograms were drawn based on these positive correlations between VV and flow rates.

The use of nomograms avoids the dangers of referencing flow rates to single VV. A particular Q_{max} might fall just inside the fifth centile curve at 200 mL VV, although well outside the same curve at 400 mL. The normality of these flow rates may then be interpreted quite differently at these two VVs [9].

Siroky and colleagues [3] were among the first to develop a nomogram that allowed uroflow to be corrected for VV. They also applied their nomogram to evaluation of men with bladder outlet obstruction. The use of statistical transformation by Gierup [14] and Jensen et al. [12] overcame the problems created by inaccuracy when untransformed standard deviations were used. Churchill et al. [15] in 1987 first created nomograms of Q_{max} for boys aged 8—14 years using regression analysis to fit functions to the data. Similarly, normal curves Q_{max} and Q_{avg} of girls and boys for three different body surfaces were presented in centile form by Szabo and Fegyverneki [16] in their famous Miskolc nomograms in 1995. Both these nomograms were based on BSAs. However, the study was not reproducible by Yang et al. [17] and they clearly concluded that age and gender specific nomograms would be clinically more important. They made the Tzu-Chi age and gender specific nomograms for single and dual Q_{max} for clinical practice.

There are racial differences described in African and Caucasian women for urodynamic parameters [18]. Studies constructing pediatric nomograms are very less around the world and even lesser in India. Moreover in this region, this is the first study. Therefore, considering the diverse races in our country, such a study will contribute strongly to normal parameters and nomograph plotting for assessing pediatric population.

We had a significant number of children who voided less than 50 mL and had abnormal voiding patterns (31.82%). Hence, majority of children probably were advised for further investigation and treatment options. To avoid this, Yang et al. [17] have advised two or more uroflow tests for children who voided less than 50 mL or had abnormal voiding patterns.

Our study has certain limitations. Firstly, the sample size could have been more and the duration of study was also limited. Secondly, we have taken only single uroflow reading for evaluation. We believe that if children are properly explained and comfortable, they will void without any hesitation as compared to adults. As we selected

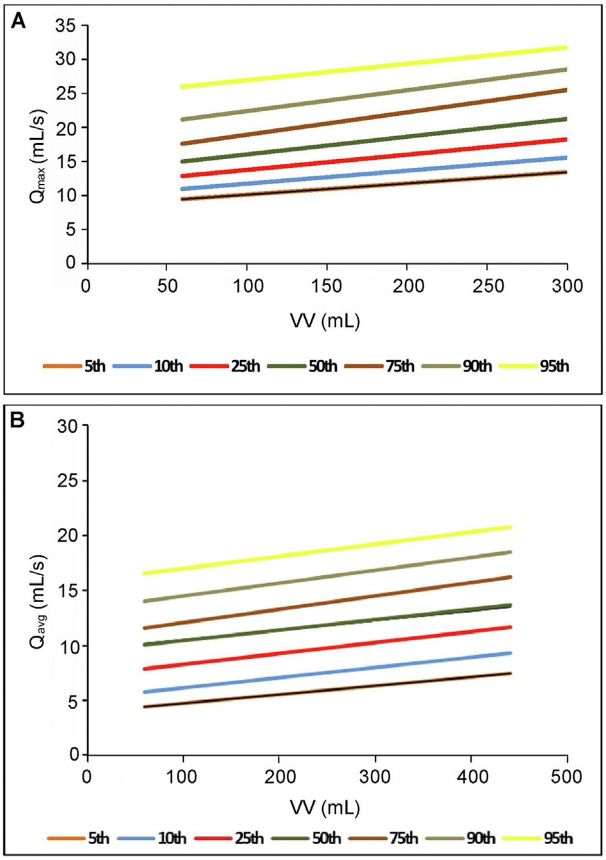

Figure 3 Nomograms for Q_{max} and Q_{avg} in girls aged 5–15 years. (A) Nomogram for Q_{max} rate in girls age 5–15 years; (B) Nomogram for Q_{avg} in girls aged 5–15 years. The quintile regression method was used to establish the percentile levels (5th, 10th, 25th, 50th, 75th, 90th, and 95th). Q_{max}, maximum flow rate; Q_{avg}, average flow rate; VV, voided volume.

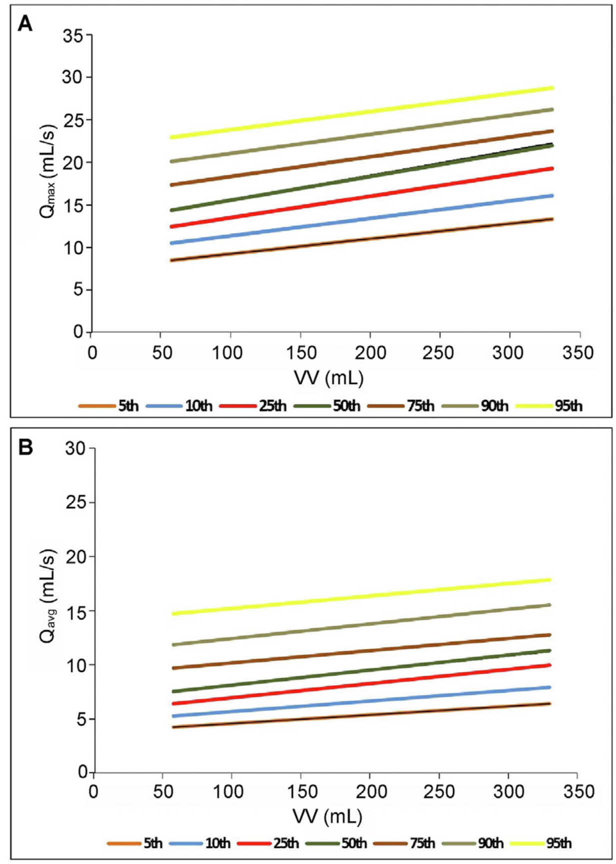

Figure 4 Nomograms for Q_{max} and Q_{avg} in boys aged 5–15 years. (A) Nomogram for Q_{max} flow rate in boys aged 5–15 years; (B) Nomogram for Q_{avg} in boys aged 5–15 years. The quintile regression method was used to establish the percentile levels (5th, 10th, 25th, 50th, 75th, 90th, and 95th). Q_{max}, maximum flow rate; Q_{avg}, average flow rate; VV, voided volume.

asymptomatic children and requested them to participate, it was difficult to make them void twice for the study. Study by Gierup [14] showed no significant difference in the flow rates between the first and second uroflow records and suggested that only one reading was sufficient for evaluation. Accordingly, most of the studies conducted have taken single readings of uroflowmetry [2,4,10,13,16]. Thirdly, we excluded children who voided less than 50 mL of urine for all ages, though the bladder capacity would differ according to the age of the child. Ideally, the uroflow interpretation should be done at an optimal bladder capacity *i.e.*, VV between 50% and 100% of the expected bladder capacity, as advised by Yang et al. [6]. The uroflowmetry curve can show changes if the VV is less than 50% of the expected bladder capacity [19]. Mattsson et al. [20] also noted an interesting finding that most voids during the day were considerably smaller than the maximum VV. Single voids below 50% of the maximum VV were observed in more than 80% of children. It was observed that there was an intra-individual and interindividual variation in each VV in healthy children.

5. Conclusion

The nomograms derived from this study, especially for Indian paediatric population, can be used not only as an important screening tool, but also for assessing response to treatment. Girls have greater Q_{max} and Q_{avg} than boys. Q_{max} increases with age, BSA and VV. The results will add to the literature of this already scantily researched topic.

Author contributions

Study concept and design: Abhay D. Mahajan, Martand G. Patil.
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Data analysis and interpretation: Abhay D. Mahajan, Prashant P. Darakh.
Drafting of manuscript: Lakshman P. Singh, Abhay D. Mahajan.
Critical revision of the manuscript: Abhay D. Mahajan, Martand G. Patil, Sandeep T. Bathe.
Final approval of the version: Abhay D. Mahajan.

Conflicts of interest

The authors declare no conflict of interest.

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