ARTICLE

Growth and Development of Male External Genitalia

A Cross-sectional Study of 6200 Males Aged 0 to 19 Years

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Objective: To provide estimates of normal variations in penile measurements and testicular volumes, and to establish reference ranges for clinical use.

Design: Cross-sectional, population-based study.

Setting: Schools, kindergartens, and child care centers in different parts of Bulgaria.

Participants: A population of 6200 clinically healthy white males aged 0 to 19 years.

Interventions: The study physician chose schools, kindergartens, and child care centers randomly and examined children at random until he reached the required number. Each of the 20 age groups (age range, 0-19 years) had an equal number of males (ie, 310).

Main Outcome Measures: The mean (SD) values and fifth, 50th, and 95th percentiles of height (Siber Hegner anthropometer), weight (beam balance), testicular volume (Prader orchidometer), penile length (rigid tape), and penile circumference (measuring tape) from birth to 19 years of age.

Results: Testes did not show any increase in size until the onset of puberty at age 11 years, whereas penile growth was gradual after birth. However, both penile and testicular development demonstrated peak growth from 12 to 16 years of age, which coincided with the maximal male pubertal growth spurt. Data indicate an earlier pubertal development for this study population than that for a similar population several decades ago. Significant differences between urban and rural populations regarding penile length were also noticed.

Conclusions: Our study provides the contemporary reference range values for height, weight, testicular volume, and penile length and circumference of males aged 0 to 19 years. Our data show that, even by the end of 20th century, there is still some acceleration of male pubertal development. For the first time are reported somatic differences in genitalia within a population between urban and rural representatives.

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ASSESSMENT OF GROWTH OF external genitalia is an essential component of health surveillance in pediatric and adolescent populations. Because of rapid changes and great interindividual differences at the time of puberty, a universal reference range of hormone values cannot be established at this period of life. Therefore, anthropometric data are quite useful for clinical evaluation and prognosis. Medical consultations related to the size of the penis and testicles are quite common at pediatric, endocrinology, and urology clinics because of the associated medical, sexual, psychological, and social concerns. Aberrant growth of male external genitalia may be the first sign of an underlying biophysiologic or psychosocial illness.[1]

It is important to establish reference ranges of penile length and circumference and of testicular volume when considering significant variation in the general population. Although tables and growth charts exist that provide reference ranges for the weight and height of children and adolescents, data on penile and testicular measurements are available only for some populations. In the latter half of the 20th century, among the studies conducted in Europe and the United States,[2-10] some investigators discussed large interindividual variations in the onset and duration of normal puberty.[5,6]

To establish reference ranges of various anthropometric measurements, especially for the male external genitalia, we conducted, to the best of our knowledge, the largest cross-sectional, population-based study on male sexual growth and development.

METHODS

Our study was approved by the institutional review board of the Medical University of Sofia,

Bulgaria. In a cross-sectional, population-based study, we examined 6200 white males aged 0 to 19 years from the capital city of Sofia and from 4 other regions of Bulgaria. In the 4 regions, an equal number of males were selected from urban and rural areas. The towns and villages were chosen at random, and they are representative of the country's population and structure. Informed consent was obtained from these males and/or their parents. All 6200 males were clinically examined by only 1 physician, who is an endocrinologist (P. K.). In each area, the physician chose schools, kindergartens, and child care centers randomly and examined males at random until he reached the required number. Each of the 20 age groups (age range, 0-19 years) consisted of an equal number of males (ie, 310), and these males were included in their respective age groups according to their age at the time of examination. All 6200 males were clinically healthy at the time of examination, and they were from various strata of society.

The protocol of the clinical examination comprised the following somatometric parameters: height (in centimeters), weight (in kilograms), testicular volume (in milliliters), penile length (in centimeters), and penile circumference (in centimeters). The Prader orchidometer was used to measure the volume of the testicles; data are given separately for the left and right testicles. It has been demonstrated that measurements of testicular volume determined by use of the Prader orchidometer, especially when used by an experienced examiner, correlate highly with those determined by use of ultrasonography.[11-13] Moreover, in a large population-based study like our own, use of ultrasonography to measure the volume of testicles is not practical or feasible. The height of these males was measured with an anthropometer (Siber Hegner; Zurich, Switzerland). The weight of these males was measured by use of a beam balance, with each male wearing only pants and a shirt. The stretched penile length in the flaccid state was measured with a rigid tape from the pubopenile skin junction to the top of the penis, excluding the prepuce under maximal but not painful extension. The penile circumference was measured at the base of the penis (close to the pubis) with a measuring tape. For obese males, the abdominal adipose tissue was shifted manually to one side to measure penile length and circumference.

Statistical evaluation of the data was performed by use of SPSS version 11.0.1 statistical software (SPSS Inc; Chicago, Illinois). Descriptive statistics were used to report the data in the form of mean (SD) values and of percentiles (ie, fifth, 50th, and 95th percentiles). The percentiles of greatest clinical importance for anthropometric measurements were used to plot graphs showing the distribution for all ages. The Kolmogorov-Smirnov test was used to determine the normality of the distribution. The nonparametric Mann-Whitney test was used to analyze whether there was any change in the parameters between rural and urban populations. The *t* test was used whenever appropriate. $P < .05$ was considered to be statistically significant.

RESULTS

The mean (SD) values and 5th, 50th, and 95th percentiles of height (in centimeters), weight (in kilograms), penile length (in centimeters), penile circumference (in centimeters), and right and left testicular volumes (in milliliters) are shown in the **Table**. Growth curves were drawn using the growth parameters of external genitalia in the form of percentiles by age (**Figure**).

The males in our study underwent characteristic changes in height and weight during their growth and development. The growth was intensive, especially at 12 to 14 years of age. In comparison, the increase in weight was more uniform until 12 years of age and ranged from 1.85 to 4.34 kg among the different age groups. Among 12- and 13-year-old boys, the difference increased sharply to 7.12 kg and thereafter diminished gradually to 0.22 kg after 17 years. For boys aged 11 to 16 years, the body mass index had a significant positive correlation with testicular volume, penile measurements, and pubic hair growth. However, in boys aged 17 to 19 years, the body mass index had only a weakly positive correlation with testicular volume and pubic hair growth but not penile measurements (data not shown).

The testes begin to increase in size at the ages 8 to 9 years. Before the onset of puberty, the growth of testes was minimal: from a mean (SD) testicular volume of 1.02 (0.19) mL at age 1 year to 1.83 (1.31) mL at age 10 years. There was no significant difference in testicular volume between children in the first 6 months of life and children aged 6 months to 1 year. A marked increase in testicular volume was observed after 10 years of age. The rate of growth, as depicted by the slope of the growth curve, was more pronounced from 11 to 15 years of age. After 16 years of age, testicular growth slowed down, and the changes were small (Figure, A). The pubic hair (Tanner stage II) first appeared at age 12 years, when the mean (SD) testicular volume was 5.20 (3.45) mL. Tanner stage V was reached at age 15 years, when the mean (SD) volume of testes was 12.73 (3.98) mL.

Although penile length and circumference demonstrated gradual growth, the period of maximum growth was approximately 12 to 16 years of age. Until age 10 years, the mean penile length remained less than 5 cm, and mean (SD) penile circumference reached 5.52 (0.71) cm in the 10-year-old age group (Figure, B and C). Whereas the increase in testicular volume at ages 11 to 16 years was more steep, the changes in penile length and circumference were much more uniform. An increase in penile length was observed 1 year after the enlargement of testes, and the changes ceased to be significant after 16 years. The penile length increased simultaneously with penile circumference.

A modest though significant difference was found with respect to penile size between urban and rural populations. On average, the children from rural regions were born with longer penises than their urban counterparts (mean [SD] length, 3.64 [0.49] cm vs 3.49 [0.49] cm at age 1 year; $P < .01$). During the course of pubertal development, the disparity in penile length continued to be significant (mean [SD] length, 9.72 [1.17] cm vs 9.29 [1.04] cm at age 19 years; $P < .01$).

COMMENT

There is no general agreement on the normal values of penile and testicular size at each age group or on the average timing of various pubertal signs. It is unclear whether there might be specific differences between ethnic groups, between populations from different parts of the world, and even between generations within 1 ethnic group or country.[14-16] Assessment of male sexual development includes the precise measurement of penile length and/or circumference and testicular volume to compare with age-matched nor-

Table. Indices of Growth and Sexual Development in 6200 Males Aged 0 to 19 Years From Bulgaria, Stratified by Age Group

Age, y	Height, cm	Weight, kg	Penile Length, cm	Penile Circumference, cm	Volume of Right Testis, mL	Volume of Left Testis, mL
0						
Mean (SD)	66.02 (7.62)	7.59 (2.23)	3.55 (0.46)	4.38 (0.45)	0.99 (0.19)	1.01 (0.11)
P50	67.00	7.70	3.50	4.50	1.00	1.00
P5-P95	53.00-77.00	4.00-10.94	2.80-4.40	3.50-5.00	1.00-1.00	1.00-1.00
1						
Mean (SD)	80.86 (5.22)	11.36 (1.76)	3.75 (0.54)	4.51 (0.49)	1.03 (0.19)	1.02 (0.20)
P50	80.60	11.27	3.70	4.50	1.00	1.00
P5-P95	73.00-89.73	8.53-14.36	3.00-4.60	3.50-5.20	1.00-1.00	1.00-1.00
2						
Mean (SD)	91.50 (5.31)	14.07 (1.94)	3.87 (0.55)	4.53 (0.51)	1.05 (0.28)	1.06 (0.26)
P50	91.50	14.00	4.00	4.50	1.00	1.00
P5-P95	83.00-99.73	11.00-17.54	3.00-4.80	3.70-5.40	1.00-2.00	1.00-2.00
3						
Mean (SD)	99.00 (4.46)	15.92 (1.88)	4.03 (0.60)	4.64 (0.56)	1.12 (0.34)	1.1 (0.33)
P50	99.00	16.00	4.00	4.70	1.00	1.00
P5-P95	91.67-106.05	13.00-19.00	3.00-5.00	3.70-5.50	1.00-2.00	1.00-2.00
4						
Mean (SD)	105.79 (4.84)	17.92 (2.47)	4.26 (0.67)	4.76 (0.63)	1.12 (0.37)	1.12 (0.35)
P50	105.95	17.50	4.20	4.90	1.00	1.00
P5-P95	97.11-114.45	14.50-23.00	3.20-5.30	3.70-5.60	1.00-2.00	1.00-2.00
5						
Mean (SD)	112.51 (5.24)	20.52 (3.43)	4.39 (0.62)	4.86 (0.62)	1.15 (0.37)	1.12 (0.37)
P50	112.35	20.00	4.50	5.00	1.00	1.00
P5-P95	104.28-120.89	16.00-26.94	3.46-5.50	3.90-6.00	1.00-2.00	1.00-2.00
6						
Mean (SD)	118.38 (5.37)	22.54 (3.52)	4.53 (0.60)	5.00 (0.55)	1.15 (0.40)	1.15 (0.39)
P50	119.00	22.00	4.50	5.00	1.00	1.00
P5-P95	110.00-127.09	18.50-28.89	3.50-5.50	4.00-5.94	1.00-2.00	1.00-2.00
7						
Mean (SD)	125.27 (6.33)	25.50 (5.24)	4.66 (0.68)	5.20 (0.62)	1.21 (0.45)	1.20 (0.44)
P50	125.10	24.50	4.60	5.20	1.00	1.00
P5-P95	115.00-135.28	19.00-36.00	3.56-6.00	4.06-6.20	1.00-2.00	1.00-2.00
8						
Mean (SD)	130.07 (6.27)	28.62 (6.20)	4.71 (0.67)	5.26 (0.60)	1.26 (0.49)	1.27 (0.46)
P50	130.40	27.50	4.60	5.30	1.00	1.00
P5-P95	120.26-140.45	21.00-40.72	3.70-6.00	4.10-6.30	1.00-2.00	1.00-2.00
9						
Mean (SD)	136.02 (6.46)	32.13 (7.43)	4.66 (0.67)	5.34 (0.66)	1.39 (0.63)	1.37 (0.59)
P50	136.05	30.00	4.60	5.40	1.00	1.00
P5-P95	125.00-146.50	24.00-44.72	3.61-5.89	4.20-6.44	1.00-2.00	1.00-2.00

(continued)

mal data.[17] The consensus is that measuring of testicular volume and penile length and circumference is more objective for evaluation of sexual development rather than the genital stages introduced by Marshall and Tanner.[18] Because of the absence of adequate reference data for Bulgaria and even for eastern and southern Europe, we conducted this cross-sectional, population-based study using the appropriate method: the sample size was large enough in each age group, and all the males were examined by a single physician to reduce interobserver bias.

The sizes of testes and the penis, as well as the stage of pubic hair, are crucial indices for male sexual development. According to Prader,[19] an increase in testicular volume greater than 2 mL is considered the first perceptible sign of oncoming puberty. In our study, the beginning of pubertal development was marked by an increase in testicular volume at age 11 years (Table). We have seen that with a testicular volume of 5 mL at age 12 years, the pubic hair was already at Tanner stage II. This indicates that the growth of testes tends to start before pubic hair development, which is in agreement with other studies.[8,20] This finding was also confirmed in our longitudinal study of pubertal development in boys aged 7 to 14 years (unpublished data). We could not find any significant differences in testicular volume between children in the first half of their first year of life and children in the second half of their first year of life. Hence, we could not confirm any previous suggestions of a transient increase in testicular volume or of the so-called minipuberty during the first year of life.

According to Tanner and Whitehouse,[21] a mean testicular volume of 12 mL indicates that an adolescent is proceeding toward a late stage of pubertal development. The boys investigated in our study reached this testicular size, on average, at the age of 15 years; after that age, testicular augmentation continued, but with smaller dif-

Table. Indices of Growth and Sexual Development in 6200 Males Aged 0 to 19 Years From Bulgaria, Stratified by Age Group (continued)

Age, y	Height, cm	Weight, kg	Penile Length, cm	Penile Circumference, cm	Volume of Right Testis, mL	Volume of Left Testis, mL
10						
Mean (SD)	141.78 (6.96)	36.47 (9.04)	4.84 (0.75)	5.52 (0.71)	1.84 (1.35)	1.82 (1.27)
P50	141.55	34.00	4.80	5.50	2.00	2.00
P5-P95	129.82-152.63	27.00-53.00	3.66-6.00	4.50-6.50	1.00-4.00	1.00-4.00
11						
Mean (SD)	146.48 (6.60)	39.19 (8.43)	5.10 (0.88)	5.81 (0.84)	3.16 (2.08)	3.09 (2.05)
P50	146.55	37.75	5.00	5.80	3.00	2.00
P5-P95	135.46-158.89	28.28-56.22	4.00-6.90	4.56-7.24	1.00-6.90	1.00-6.00
12						
Mean (SD)	151.42 (7.74)	43.95 (10.16)	5.86 (1.44)	6.59 (1.31)	5.30 (3.51)	5.09 (3.39)
P50	150.60	42.00	5.60	6.40	4.00	4.00
P5-P95	139.56-165.09	30.78-62.45	4.00-8.80	4.76-9.04	1.00-12.00	1.00-12.00
13						
Mean (SD)	158.91 (8.74)	51.07 (12.54)	7.11 (1.65)	7.70 (1.52)	8.36 (4.35)	8.02 (4.21)
P50	159.10	48.50	7.25	7.90	8.00	8.00
P5-P95	145.37-173.40	34.00-75.45	4.50-9.50	5.10-10.00	2.00-15.00	2.00-15.00
14						
Mean (SD)	165.43 (8.00)	56.73 (12.21)	8.04 (1.28)	8.65 (1.20)	10.99 (3.86)	10.37 (3.92)
P50	166.00	55.75	8.00	8.80	10.00	10.00
P5-P95	150.76-177.50	39.00-80.00	5.56-10.00	6.50-10.50	5.00-20.00	4.00-15.00
15						
Mean (SD)	170.42 (7.79)	61.62 (11.33)	8.69 (1.16)	9.10 (1.08)	13.03 (4.05)	12.42 (3.91)
P50	170.35	60.00	8.70	9.00	12.00	12.00
P5-P95	156.67-182.83	45.28-83.45	7.00-10.50	7.20-11.00	8.00-20.00	6.00-20.00
16						
Mean (SD)	172.24 (6.20)	64.97 (11.28)	9.01 (1.08)	9.26 (0.97)	14.05 (4.04)	13.33 (3.55)
P50	171.85	63.25	9.00	9.25	15.00	12.00
P5-P95	162.00-182.94	50.00-85.00	7.20-11.00	7.66-10.94	8.00-20.00	8.00-20.00
17						
Mean (SD)	174.14 (6.15)	69.14 (11.37)	9.15 (1.07)	9.46 (0.95)	14.58 (4.22)	14.04 (4.15)
P50	173.7	68.00	9.00	9.50	15.00	13.50
P5-P95	164.27-185.29	54.28-90.00	7.41-11.00	8.00-11.10	10.00-25.00	8.00-22.25
18						
Mean (SD)	174.15 (6.23)	69.82 (10.53)	9.07 (1.05)	9.23 (0.94)	15.30 (4.37)	14.46 (4.00)
P50	174.35	69.00	9.00	9.20	15.00	15.00
P5-P95	164.46-184.51	53.78-88.45	7.50-11.00	7.96-11.00	10.00-25.00	10.00-20.00
19						
Mean (SD)	173.53 (6.49)	70.39 (9.55)	9.46 (1.12)	9.67 (0.91)	16.56 (4.39)	15.99 (4.52)
P50	173.50	69.50	9.50	9.50	15.00	15.00
P5-P95	163.17-184.00	57.00-89.45	8.00-11.00	8.20-11.35	10.00-25.00	10.00-25.00

Abbreviations: P5, fifth percentile; P50, 50th percentile; P95, 95th percentile.

ferences between various age groups. After 16 years of age, the difference between various age groups was not significant, which indicates that puberty has more or less been completed. However, our Table and Figure, A, clearly demonstrate differences between the fifth and 95th percentiles. Therefore, the relatively large variations in the timing of puberty should always be kept in mind when evaluating growth and development in healthy populations. The testes of a 19-year-old male have the volume typical for maturity (mean [SD] volume, 16.28 [4.46] mL; fifth to 95th percentile, 10.00-5.00 mL) (Table). Therefore, we regard the data on the 19-year-old males in our study to be equivalent to data on men who are in their reproductive age.

Interestingly, our study demonstrated that, at least in Bulgaria, the average penis size is bigger at birth and also at the end of sexual maturation in rural populations compared with urban populations. However, this difference is small (ie, less than 0.5 cm), and at present, it is not clear whether it is of any clinical significance. The reasons are unknown but may be attributed to genetic and environmental factors.

We have compared our data with the results of a cross-sectional study from the 1970s,[20] which was conducted using similar methods (ie, use of the Prader orchidometer, the Tanner stages for pubic hair growth, and an analogous measurement of flaccid penis length and circumference) and, by coincidence, in one of the same towns studied by us. The authors of the study reported that a leap forward in sexual development occurs at 13 to 16 years of age.[20] However, our study indicated that this spurt takes place at 12 to 15 years of age. We have found that the mean testicular volume of boys aged 11, 12, 13, 14, and 15 years was significantly larger than the mean testicular volume of boys of the same age in the cross-sectional study from the 1970s in our country ($P<.001$).[20] However, at ages 16 to 17 years, the difference became statistically nonsignificant. The same was true for pe-

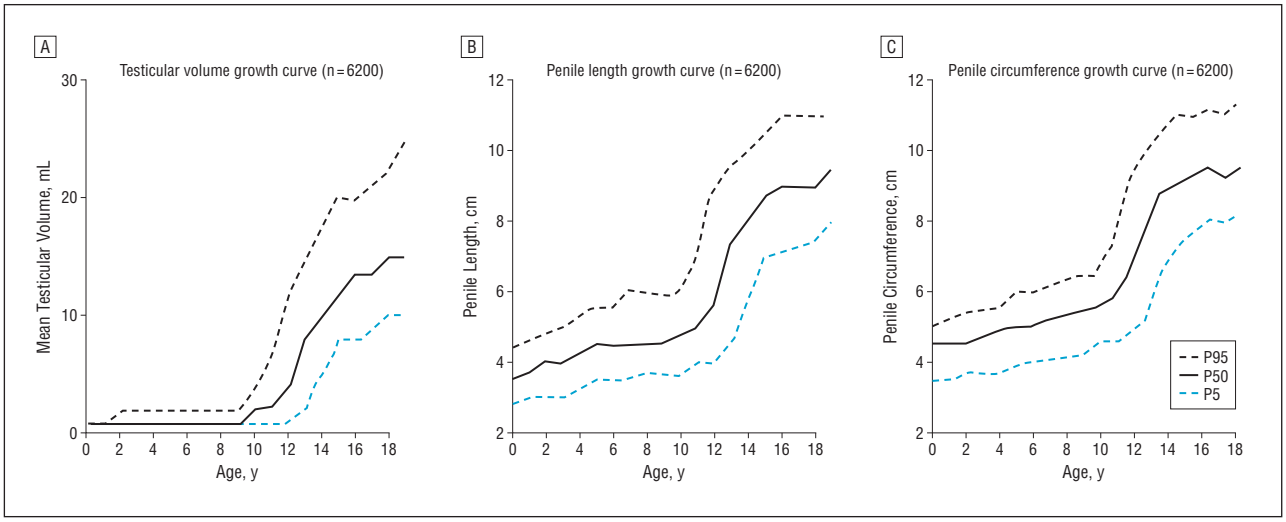

Figure. Growth curves demonstrating various growth parameters of external genitalia in males aged 0 to 19 years from the capital city of Sofia and from 4 other regions of Bulgaria. P5 indicates fifth percentile; P50, 50th percentile; and P95, 95th percentile.

nile length. In our study population, the penis was longer in every age group, except for ages 17 years and older. Our data indicate earlier pubertal development in Bulgaria, compared with the Bulgarian population several decades ago. Our data show that, even by the end of the 20th century, there is still some acceleration in male pubertal development. In a recent longitudinal study on girls aged 7 to 14 years, which was conducted by our group,[22] we presented data that showed evidence of a 1-year acceleration in the age of menarche, compared with data from 1950s.

Previous studies from the United States and the United Kingdom have shown that the beginning of male pubertal development starts at ages 9.7 to 14.1 years and that this development is completed by ages 13.7 to 17.9 years, which is a little later than that in the boys included in our observation.[6,10,23] However, the study by Marshall and Tanner[6] was not absolutely representative of the British population. Moreover, the different stages of development were determined by use of photographs, which is not an appropriate method for determining the appearance of pubic hair and its early development.[5] Zachmann et al[8] reported that 13-year-old boys in Switzerland had a mean (SD) testicular volume of 8.0 (4.4) mL, which is not significantly different from our results at this age. Data from the National Health and Nutrition Examination Survey III,[9] which was conducted from 1988 to 1994 in the United States, demonstrated that the median age for the onset of genital development was approximately 9.2 years for non-Hispanic black boys, 10.0 years for non-Hispanic white boys, and 10.3 years for Mexican American boys, whereas the median age for the onset of pubic hair development was approximately 11.2 years for non-Hispanic black boys, 12.0 years for non-Hispanic white boys, and 12.3 years for Mexican American boys.[9,23] In 1950, Marshall and Tanner[6] started a 15-year longitudinal study on 228 British boys and reported that the onset of sexual development was between 9.5 and 13.5 years in 95% of boys. According to Lee,[10] the beginning of puberty is at ages 9.7 to 14.1 years, and the end of puberty is at ages 13.7 to 17.9 years. Tanner stage II pubic hair was observed at a mean (SD) age of 12.3 (0.8) years mainly in the white boys. This stage of pubic hair (Tanner II) appeared in the boys investigated by us at a median age of 12 years, which corresponds with data from the National Health and Nutrition Examination Survey III.[9] Data from Sweden showed that the mean age for Tanner II stage pubic hair was 12.7 years.[2]

When analyzing the results from various studies on puberty from different parts of the world, it may be concluded that the sequence of events underlying this development is the same but that the timing and rate differ among different populations, likely attributable to genetic, environmental, nutritional, and educational factors.

The measurement of external genitalia (ie, testicular volume, penile length, and penile circumference) is very important in clinical practice. Notwithstanding contemporary possibility for hormonal assessment, it remains an easy and cheap method for determining pubertal development and for finding pathological disturbances in the sexual maturation of boys. There is a lack of well-defined, rigid norms for serum values of testosterone and gonadotrophins during the first 2 decades of life. On the contrary, norms for height, weight, testicular volume, penile length and circumference, and pubic hair are easy to use in anthropometric studies and for clinical practice.

In conclusion, to the best of our knowledge, this is the largest cross-sectional, population-based study on male growth and sexual development conducted by a single investigator. Our results demonstrated that testicles do not show any increase in size until the onset of puberty, whereas penile growth is gradual since birth. However, both the penis and the testes demonstrated peak growth between the ages of 12 and 16 years, which coincided with the pubertal growth spurt. Longitudinal studies are needed to corroborate these findings. Furthermore, we have provided data on the height, weight, testicular volume, and penile length and circumference of males aged 0-19 years (Table), which can serve as a useful reference source for physicians in diverse clinical practices.

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> The young always have the same problem—how to rebel and conform at the same time. They have now solved this by defying their parents and copying one another.
> —Quentin Crisp