Journal of Pediatric Endocrinology & Metabolism, 16, 169-178 (2003)

Physical Growth and Sexual Maturation of Boys in Chapaevsk, Russia

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ABSTRACT

We characterized physical growth and sexual maturation in 2,579 boys, ages 10 through 16.99 years, residing in Chapaevsk, Russia in order to establish region-specific reference data. Age-specific norms were established for height, weight, and BMI, and compared to US reference data by z-score analysis, while mean heights and weights by age were compared to published national Russian data. Compared to US boys, height was slightly lower (overall z-score -0.18) at all ages except the oldest (16-16.99 yr), while weight and BMI were moderately lower (overall z-score -0.52 and -0.61, respectively). Chapaevsk boys were significantly taller (1.15 cm) and thinner (-1.28 kg) than the broader Russian sample. The median ages of stage 2 genitalia and pubic hair development were 11.9 and 12.7 years, respectively. In conclusion, Chapaevsk boys are thinner than both US and Russian boys, and have a later onset of puberty and attainment of sexual maturity than boys from other countries.

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KEY WORDS

growth, pubertal maturation, height, weight, body mass index

INTRODUCTION

Extensive anthropometric data have been compiled by the National Center for Health Statistics (NCHS) in the United States to generate standard reference data for the assessment of statural growth and weight gain in children and adolescents[1-5]. The growth charts created from these data are used widely in the United States and were adapted by the World Health Organization for use in other countries[6]. However, a number of studies have demonstrated effects of ethnicity and environmental conditions, such as nutrition, socio-economic status and industrialization, on patterns of growth and weight gain[7,8]. Thus, the applicability of using normative data from the US population for the assessment of growth in other regions with their own unique genetic, ethnic, and environmental conditions has been challenged[9]. In addition to influencing linear growth and weight gain, these factors may also influence the onset and rate of progression of pubertal maturation, thereby affecting the tempo of growth during adolescence. Consequently, many clinicians and researchers have established region- or country-specific reference data to evaluate alterations in normal growth[10-13].

Limited anthropometric data are available from Russia, a country that has experienced substantial political and economic instability over the past 20 years. The city of Chapaevsk is a small industrial town in the Samara region of central Russia with a population of 80,000. The population of Chapaevsk is homogeneous ethnically and economically. Approximately half of the city's workforce is employed in civilian chemical plants that were converted from military industrial plants in the 1960s. Production processes in these plants have released pollutants into areas of the town that are in close proximity to the plants, thereby raising concerns about exposure to environmental contaminants.

We undertook this study to establish general anthropometric reference data for the population in the area. Anthropometric measurements and pubertal staging were determined in 2,579 boys residing in Chapaevsk, Russia. These cross-sectional data were used to establish regional age-specific norms for height, weight, BMI, and the progression of sexual maturation.

METHODS

Study subjects

Boys born in Chapaevsk between October 1st, 1982 and October 1st, 1988 (10-16.99 years of age at time of recruitment) who were enrolled in secondary schools were eligible for participation. Seven 1-year birth cohorts were enrolled, each representing a 1-year age group (e.g. 10-10.99 years). The population in Chapaevsk is fairly stable with minimal movement from city to city, thus most children in the area were born and grew up locally.

Human subject approval from the Chapaevsk Medical Association was received prior to starting the study. The physician investigator obtained informed verbal consent from the subject and all examination information was kept strictly confidential. However, when medical concerns were identified, the parent was notified and medical follow-up was arranged with the permission of the parent and child. The study was also approved by the Human Studies Institutional Review Board of the Harvard School of Public Health.

Examination

In the presence of a research nurse, a pediatric endocrinologist (O.S.) and urologist (Dr. Sergey Kartavzcev) performed all physical examinations, including anthropometric measurements and assessment of pubertal maturation. The majority of the data was collected in the winter and spring of 1999. Standing height was measured using a fixed stadiometer by taking the mean of three measurements each reported to the nearest 0.5 cm. Weights were obtained with shoes removed using a balance scale and reported to the nearest 50 g. Pubertal maturation was graded according to previously defined criteria for assessment of pubic hair development (P1-5) and maturation of the testes and genitalia (G1-5)[14,15].

Statistical analysis

Analysis of anthropometric data focused on height, weight, and body mass index (BMI), defined as weight (kg)/height^2 (m^2). Each of these anthropometric measures was summarized by calculating the 5th, 25th, 50th (i.e. median), 75th, and 95th percentiles of the distribution of values within each 6-month age interval. The percentiles were joined at each 6-month age interval to generate percentile curves for height, weight, and BMI.

The distributions of height, weight, and BMI were compared to US reference data for 2000 by computing a z-score for each individual, then calculating the mean z-score within each 1-year age interval and an overall z-score. Calculation of z-scores was based on tabled values of age-specific estimates of 'LMS' parameters supplied by the Centers for Disease Control and Prevention (CDC) growth chart website (http://www.cdc.gov/growth charts). The LMS procedure involves estimation of three parameters based on applying a Box-Cox transformation to percentile curves to improve the normality; these parameters are the median (M), the standard deviation (S), and the power (L) in the Box-Cox transformation[4]. Given the L, M, and S parameter estimates and a physical measurement, X (such as height or weight), the z-score is then calculated as:

$$Z = [(X/M) L - 1] / [L \times S]$$

This z-score represents the critical value of a standard normal distribution corresponding to the percentile for value X. For example, a weight z-score of -1.645 would fall at the lower 5th percentile of weight.

The resulting distributions of z-scores for height, weight, and BMI for the Chapaevsk boys were approximately normal, as expected. Statistical testing for whether the mean z-score was significantly different from zero was accomplished via one-sample t-tests, along with calculation of the corresponding 95% confidence interval for the mean z-score within each age group and overall.

Under the assumption of normality, two-sample t-tests were conducted to compare mean heights and weights of the Chapaevsk boys to those of published Russian data[13].

Pubertal maturation data were evaluated in two ways. First, within each 1-year age interval, the percent of boys classified into each Tanner stage was summarized. Secondly, age percentiles were calculated for all boys classified as falling into a particular Tanner stage.

RESULTS

Study subjects

Among 3,040 age-eligible boys identified via birth and school records, 2,579 (84.8%) were enrolled in the study. One hundred and twenty-nine boys (4.2%) who had moved to the area (primarily children of military servicemen) were excluded, 24 (0.8%) declined participation, 122 (4%) were ill at

TABLE 1

Height, weight, and body mass index (BMI) percentiles for Chapaevsk boys by age

Age (yr)	n	Height (cm) percentiles			Weight (kg) percentiles			BMI (kg/m^2) percentiles		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
10	4	132.0	135.8	144.0	26.8	30.9	38.8	15.4	16.8	18.7
10.5	177	131.0	141.0	152.0	25.5	31.7	44.2	14.3	15.8	20.9
11	236	133.0	144.0	156.5	26.3	33.5	52.4	14.0	16.2	22.2
11.5	246	133.5	146.0	160.0	27.5	35.1	50.4	14.3	16.4	21.0
12	231	136.5	149.0	160.0	28.7	37.6	53.1	14.7	16.8	22.1
12.5	273	139.5	152.0	166.0	29.7	39.1	58.5	14.4	16.8	22.6
13	232	143.5	157.0	171.0	31.7	42.3	61.1	14.6	17.4	22.4
13.5	249	145.5	159.5	174.0	33.6	45.0	65.7	15.0	17.7	22.8
14	229	150.5	164.5	177.0	34.8	50.0	66.0	15.0	18.2	23.1
14.5	226	150.0	166.0	181.5	37.0	50.8	70.0	15.2	18.0	22.9
15	214	154.5	169.0	184.0	38.2	52.8	73.2	15.3	18.3	24.4
15.5	132	159.5	173.0	185.0	41.3	57.0	82.5	15.9	19.0	25.4
16	114	158.0	175.5	187.0	45.0	60.1	75.1	16.8	19.4	24.7
16.5	16	160.0	173.5	184.5	50.0	56.9	71.6	16.0	19.5	22.4

* Each age category includes subjects from that age up to the next age category, i.e. the 10 year-old group includes boys who are at least 10 up to, but not including, 10.5 years.

the time of recruitment or examination, and 186 (6.1%) were absent from school for other reasons (e.g. sports competition, family vacation).

Somatic growth

The age distribution and the 5th, 50th (median), and 95th percentiles for height, weight, and BMI at 6-month intervals for the entire study group are shown in Table 1. These percentiles along with the quartiles (25th and 75th percentiles) are also plotted by age in Figure 1. The height data from this study population were normally distributed but the weight and BMI data were skewed to the right. Of note is that the youngest (10-10.5 years) and the oldest (16.5-16.99 years) age groups were under-represented due to the initial recruitment criteria; the data for these two age groups thus reflect a substantially smaller number of subjects. A progressive increase in height is observed except for a decline in the 50th and 95th percentiles for height in the oldest group, probably reflecting the small number of subjects (n = 16) in this group. Similarly, a decline in weight was observed in the oldest group. The two greatest increments in median height (10 cm/year) occurred between 12.5-13 years and 13.5-14 years (excluding the 10.4 cm/year increase at 10-10.5 years that represents only four individuals).

For each 1-year age cohort, the mean and standard deviation (SD) for height, weight, and BMI are shown in Table 2 and compared to US reference data[4] by calculation of mean z-scores. The US data were collected in five sequential surveys from 1963 to 1994 (NHES II and III, NHANES I, II and III)[1-5]. The growth charts revised in 2000[4] reflect all height data from the surveys, but weights from the most recent data collection (NHANES III, 1988-1994) were not included to avoid incorporating the general increase in weight (and obesity) observed between NHANES II (1976-1980) and III (1988-1994) into reference data.

For all 1-year birth cohorts, except for height in the oldest subjects (ages 16-16.99 years), Chapaevsk boys had significantly lower height, weight, and BMI than US boys by z-score analysis. The greatest height difference was observed at ages 12-14 years. In the 16-16.99 year-old age range, the

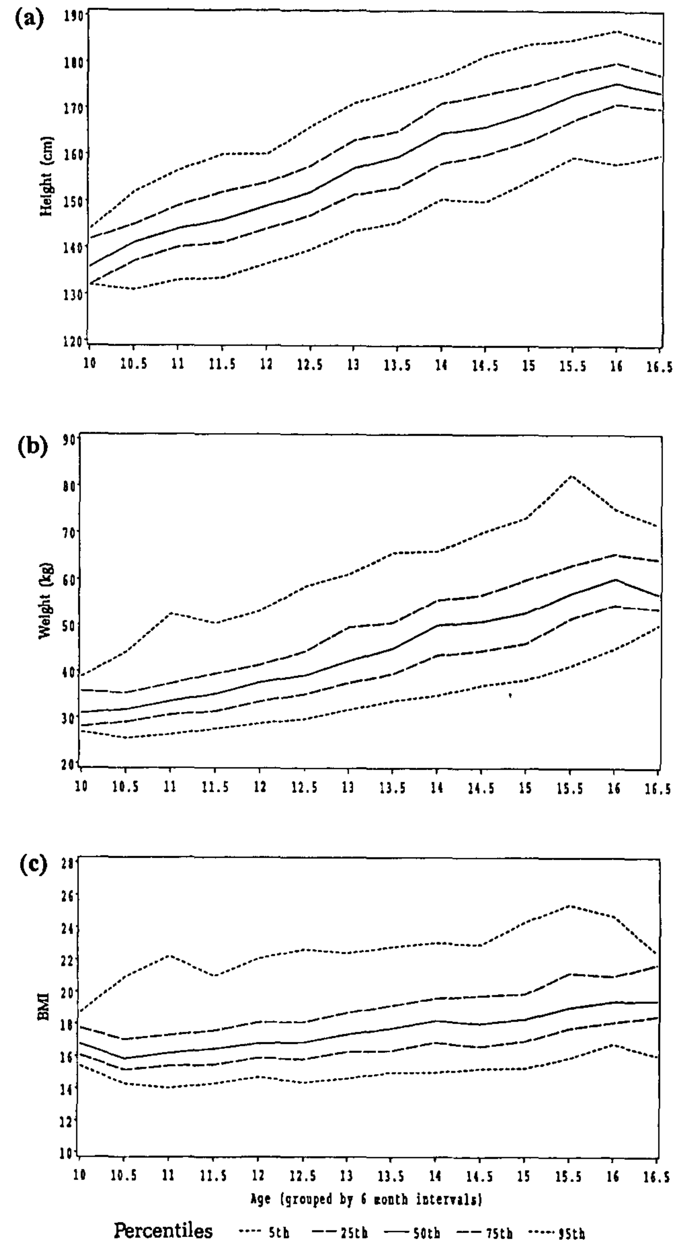

Fig. 1: Percentiles of (a) height, (b) weight and (c) body mass index (BMI) by age group.

height z-score was 0.10, indicating that the height deficits noted for younger birth cohorts (z-scores between -0.12 and -0.27) were no longer evident in the cohort closest to achieving adult height. In contrast, the mean weight and BMI (z-scores ranging from -0.27 to -0.62) were consistently lower than the US norms for all age groups.

TABLE 2

Height, weight, and BMI (mean, SD and z-score) for Chapaevsk boys compared to US reference data[4]

Age (yr)	n	Height		Weight		BMI	
		mean (SD)	mean Z-score (95% CI)	mean (SD)	mean Z-Score (95% CI)	mean (SD)	mean Z-Score (95% CI)
10	181	141.3 (6.9)	-0.18 (-0.33, -0.04)	33.1 (7.7)	-0.52 (-0.66, -0.38)	16.4 (2.4)	-0.53 (-0.67, -0.40)
11	482	145.5 (7.6)	-0.12 (-0.22, -0.04)	35.8 (7.5)	-0.54 (-0.63, -0.45)	16.8 (2.3)	-0.58 (-0.67, -0.49)
12	504	150.6 (8.0)	-0.27 (-0.36, -0.18)	39.6 (8.3)	-0.62 (-0.71, -0.53)	17.3 (2.5)	-0.59 (-0.68, -0.50)
13	481	158.1 (9.1)	-0.23 (-0.33, -0.13)	45.1 (9.6)	-0.54 (-0.64, -0.44)	17.9 (2.5)	-0.61 (-0.71, -0.51)
14	455	165.3 (9.3)	-0.20 (-0.30, -0.09)	50.8 (10.1)	-0.47 (-0.57, -0.37)	18.5 (2.5)	-0.64 (-0.75, -0.54)
15	346	170.3 (8.8)	-0.14 (-0.26, -0.02)	55.7 (11.6)	-0.47 (-0.59, -0.34)	19.1 (2.9)	-0.69 (-0.82, -0.57)
16	130	174.6 (7.9)	0.10 (-0.09, 0.28)	60.6 (10.1)	-0.27 (-0.43, -0.11)	19.8 (2.4)	-0.51 (-0.67, -0.35)
Total	2579		-0.18 (-0.22, -0.14)		-0.52 (-0.56, -0.48)		-0.61 (-0.65, -0.56)

Note: One subject (age 10 yr) missing weight, two subjects (aged 11 and 16 yr) missing height; these three subjects are thus missing BMI.

Overall, the mean z-scores for height, weight, and BMI as compared to the US data were -0.18, -0.52, and -0.61, respectively, indicating that across all ages, the Russian youths were consistently thinner and slightly shorter than US boys.

The mean heights and weights for Chapaevsk boys were compared to previously published Russian data drawn from a larger geographic area, which included urban youth from the cities of Moscow and St. Petersburg, as well as other urban and rural regions in Russia[13]. The ethnic composition of the boys in both studies was similar, primarily Caucasian. The Chapaevsk boys were consistently taller but lighter than the general Russian sample (Table 3)[13]. When a weighted regression model was fitted to the mean heights and weights (weighting inversely by the variance), the Chapaevsk boys were on average 1.15 cm taller ($p = 0.01$) and 1.28 kg lighter ($p = 0.06$).

Pubertal development

The maturational stages of pubic hair and genitalia development were observed across wide age ranges (Table 4 A,B). While a small percentage of the 10 year-old cohort was already in P3 or G3, 3% of the 15- and 16-year groups were still prepubertal for pubic hair (P1). Although genital development generally preceded the onset of pubic hair, none of the subjects was discordant by more than two stages. The age percentiles for each stage of pubic hair and genital development are shown in Table 5. The median age for stage 2 genitalia

TABLE 3

Mean height and weight (SD) of Chapaevsk boys compared to a national Russian sample[13]

Age group (yr)	n	Chapaevsk Height mean (SD)	n	Russia (Martinchik) Height mean (SD)	P-value
10.5-11.5	412	143.2 (7.2)	275	141.5 (8.3)	<0.01
11.5-12.5	477	147.5 (7.9)	274	147.3 (7.7)	>0.1
12.5-13.5	504	154.3 (8.9)	236	153.6 (9.1)	>0.1
13.5-14.5	478	161.7 (9.2)	243	160.0 (10.2)	<0.05
14.5-15.5	440	167.6 (9.4)	237	166.7 (8.8)	>0.1
15.5-16.5	246	173.7 (8.1)	255	172.0 (7.9)	<0.05
Age group (yr)	**n**	**Chapaevsk Weight mean (SD**	**n**	**Russia (Martinchik) Weight mean (SD)**	**P-value**
10.5-11.5	412	34.3 (7.7)	275	35.1 (7.0)	>0.1
11.5-12.5	477	37.4 (7.6)	274	39.4 (7.6)	<0.01
12.5-13.5	504	42.0 (9.1)	236	43.5 (8.8)	<0.05
13.5-14.5	478	48.2 (10.2)	243	48.4 (9.5)	>0.1
14.5-15.5	440	52.7 (10.8)	237	54.5 (9.1)	<0.05
15.5-16.5	246	60.0 (11.1)	255	60.5 (8.4)	>0.1

TABLE 4

Percent of Chapaevsk boys at each maturational stage for pubic hair (A) and genitalia (B) development by age

A. Pubic hair development

Age (yr)	n	Tanner stage Percent of subjects in stage				
		P1	P2	P3	P4	P5
10	181	75	25	1		
11	482	63	35	2		
12	504	41	45	12	2	<1
13	481	19	38	29	14	<1
14	455	6	17	35	39	3
15	346	2	6	21	57	14
16	130	1	2	11	65	22

B. Genital development

Age (yr)	n	Tanner Stage Percent of subjects in stage				
		G1	G2	G3	G4	G5
10	181	20	76	3		
11	482	13	72	15	1	
12	504	5	52	36	8	
13	481	1	23	45	29	1
14	455	1	6	29	55	10
15	346		2	14	66	18
16	130		1	5	72	22

Note: Row totals may not add up to 100% because of rounding.

TABLE 5

Age percentiles for each Tanner stage of pubic hair (P1-5) and genital development (G1-5)

Tanner stage	No. of subjects	Percentiles of age within Tanner stage				
		5th	25th	50th	75th	95th
P1	775	10.7	11.2	11.8	12.6	14.0
P2	723	11.0	11.9	12.7	13.6	14.8
P3	455	12.3	13.3	14.1	14.8	15.8
P4	536	13.3	14.4	15.1	15.7	16.4
P5	91	14.2	15.2	15.6	16.1	16.4
G1	134	10.5	11.0	11.4	12.0	13.0
G2	893	10.8	11.3	11.9	12.7	13.9
G3	660	11.5	12.6	13.3	14.2	15.2
G4	752	12.9	14.0	14.8	15.5	16.3
G5	141	14.1	14.8	15.4	15.9	16.4

development, the first evidence of sexual maturation, occurred at 11.9 years, while the median age for the onset of pubic hair growth (stage 2) was 12.7 years. The median age for attainment of full sexual maturity in the study population, defined as stage 5 genitalia and pubic hair, occurred at 15.4 and 15.6 years, respectively. However, as the majority of boys in the oldest age cohorts had not yet achieved stage 5 maturation, these numbers are likely to underestimate the median ages for reaching sexual maturity in Chapaevsk boys.

DISCUSSION

We compiled reference data for physical growth and sexual maturation in a large sample of boys from a small industrial city in Russia. The general secular trends of increased weight gain and obesity observed in the US are not evident in these subjects. When the US growth charts were updated in 2000, newly collected weight data were not included. The current US weight curves reflect only data collected up to 1980 because of concerns that inclusion of recent data would shift the weight reference curves upward, thereby underestimating obesity[4]. Therefore, the current pattern of weight gain during adolescence in Chapaevsk youth was compared to US data collected more than 20 years ago. The differences in weight and BMI in Chapaevsk boys would be more striking if compared with contemporary American youth. The Chapaevsk boys are also thinner than boys from a broader sampling of Russian communities including several major metropolitan areas[13]. We speculate that the consistently lower BMI in Chapaevsk boys reflects differences in diet and/or physical activity levels of boys in this small Russian city compared to US boys, or the small sampling from a broader region of Russia. The Chapaevsk boys did not appear to be undernourished however, as their linear growth was not compromised; they were minimally shorter than US boys and taller than Russian boys in the previous study[13]. These previously published Russian reference data were obtained from selected families in both large urban areas and rural communities and represent a minority of boys in these regions, whereas our study includes 85% of all age-eligible boys in the community. Thus, our data may more accurately represent current anthropomorphic standards in the study region.

The first evidence of sexual maturation, stage 2 genitalia development, occurred at a median age of 11.9 years among Chapaevsk boys, which is similar to the median age (12.0 years) reported in contemporary Hungarian boys[16], but generally older than that reported elsewhere. For example, the median age of stage 2 genitalia reported recently from East Germany is 10.8 years[17], and from the US is 11.5 years according to data reported by Tanner and Davies in 1985[1] and 10.1 years for US Caucasian boys according to 1988-1994 NHANES III data[18]. Considering the method of data collection, the disparity in pubertal onset compared to US boys may be even more pronounced than this. While we determined pubertal staging by examination, the NHANES III was an observational study that may delay recognition of early changes in testicular volume and scrotal skin thinning signifying stage 2 genitalia. The median age of 12.7 years for stage 2 pubic hair growth in Chapaevsk boys is older than that reported recently from East Germany (11.5 years)[17], Hungary (11.8 years)[16], and from both the 1985 and the 1988-1994 NHANES III US data (12.0 years)[1,18].

Consistent with the delayed onset of puberty, the attainment of full sexual maturity appears to occur at an older age in the Chapaevsk boys compared with other populations. In East Germany, by 16.99 years of age, more than 75% of boys have attained stage 5 maturation for pubic hair or genitalia[17], whereas in a comparable age group, fewer than 20% of the Chapaevsk boys have attained stage P5 or G5 (Table 4). In conjunction with the trend towards a later onset of puberty and attainment of sexual maturity, the lower mean height in the Chapaevsk boys compared to US boys, particularly at 12-14 years of age, is suggestive of an apparent delay in timing of the pubertal growth spurt.

We speculate that this pattern of linear growth and pubertal maturation is related to the lower weights and BMIs during adolescence in this population, as suggested for other groups[19]. Differences in overall health, nutrition, and physical activity may all contribute to the significantly lower mean weights and delayed pubertal maturation observed in the Chapaevsk boys. Industrialization has also been reported to affect growth and sexual maturation[8], and production processes in the Chapaevsk industrial plants are suspected to have polluted some of the residential neighborhoods that are in close proximity to the plants. The finding of soil and cow's milk contamination with dioxins, putative endocrine disruptors, has raised concerns about environmental contaminant exposure for some neighborhoods in Chapaevsk[20,21]. Examination of various factors, such as nutrition, physical activity and environmental pollution, that may be related to the pattern of physical growth and reproductive development of boys in Chapaevsk are beyond the scope of this study but will be explored in a future prospective study.

In summary, there are notable differences in physical growth and pubertal maturation in the Chapaevsk boys compared with other populations. For example, the study boys have significantly lower body weight and BMI than US boys in all age cohorts (Table 2). In addition, the onset of puberty is generally later than that reported in other countries[1,16-18] and full sexual maturation appears to be achieved at an older age. These findings suggest that the use of reference data obtained in Chapaevsk would be a more appropriate standard for evaluating abnormalities in growth for Russian boys, particularly those residing in small industrial cities, than standards derived from individuals in other countries.

ACKNOWLEDGEMENTS

We thank Larisa Altshul and Jennifer Adibi, Harvard School of Public Health, Dr. Tatiana Ushakova, Russian Academy of Medicine Sciences, and Dr. Sergey Kartavzcev, Chapaevsk Central Hospital, for their advice and assistance with the study. This work was funded by the US EPA, Grant number R-82943701-0.

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