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RESEARCH PAPER

Contemporary height, weight and body mass index references for children aged 0 to adulthood in Switzerland compared to the Prader reference, WHO and neighbouring countries*

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ABSTRACT
Background: In 2011, WHO growth curves replaced those of Prader and colleagues (First Zurich longitudinal study) in Switzerland.
Aim: To present contemporary height-, weight- and body mass index (BMI)-for-age references reflecting children's growth in modern Switzerland.
Subjects and methods: Cross-sectional sample comprising 30,141 boys and girls aged 0–20 years measured between 2012 and 2019. Height, weight and BMI reference curves were created using the LMS method. Derived percentiles were compared with those of Prader, WHO and neighbouring countries.
Results: Growth in the first 5 years is almost identical with Prader curves. Thereafter children are taller, yet their final height is only about 1 cm higher. Today's children, in particular boys, are considerably heavier. In comparison with WHO growth references, Swiss children are taller from the second year until adulthood; the WHO 3rd percentiles lie about 4 cm below those of our updated references. Weight and BMI median percentiles from our sample are similar to those of WHO and higher than the Prader curves. However, the course of the 97th BMI percentile WHO curves extends well below the 97th percentile of the updated Swiss curves.
Conclusion: This study provides contemporary reference data for assessing individual growth based on height, weight and BMI of Swiss children.

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Growth references; height; weight; BMI; children; percentile

Introduction

Growth is a direct indicator of health. Monitoring growth and weight gain is therefore an important tool for healthcare providers. Until 2011, the First Zurich longitudinal study (Prader et al. 1989) was the main growth reference in Switzerland, comprising data from 137 healthy children of each sex born in Zurich between 1954 and 1956. Although this data set is recognised as the largest and most complete for child growth (Tanner 1998), it can no longer be regarded as contemporary and is also associated with low precision 3rd and 97th percentiles due to the small number of children investigated. The Swiss Society of Paediatrics superseded the Prader curves for height, weight and body mass index (BMI) in 2011 with the World Health Organisation (WHO) Child Growth Standards for children from 0 to 5 years (de Onis 2006) and the WHO growth reference for school-aged children and adolescents (de Onis et al. 2007).

WHO growth standards for 0–5 year old children are based on data from the WHO Multicentre Growth Reference Study (1997–2003) that included healthy children of various ethnic backgrounds (de Onis 2006). The WHO growth standards have since been adopted in many countries advocating the healthy breast-fed infant as a model for optimal growth (Ong 2017). WHO reference curves for children of 5 years and above are a reconstruction of the 1977 NCHS/WHO growth reference based on a sample of white, black, Hispanic and Asian US children (5–19 years) born in the 1950s and 1960s (de Onis et al. 2007). These reference data are essentially as dated as the Prader curves. Thus, the question arises as to how well the WHO reference curves describe the growth of contemporary children of 5 years and above in Switzerland.

During the last 10 years, national growth references for height, weight and BMI have been published for the following neighbouring countries of Switzerland: Italy, Germany and Austria, as well as a number of other European and non-European countries (Júlíusson et al. 2011; Schaffrath Rosario et al. 2011; Bonthuis et al. 2012; Vignerova et al. 2012; Gleiss et al. 2013; Tanaka et al. 2013; Zong and Li 2013; Tinggaard et al. 2014; Dwipoerwantoro et al. 2015; Christesen et al. 2016; Orden and Apezteguia 2016; Park et al. 2017; Esmaili et al. 2018; Regecová et al. 2018). The general assumption is to use, if available, local percentiles that seem to better reflect children's growth. Furthermore, the working group of Christesen found that the use of the 3rd percentile of the WHO height

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standard and reference curves could lead to missed or delayed diagnoses in European populations (Christesen et al. 2016).

Our aim is to establish contemporary height-, weight- and BMI-for-age reference curves for monitoring the growth of children in Switzerland. We also compare our new data with the Prader curves, WHO growth standards and reference curves as well as the growth references of our neighbouring countries.

Subjects and methods

Study design and sample

Cross-sectional data were prospectively collected from 34 paediatric practices and 25 educational institutions (public preschools, primary and secondary schools as well as vocational colleges and trade schools) located in the central and eastern parts of Switzerland between the lakes of Lucerne and Constance. Children who had undergone paediatric consultation for growth problems or had a disease affecting growth (e.g. coeliac disease, renal insufficiency, hormonal disorders) were excluded. Schools were chosen based on their ability to provide data for a sample representing children from diverse urban areas, sociodemographic origin and school types. Measurement in schools was voluntary; < 20 students (< 0.4%) refused to participate.

We included three additional retrospectively collected data sets in our cross-sectional sample:

1. Data of all births registered in Switzerland from 2012 to 2016 were provided by the Federal Office for Population Statistics (BEVNAT). We excluded births of pre- and late-term children (gestational age < 37 0/7 weeks or > 41 6/7 weeks) and used stratified random drawing to obtain data of 300 girls and 300 boys per year. To correspond with the regional distribution of the prospective data collection, we chose a quotum of 70% coming from the Canton of Zurich and 30% from the rest of Switzerland.
2. Data of the Zurich school medical service were provided from 2017 for children in the second year of kindergarten (main age = 5 years), 5th grade (main age = 10–11 years) and 8th grade (main age = 13–14 years). Exclusion criteria could not be ascertained due to the lack of available medical information.
3. Data of recruits from the Swiss military medical service were provided from 2013 to 2017. We used stratified random drawing to obtain data of 150 men per year of age 18–20 and per year of recruitment (2,250 of 129,273 male recruits). To correspond with the regional distribution of the prospective data collection, we chose a quotum of 70% coming from the Canton of Zurich and 30% from the rest of Switzerland. From 18-year-old female recruits, we drew 25 cases (from 181 female recruits) without regional restrictions.

We aimed for a sample size of at least 300 cases per sex and year of age, which is regarded to be sufficient for a robust estimate of the 3rd and 97th percentiles (Guo et al. 2000). After data cleaning procedures and restricting age to a maximum of 21.0 years for males and 19.0 years for females, our sample included a total of 16,540 boys and 13,601 girls (Table 1). Age groups per year included 303–1726 cases.

Our research project includes data regarded as 'anonymously collected health-related data', which does not fall under the Human Research Act according to Swiss law. Therefore, the local ethics committee was not within its jurisdiction to evaluate our project, but stated that the conduct of this study is ethically harmless and involves no risk and/or a low burden for the participants, with only anonymised data being collected. Consent procedures were executed as follows:

- In paediatric practices, information leaflets were provided and verbal consent was obtained from the attending parent.

Table 1. Number of cases for boys and girls per data source by 2-year increment age groups.

	Boys				Girls			
	Prospective				Prospective			
Age group (years)	Paediatric practice	Schools	Retrospective	Total	Paediatric practice	Schools	Retrospective	Total
< 2.00	2742	0	1471[b]	4213	2757	0	1499[b]	4256
2–3.99	900	4	0	904	805	4	0	809
4–5.99	765	3	1661[c]	2429	658	2	1513[c]	2173
6–7.99	628	207	297[c]	1132	607	199	228[c]	1034
8–9.99	339	321	10[c]	670	345	302	10[c]	657
10–11.99	646	106	1028[c]	1780	628	93	1027[c]	1748
12–13.99	358	210	257[c]	825	352	261	272[c]	885
14–15.99	368	390	276[c]	1034	319	359	271[c]	949
16–17.99	78	689	3[c]	770	61	680	3[c]	744
18–20.00[a]	6	529	2248[d]	2783	8	313	25[d]	346
Total	6830	2459	7251	16,540[e]	6540	2213	4848	13,601[f]

[a]Age group for girls: 18–19 years.
[b]Data source: births.
[c]Data source: school medical service.
[d]Data source: military recruits.
[e]The number of deleted duplicate cases, outliers and obvious input errors (not included in total) were 33 (0.2%), 117 (0.7%) and 41 (0.2%), respectively. The number of corrected input errors included in the total was 30 (0.2%).
[f]The number of deleted duplicate cases, outliers and obvious input errors (not included in total) were 45 (0.3%), 68 (0.5%) and 54 (0.4%), respectively. The number of corrected input errors included in the total was 20 (0.1%).

- School measurements were done with the consent of both the participating school and education department of Zurich. Information leaflets for dissemination to the parents were provided before measurements and oral information about the project were presented to each participating class by the project staff. The possibility of dissent was clearly explained. Data privacy was guaranteed by executing all measurements for each participant separately from the class.

Anthropometric measurements

Prospective data collection took place between January 2017 and May 2019. All paediatricians were trained in their own practice by the first author, an experienced paediatric endocrinologist and growth specialist. Training included how to measure height and weight according to the study protocol. Additionally, each stadiometer used in paediatric practice was checked, calibrated and adjusted, as required. Control visits were conducted after 4 months. The three medical staff members who made the school visits were also trained in the same way. The millimetre-precise measurement was always spoken out loud, double controlled by the assistant (based on the 4-eyes principle) and immediately entered into the computer.

All participating paediatric practices were provided with a specially configured tablet computer on which the following data were entered anonymously and immediately transmitted to our research server: date of measurement, date of birth, residential postal code, gender, height, weight, nationality of both parents.

Height was measured on a stadiometer to the nearest millimetre. Children were told to stand as straight as possible (knees stretched, heels onto the floor, arms loosely at their side). For children under 5 years of age, the parent (or assistant) was asked to hand-press both feet of the child firmly on the ground. The person taking the measurement placed their hands on the child's jaw so their fingers reached the mastoid process. The calliper was placed on the child's head and, by slightly tilting the head forwards and backwards, the highest point of the vertex was found. Children younger than two years were measured in a supine position. The assistant (or parent) was asked to hold the head, while the paediatrician stretched one leg of the child (to prevent a reflex-like toe position) and brought the movable part of the measuring device into contact with the lower surface of the foot to read the size to the nearest millimetre. For all newborn babies, head to toe assessments (to the nearest centimetre) were taken immediately after birth by the responsible medical personnel. All military recruits were measured (also to the nearest centimetre) by the medical staff of six regional conscription centres.

Body weight was measured on a professional medical scale to the nearest 100 grams. Children attending paediatric practices were measured in their underwear. At schools, measurements took place during physical education lessons; 200–400 grams were subtracted from the final measured body weight to account for the sporting clothes worn on the day of measurement. The weight of newborns was reported to the nearest 10 grams, weight measurements of the Zurich school medical service were reported to the nearest 100 grams, and the weight of recruits was reported to the nearest kilogram. BMI was calculated as the ratio of weight (kg) to the square of height (m^2).

Parent nationality and residential postcode were recorded from all prospectively collected data sets. Postcodes were also attained for military conscripts. Parent nationality was also known for newborns.

Data handling and statistical analysis

Sex-specific percentile curves were calculated with the LMS method (Cole and Green 1992). This method uses a Box-Cox power transformation to normalise the data at each age. Natural cubic splines were fitted to three curves: Box-Cox power (L), median (M) and coefficient of variation (S). The standardised residual (also referred to as the '*z*-score' or 'standard deviation score' (SDS)) of a measurement *y* can then be calculated from the sex- and age-specific values of L, M and S: for $L \neq 0$, which applied to our models, $z = [(y/M)L - 1]/(L * S)$ (Pan and Cole 2011).

Notation for LMS models was given as L/M/S*x*, where L, M, and S stand for the equivalent degrees of freedom (i.e. a measure of curve complexity) and *x* stands for the transformation used for the age scale. In our height and weight models, the rescaling option (r) was chosen for *x*. Since the behaviour of the BMI-for-age curve in the first year is dynamic, but of limited practical value for paediatricians, we estimated our BMI-for-age models only from 1 year onwards; the age scale was not transformed. BMI-for-age tables were provided from 2 years onwards. For the evaluation of model fit, we used Q-tests (Pan and Cole 2004) and worm plots (van Buuren and Fredriks 2001).

Data cleaning included computer-aided checking for duplicates, obvious input errors and typical input errors such as confusing weight with height or errors in the decimal place. Data were checked for outliers by applying different outlier definitions from sex- and age-specific percentiles. Visual inspection was used to choose equations for identifying outliers. Finally, height values lying outside the interval [P25 – 4.5(P50 – P25); P75 + 4.5(P75 – P50)] and weight values lying outside the interval [P25 – 5(P50 – P25); P75 + 9(P75 – P50)] were defined as outliers and the respective cases were excluded. To prevent bias due to the potential of some age groups being over-represented, weighting of the cases in these groups was reduced according to the degree of over-representation; weighting factors ranged from 0.25–1.

Selected sex-specific percentiles of height and BMI were compared with those of other established references (Supplementary Appendix 1) based on calculating the differences in measurement units and as the SDS based on the LMS parameters of our data. Comparisons of weight-for-age percentiles were not made because of their dependency on height.

To determine the prevalence of overweight (including obesity) status and obesity alone, we used the WHO 90th and 97th percentiles as well as the International Obesity Task Force (IOTF) cut-offs for overweight and obesity (Cole et al. 2000). The IOTF approach applies the percentiles at BMI values of 25 kg/m^2 and 30 kg/m^2 at the age of 18 years throughout childhood and adolescence as cut-off values for overweight status and obesity, respectively. We also applied the IOTF method on our data to obtain our own empirically determined cut-off percentiles.

We examined whether height-for-age or BMI-for-age percentiles are influenced by the high proportion of foreigners and second-generation immigrants in Switzerland. Therefore, we compared the mean height-for-age and BMI-for-age SDS of children whose parents were: (1) either Swiss or belonging to the most important immigrant groups originating from (2) Germany, Austria, France and countries within the Scandinavian or Benelux regions as well as (3) Italy, Portugal or Spain or (4) the Balkan region.

In order to assess the socioeconomic influences on height and BMI, we used the construct of the Swiss neighbourhood index of socioeconomic position (SEP) (Panczak et al. 2012). This area-based index (data based on the Structural Survey of 2012–2015) was expressed as median SEP per postal code area and added to our data set. We compared the heights of children living in areas with the highest and lowest SEP quartiles. This analysis included only children with Swiss parents to prevent bias due to national origin.

Furthermore, we applied logistic regression analysis to calculate the probability of being overweight for children dependent on their parents' origin and the SEP of their postal code area. Origin was dichotomised into 'both parents from Switzerland' vs 'both parents from southern Europe (Italy, Portugal, Spain or Balkan region or Turkey)'. This analysis was done for children of 8 years and older, as differences between the BMI-for-age percentiles of different populations become apparent at this age.

For LMS modelling, we used LMSchartmaker Pro version 2.54 (Medical Research Council, Cambridge, UK). All other analyses were performed with IBM SPSS Statistics for Windows version 24 (IBM Corp., Armonk, NY).

Results

Height

We specified the LMS models as 0/12/9r for boys and 0/8/4r for girls. Worm plots suggest a reasonable fit of M (no offset), S (no slopes) and minor issues with the skewness in some age groups (U-shapes) (Supplementary Appendix 2).

Sex-specific percentile values for height are presented in Table 2 (and Supplementary Appendices 3 and 4). The median final heights of boys and girls living in Switzerland are 178.6 cm and 166.1 cm, respectively. Median birth length is 50.5 cm for boys and 50 cm for girls.

Comparison with Prader curves

Girls and boys today have the same median birth length as those from the Prader sample. Median height remains almost identical until the age of 5 years. Between 6–9 years, boys are now 1.0 cm taller (Prader: −0.2 SDS) (Figure 1). After the age of 9 years, the discrepancy increases further until the age of 13.5, where the median height for boys is 4.2 cm more (Prader: −0.5 SDS). The median final height of men today at age 20 is 1.1 cm higher (Prader: −0.2 SDS).

Table 2. Smoothed height percentiles (in cm) for boys and girls.

Age (years)	Boys							Girls						
	3rd	10th	25th	50th	75th	90th	97th	3rd	10th	25th	50th	75th	90th	97th
0	46.6	47.8	49.1	50.5	51.9	53.1	54.4	46.1	47.3	48.6	50.0	51.4	52.6	53.9
0.25	56.7	58.0	59.4	60.9	62.4	63.7	65.1	54.0	55.4	56.8	58.4	60.0	61.4	62.9
0.5	63.6	65.0	66.4	68.0	69.6	71.0	72.4	60.6	62.1	63.7	65.4	67.1	68.7	70.2
0.75	68.0	69.5	71.0	72.7	74.3	75.8	77.3	65.6	67.3	68.9	70.7	72.5	74.2	75.8
1	71.4	73.0	74.6	76.4	78.2	79.8	81.3	69.6	71.3	73.0	74.9	76.8	78.5	80.2
1.25	74.5	76.2	77.9	79.8	81.7	83.4	85.0	73.0	74.7	76.5	78.4	80.4	82.1	83.9
1.5	77.3	79.1	80.9	82.9	84.9	86.7	88.5	75.9	77.7	79.5	81.6	83.6	85.4	87.2
1.75	80.0	81.8	83.7	85.8	87.9	89.7	91.6	78.6	80.5	82.3	84.4	86.5	88.4	90.3
2	82.4	84.3	86.3	88.4	90.6	92.5	94.5	81.1	83.0	84.9	87.1	89.3	91.2	93.1
3	90.4	92.6	94.8	97.2	99.7	101.9	104.0	89.3	91.5	93.7	96.2	98.6	100.8	103.0
4	97.1	99.5	101.9	104.6	107.3	109.8	112.2	96.0	98.4	100.9	103.6	106.3	108.8	111.2
5	103.1	105.8	108.5	111.5	114.5	117.2	119.9	102.0	104.7	107.4	110.4	113.4	116.1	118.8
6	108.8	111.7	114.7	118.1	121.4	124.4	127.3	107.8	110.7	113.7	117.0	120.3	123.3	126.3
7	114.5	117.7	120.9	124.5	128.0	131.2	134.4	113.4	116.6	119.8	123.4	127.0	130.2	133.4
8	120.1	123.4	126.7	130.4	134.0	137.4	140.6	118.6	122.1	125.5	129.4	133.2	136.6	140.1
9	125.3	128.6	132.1	135.9	139.7	143.1	146.5	123.9	127.6	131.2	135.3	139.3	143.0	146.6
10	130.0	133.5	137.1	141.1	145.1	148.7	152.3	129.5	133.3	137.1	141.4	145.6	149.5	153.2
11	134.4	138.3	142.2	146.5	150.8	154.7	158.5	135.3	139.2	143.1	147.5	151.9	155.8	159.7
12	138.8	143.0	147.3	152.1	156.9	161.1	165.4	141.0	144.9	148.9	153.3	157.7	161.7	165.6
13	144.4	149.0	153.7	158.9	164.1	168.8	173.4	146.1	150.0	153.9	158.3	162.7	166.7	170.6
14	151.3	156.0	160.9	166.2	171.6	176.4	181.1	149.9	153.7	157.7	162.0	166.4	170.3	174.2
15	157.6	162.2	166.8	172.0	177.1	181.7	186.3	152.2	156.1	159.9	164.3	168.6	172.5	176.3
16	162.1	166.4	170.7	175.6	180.4	184.8	189.0	153.4	157.2	161.1	165.4	169.7	173.6	177.4
17	164.3	168.4	172.6	177.2	181.9	186.1	190.2	153.9	157.8	161.6	165.9	170.2	174.1	177.9
18	165.4	169.4	173.5	178.0	182.6	186.7	190.7	154.2	158.0	161.8	166.1	170.4	174.3	178.1
19	165.7	169.7	173.8	178.3	182.8	186.9	190.9							
20	166.1	170.0	174.1	178.6	183.0	187.1	191.0							

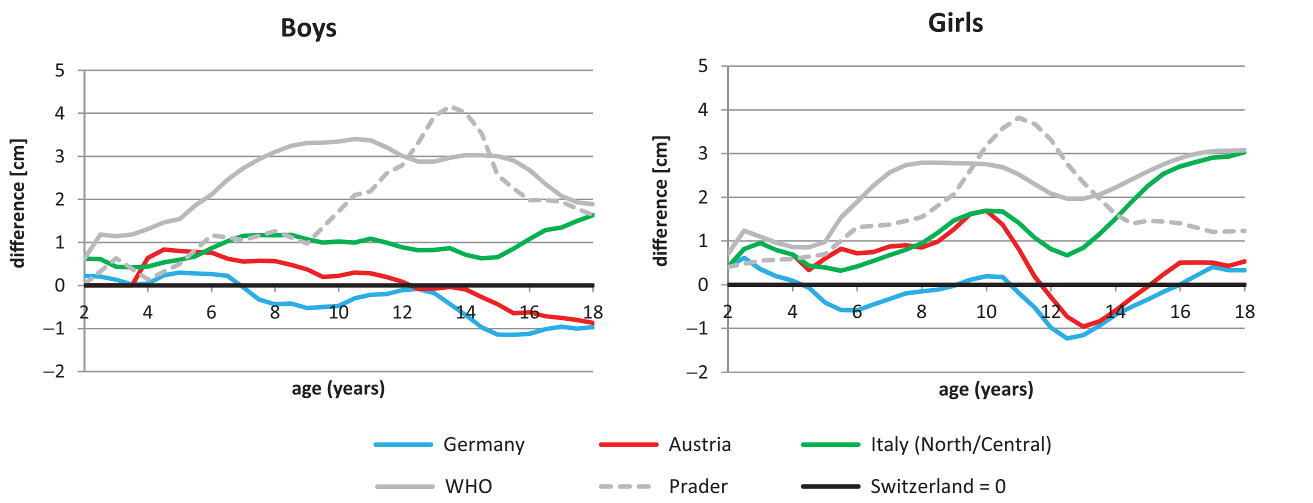

Figure 1. Differences in the 50th height-for-age percentile between our results and those of neighbouring countries, World Health Organisation (WHO) and Prader et al. (1989). Positive differences indicate that our results are higher than those of the compared reference, whereas negative differences indicate lower results.

The median height of girls between 6–8 years is up to 1.6 cm higher (Prader: −0.3 SDS). The discrepancy increases until the age of 11, where the median height is 3.8 cm more (Prader: −0.6 SDS). The median final height of today's 18-year-old women is 1.2 cm higher (Prader: −0.2 SDS) (Figure 1).

Comparison with the WHO Child Growth Standards/ Reference Curves

At birth and until the age of 2 years, the median length of our male sample is similar to the WHO data (WHO: −0.2 SDS). At the age of 5 years—where the WHO child growth standards end—the difference of the medians is 1.5 cm (WHO: −0.3 SDS). Thereafter, the distance between both median curves increases further, with a peak at 10 years, when the median height of our sample is 3.4 cm higher compared to the WHO reference (WHO: −0.6 SDS). The median height of boys aged 19 years is 1.7 cm higher (WHO: −0.3 SDS) (Figure 1 and Supplementary Appendix 5).

At birth and until the age of 2 years, the median length of both our female sample and that from WHO are quite similar (WHO: −0.3 SDS), followed by a taller median height of our sample. Between 8–18 years, the difference is around 3 cm (WHO: −0.4 to −0.5 SDS) with a trough at the age of 13, where the difference is 2 cm (WHO: −0.3 SDS) (Figure 1 and Supplementary Appendix 6).

There were differences between the 3rd percentile of our sample and WHO values (Figure 2). For boys, the distance between the two 3rd percentiles continually increases with age, showing an initial peak at age 10, where our 3rd percentile lies 4.2 cm above the WHO percentile (WHO: −0.7 SDS). A second peak occurs at age 16 where our 3rd percentile lies 3.8 cm above the WHO percentile (WHO: −0.5 SDS). At the end of growth, our 3rd percentile is 2.9 cm above the WHO percentile (WHO: −0.4 SDS).

Values for girls from our sample continually lie above the WHO standard and increase with age. The first peak at 3 cm above the WHO value (WHO: −0.5 SDS) occurs at 7 years and the second apex occurs at 16 years, with a final height 3.7 cm above the WHO reference (WHO: −0.6 SDS).

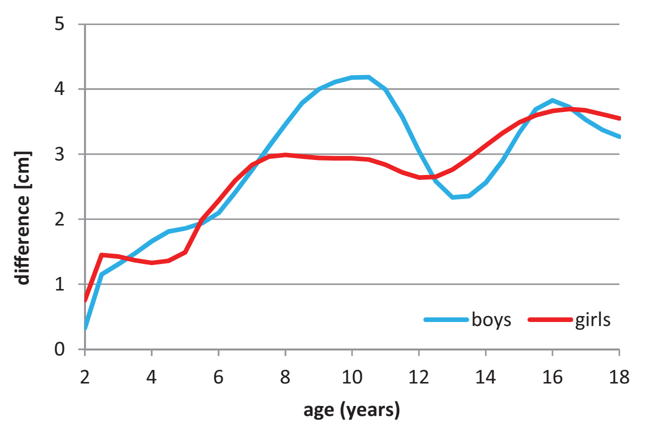

Figure 2. Differences in the 3rd height-for-age percentile between our results and those of the World Health Organisation (WHO). Positive differences indicate that our results are higher than those of the WHO.

Comparison with contemporary growth curves of neighbouring countries

Our 50th and 3rd percentile height-for-age curves are similar to recent growth reference data from Germany and Austria (Figure 1 and Supplementary Appendices 5 and 6). Maximal deviation on the 50th percentile throughout the entire growth period to 18 years is 1.1 cm and 1.7 cm for 15-year-old boys (Germany: 0.2 SDS) and 10-year-old girls (Austria: −0.3 SDS), respectively. Differences between the 3rd percentiles do not exceed 1.1 cm for boys (16 years; Austria: 0.2 SDS) and 1.4 cm for girls (12 years; Germany: 0.1 SDS). The median curve of north/central Italian boys lies between 0.4 and 1.7 cm (−0.1 to −0.3 SDS) below our sample, with the biggest difference at final height. Italian girls are 0.3–1.7 cm (−0.1 to −0.3 SDS) smaller until the age of 13. When reaching final height, north/central Italian females are 3 cm (−0.5 SDS) smaller.

Migration and socioeconomic aspects

Forty-five per cent of the children in our sample have Swiss parents and 17% have at least one Swiss parent. The proportions of children with both parents originating from another country are: 10% from the Balkan region, 6% from Germany, Austria, France or more northern countries, 6% from Italy, Spain or Portugal and 2% from Turkey.

Table 3 reveals how children with Swiss parents and children of important migrant groups grow in comparison to the sex-specific overall median growth curve. The growth of boys and girls with Swiss parents is close to the overall median (0.0 SDS). The largest difference in boys occurred within the age interval of 4–6 years, where they were 6 mm (−0.14 SDS) smaller than the overall median and 1 cm taller (+0.15 SDS) at the age of 16–18 years. The largest difference in girls occurred with −1.3 cm (−0.2 SDS) at age 10–12 years and +1.3 cm (+0.2 SDS) at the age of 14–16 years.

Mean differences in height-for-age between children living in postal areas rated with high (better situated) vs low (less well situated) SEP indices were 0.1 SDS and 0.12 SDS for boys and girls, respectively ($p < 0.05$; Cohen's $d = 0.1$).

Table 3. Mean standard deviation scores (SDS) from the sex-specific overall height-for-age curve for boys and girls of varying origin, where both parents originate from the region as indicated.

	Boys			Girls		
Parent(s) origin	*n*	Mean	SD	*n*	Mean	SD
CH	4767	0.0	1.0	4743	0.0	1.0
DE, FR, AUT, SCAND, BENELUX	655	0.1	1.0	610	0.2	1.0
IT, ES, PT	644	−0.3	0.9	532	−0.3	1.0
BALKAN	1167	0.2	1.0	841	0.3	1.0
Turkey	228	0.0	0.9	205	0.1	0.9
CH (one parent)	1819	0.0	1.0	1855	0.0	1.0
Other / mixed / unknown	7260	0.0	1.0	4815	0.0	1.0
Total	16,540	0.0	1.0	13,601	0.0	1.0

SD, standard deviation; CH, Switzerland; DE, Germany; FR, France; AUT, Austria; SCAND, Scandinavian countries; BENELUX, Belgium, Netherlands, Luxembourg; IT, Italy; ES, Spain; PT, Portugal; BALKAN, Balkan countries.

Weight and BMI

We specified the LMS models for weight as 5/10/6r for boys and 4/10/6r for girls and for BMI they were 3/7/5o and 3/6/4o for boys and girls, respectively (Supplementary Appendices 7 and 8).

Sex-specific percentile values for weight and BMI are presented in Tables 4 and 5 (and Supplementary Appendices 9–12).

Comparison with Prader curves

Prader median BMI-for-age values are lower than our median (Figure 3 and Supplementary Appendices 13 and 14). At the ages of 11 and 18 for boys, the median is 1 kg/m^2 (−0.5 SDS) lower (equal to 2.1 kg at median height) and 2 kg/m^2 (−0.7 SDS) lower (equal to 6.3 kg at median height), respectively. The Prader median curve for girls is located around 0.5 kg/m^2 (−0.2 SDS) below our median within the age range of 6–15 years. This corresponds to 1 kg for a girl of median height at the age of 12 years. The Prader median BMI at 18 years is 1.4 kg/m^2 lower (−0.6 SDS), which corresponds to 3.9 kg for a girl of median height.

Comparison with WHO Child Growth Standards/Reference Curves

The WHO median BMI-for-age curves for boys and girls are similar to the respective median curves of our sample; maximum differences in boys are 0.3 kg/m^2 (WHO: −0.1 SDS) at the ages 5, 10–13 and 18 years (Figure 3 and Supplementary Appendices 13 and 14). Maximum differences in girls are 0.5 kg/m^2 at 2 years of age (WHO: −0.4 SDS) and 0.3 kg/m^2 at 18 years (WHO: −0.1 SDS).

Differences in the 97th percentile are more pronounced (Figure 4). The WHO reference for boys lies consistently

Table 4. Smoothed weight percentiles (in kg) for boys and girls.

	Boys							Girls						
Age (years)	3rd	10th	25th	50th	75th	90th	97th	3rd	10th	25th	50th	75th	90th	97th
0	2.71	2.94	3.18	3.46	3.75	4.02	4.30	2.58	2.79	3.02	3.29	3.58	3.85	4.13
0.25	4.90	5.27	5.67	6.14	6.65	7.13	7.63	4.49	4.83	5.21	5.64	6.12	6.57	7.04
0.5	6.34	6.79	7.28	7.87	8.51	9.12	9.77	5.89	6.31	6.77	7.32	7.91	8.48	9.09
0.75	7.31	7.81	8.37	9.03	9.76	10.47	11.22	6.85	7.33	7.84	8.46	9.13	9.79	10.49
1	8.07	8.61	9.21	9.94	10.74	11.53	12.38	7.61	8.12	8.68	9.35	10.09	10.82	11.59
1.25	8.70	9.28	9.92	10.71	11.57	12.43	13.36	8.24	8.78	9.38	10.11	10.91	11.70	12.54
1.5	9.24	9.86	10.54	11.37	12.30	13.22	14.23	8.79	9.37	10.01	10.78	11.64	12.48	13.40
1.75	9.74	10.38	11.10	11.98	12.96	13.95	15.02	9.30	9.91	10.58	11.40	12.31	13.22	14.20
2	10.20	10.87	11.62	12.55	13.59	14.63	15.78	9.78	10.42	11.13	12.00	12.97	13.93	14.98
3	11.89	12.68	13.57	14.68	15.94	17.23	18.68	11.59	12.36	13.22	14.29	15.50	16.73	18.10
4	13.61	14.53	15.57	16.90	18.43	20.05	21.90	13.22	14.14	15.17	16.47	17.97	19.53	21.29
5	15.38	16.44	17.67	19.27	21.16	23.19	25.59	14.81	15.88	17.12	18.70	20.56	22.54	24.84
6	17.07	18.30	19.74	21.64	23.94	26.49	29.60	16.39	17.65	19.13	21.05	23.36	25.87	28.88
7	18.75	20.15	21.82	24.05	26.83	29.98	33.97	18.00	19.47	21.20	23.51	26.32	29.45	33.30
8	20.47	22.06	23.97	26.57	29.85	33.68	38.67	19.68	21.38	23.40	26.12	29.49	33.29	38.05
9	22.53	24.35	26.56	29.59	33.50	38.13	44.34	21.73	23.73	26.13	29.36	33.41	38.02	43.87
10	24.96	27.08	29.66	33.24	37.88	43.44	51.00	24.29	26.68	29.56	33.45	38.33	43.91	50.97
11	27.61	30.10	33.13	37.34	42.81	49.37	58.25	27.09	29.92	33.32	37.91	43.65	50.16	58.32
12	30.30	33.23	36.80	41.74	48.11	55.67	65.71	30.29	33.52	37.39	42.60	49.08	56.38	65.44
13	33.72	37.17	41.36	47.11	54.46	63.02	74.15	34.42	37.93	42.12	47.76	54.76	62.63	72.40
14	38.21	42.14	46.89	53.35	61.52	70.91	82.90	38.50	42.10	46.39	52.13	59.25	67.26	77.22
15	43.03	47.25	52.32	59.17	67.75	77.50	89.80	41.56	45.12	49.36	55.02	62.01	69.85	79.61
16	47.50	51.83	57.00	63.97	72.66	82.53	94.96	43.62	47.15	51.33	56.90	63.76	71.44	81.00
17	51.00	55.35	60.54	67.53	76.24	86.15	98.68	45.10	48.60	52.74	58.25	65.02	72.61	82.04
18	53.45	57.82	63.02	70.03	78.78	88.76	101.44	46.24	49.72	53.83	59.29	66.01	73.52	82.85
19	55.10	59.48	64.72	71.77	80.59	90.67	103.54							
20	56.28	60.69	65.95	73.05	81.94	92.13	105.19							

Table 5. Smoothed BMI percentiles (in kg/m^2) for boys and girls.

Age (years)	Boys									Girls								
	3rd	10th	25th	50th	75th	90th	97th	OW	OB	3rd	10th	25th	50th	75th	90th	97th	OW	OB
2	14.1	14.7	15.3	16.1	17.1	18.0	19.2	17.3	18.8	13.9	14.5	15.1	15.9	16.9	17.8	18.9	17.3	18.9
3	13.7	14.3	14.9	15.7	16.7	17.7	18.8	16.9	18.5	13.5	14.1	14.8	15.6	16.6	17.6	18.8	17.0	18.8
4	13.4	14.0	14.7	15.5	16.5	17.6	18.8	16.7	18.4	13.2	13.8	14.5	15.4	16.5	17.6	18.9	16.9	18.8
5	13.3	13.9	14.6	15.5	16.5	17.7	19.1	16.8	18.6	13.0	13.7	14.4	15.3	16.5	17.7	19.1	17.0	19.1
6	13.2	13.8	14.6	15.5	16.7	18.0	19.6	16.9	19.1	12.9	13.6	14.3	15.4	16.6	17.9	19.6	17.1	19.5
7	13.1	13.8	14.6	15.6	16.9	18.4	20.3	17.2	19.6	12.9	13.6	14.4	15.5	16.8	18.3	20.2	17.4	20.1
8	13.1	13.8	14.7	15.8	17.2	18.9	21.1	17.5	20.3	13.0	13.7	14.6	15.7	17.2	18.8	21.0	17.9	20.9
9	13.3	14.0	14.9	16.1	17.7	19.6	22.2	18.0	21.3	13.2	14.0	14.9	16.2	17.7	19.6	22.0	18.5	21.9
10	13.6	14.4	15.3	16.6	18.4	20.5	23.4	18.7	22.4	13.5	14.4	15.4	16.7	18.4	20.5	23.2	19.3	23.1
11	14.0	14.8	15.8	17.2	19.1	21.4	24.7	19.5	23.6	14.0	14.9	15.9	17.4	19.2	21.4	24.5	20.2	24.3
12	14.4	15.3	16.3	17.8	19.8	22.3	26.0	20.3	24.7	14.5	15.4	16.5	18.1	20.1	22.4	25.7	21.0	25.6
13	14.8	15.8	16.9	18.5	20.6	23.3	27.2	21.1	25.8	15.0	16.0	17.2	18.8	20.9	23.4	26.9	21.9	26.7
14	15.3	16.3	17.5	19.2	21.4	24.2	28.3	21.9	26.9	15.6	16.6	17.8	19.5	21.7	24.3	27.9	22.8	27.7
15	15.9	16.9	18.2	19.9	22.3	25.1	29.3	22.8	27.8	16.1	17.2	18.4	20.2	22.4	25.0	28.7	23.5	28.5
16	16.5	17.5	18.8	20.7	23.0	26.0	30.1	23.6	28.7	16.6	17.7	18.9	20.7	22.9	25.6	29.3	24.1	29.1
17	17.0	18.1	19.5	21.4	23.8	26.7	30.8	24.3	29.4	17.0	18.1	19.4	21.2	23.4	26.1	29.8	24.6	29.6
18	17.5	18.7	20.1	22.0	24.4	27.4	31.4	25.0	30.0	17.4	18.5	19.8	21.6	23.9	26.6	30.2	25.0	30.0
19	17.9	19.1	20.6	22.5	25.0	28.0	31.9	25.0	30.0									
20	18.3	19.5	21.0	23.0	25.6	28.5	32.4	25.0	30.0									

BMI, body mass index; OW, overweight; OB, obesity.

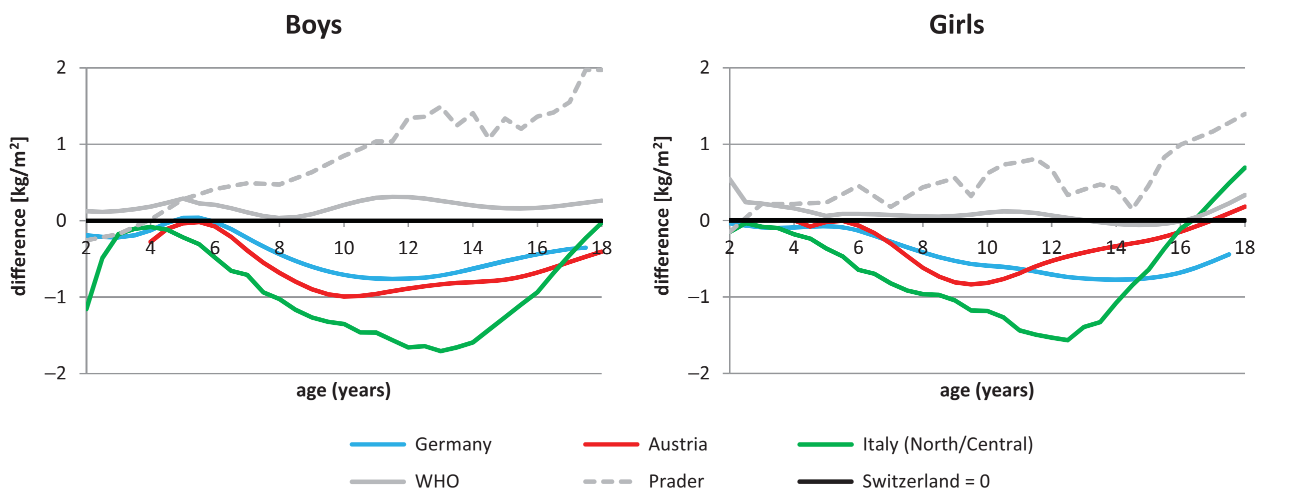

Figure 3. Differences in the 50th BMI-for-age percentile between our results and those of neighbouring countries, World Health Organisation (WHO) and Prader (unpublished data). Positive differences indicate that our results are higher than those of the compared reference, whereas negative differences indicate lower results.

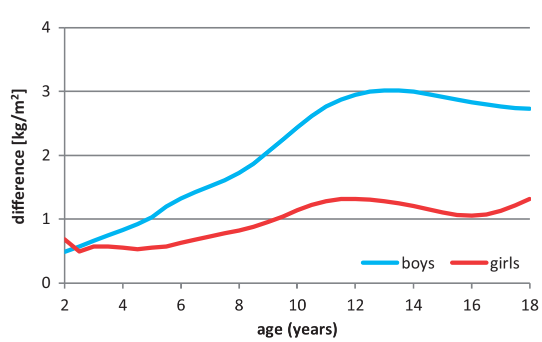

Figure 4. Differences in the 97th BMI-for-age percentile between our results and those of the World Health Organisation (WHO). Positive differences indicate that our results are higher than those of the WHO.

below our calculated 97th percentile with the largest difference of 3 kg/m^2 (WHO: −0.4 SDS) at the age of 12–14 years, which corresponds to 8 kg for a boy of median height. For 9-year-old girls or older, the WHO reference is 1–1.3 kg/m^2 below our 97th percentile (WHO: −0.2 SDS); this corresponds to 3 kg for a 12-year-old girl of median height.

Comparison with contemporary growth curves of neighbouring countries

The German and Austrian BMI median for boys aged between 10–12 years is about 1 kg/m^2 (Germany: 0.3 SDS; Austria: 0.4 SDS) higher than the Swiss equivalent. This corresponds to a weight difference of 2 kg (at 10 years) to 2.5 kg (at 13 years) for a boy of median height (Figure 3 and Supplementary Appendices 13 and 14). The Italian BMI median for 13-year-old boys is 1.7 kg/m^2 (0.6 SDS) above the Swiss median. The BMI median of German and Swiss girls differs mostly around 14 years of age; the German value is 0.8 kg/m^2 (0.3 SDS) higher than the Swiss value (corresponding to 2.2 kg for a 14-year-old girl of median height). The largest difference from the Austrian and Italian norms occurs at the age of 9 years with 0.8 kg/m^2 (0.4 SDS) and 12 years with 1.6 kg/m^2 (0.5 SDS), respectively.

Around the age of 9 years, the 97th percentiles for Italian and Austrian populations are up to 3 kg/m^2 (0.5 SDS) above the Swiss 97th percentiles for boys. The biggest difference in girls is observed between Switzerland and Germany around the age of 12 years (Germany: 3 kg/m^2 higher; 0.4 SDS).

Migration and socioeconomic aspects

The prevalence of being overweight is high in children with parents from countries of southern Europe (20–28%) (Table 6). The probability of being overweight is strongly influenced by parent origin and, to a lesser extent, by the factors of sex and SEP based on residential area (Figure 5). Having parents originating from southern European countries increases the risk of being overweight 2.5-fold. Given a median SEP, the probability of becoming overweight is 12% for boys and 9% for girls with both parents originating from Switzerland. For children with both parents from southern European countries, this probability increases to 31% for boys and 23% for girls.

Table 6. Rates of overweight and obesity (in percentages) according to parent origin (subjects ≥ 2 years).[a]

	Boys		Girls	
	Overweight[b]	Obese	Overweight[b]	Obese
Origin of both parents				
CH	9.6	1.2	8.8	1.6
DE, FR, AUT, SCAND, BENELUX	5.4	1.0	6.5	0.5
IT, ES, PT	20.5	5.7	19.7	5.3
BALKAN	28.2	9.5	20.0	6.2
Turkey	25.0	6.3	23.0	5.2
Other / mixed / unknown	19.7	4.9	18.2	3.9
Origin of one parent				
CH	9.0	1.6	9.4	1.6
Total sample	16.6	4.0	14.1	3.0

[a]Overweight and obesity status as defined by the International Obesity Task Force (IOTF) cut-offs published by Cole et al. (2000).
[b]Category including obese subjects.
CH, Switzerland; DE, Germany; FR, France; AUT, Austria; SCAND, Scandinavian countries; BENELUX, Belgium, Netherlands, Luxembourg; IT, Italy; ES, Spain; PT, Portugal; BALKAN, Balkan countries.

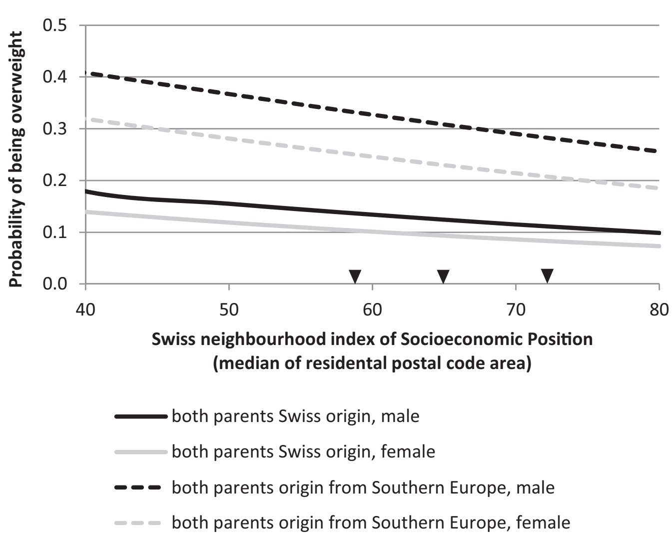

Figure 5. Probability of being overweight for children ≥ 8 years of age with both parents originating from Switzerland or both parents originating from southern European countries (Balkan region; Italy/Spain/Portugal; Turkey). Overweight status was defined by the International Obesity Task Force (IOTF) cut-off criteria (Cole et al. 2000). Black arrows indicate the observed empirical quartiles of the socioeconomic position index.

Prevalence and cut-off values for overweight and obesity

Prevalence rates of being overweight (including obesity) lie between 16% and 20% for boys, and between 13% and 17% for girls, depending on the chosen cut-off criteria (Table 7).

For boys, the cut-off percentiles for being overweight and obese (based on the percentiles of BMI values of 25 and 30 kg/m^2 at the age of 18) calculated from our data set represent the 79th and 96th percentiles of the BMI growth curve (Table 8). The respective cut-off percentiles for girls represent the 83rd and 97th percentiles. Compared to neighbouring countries, our cut-off percentiles for being overweight and obese closely resemble those of Germany and Austria.

Discussion

With around 18,000 observations of children and adolescents prospectively collected between 2017 and 2019 and supplementary data obtained in the form of three recent external retrospective data sets, we were able to establish new height-, weight- and BMI-for-age curves for children living in Switzerland. The height-for-age curves show that early growth and final adult height are similar to those observed earlier by Prader and colleagues, although our sample is taller during the interval between 5 years to adulthood. However, weight and BMI curves show that today's boys and—to a lesser extent—today's girls are heavier. The increase in BMI begins at about 5 years of age and increases, especially in boys, considerably after 10 years of age.

Table 7. Prevalence of overweight and obesity (in percentages) determined by various cut-off definitions (subjects ≥ 2 years).

Sex	BMI classification	WHO (90th & 97th percentile)	IOTF cut-offs[a]	Percentiles at BMI = 25 and 30 kg/m^2 with age 18
Boys	Overweight[b]	16.4	16.6	20.4
	Obesity	7.8	4.0	5.0
Girls	Overweight[b]	13.0	14.1	16.9
	Obesity	5.2	3.0	3.6

[a]Cut-offs published by Cole et al. (2000).
[b]Category including obese subjects.
BMI, body mass index; WHO, World Health Organisation; IOTF, International Obesity Task Force.

Table 8. Cut-off percentiles for overweight and obesity status in comparison to neighbouring countries.

Sex	BMI classification	Switzerland	Germany	Austria	Italy (north/central)
Boys	Overweight	78.9	76.7	77.2	83
	Obesity	95.5	95	94.9	98.2
Girls	Overweight	82.9	80.1	85.5	90
	Obesity	96.8	95.5	97.3	98.7

BMI, body mass index.

Height

Between the children sampled for the First Zurich longitudinal study (Prader et al. 1989) and our work, there are about two generations separating these populations. Until the age of 5 years, the Prader curve and our data set are practically identical. The differences thereafter are possibly the consequence of an earlier pubertal growth spurt and the small difference in the final adult height mirrors the declining secular trend. Follow-up growth charts have also been published for Norwegian and Danish populations that were compared with earlier national growth data (Júlíusson et al. 2009; Tinggaard et al. 2014). For these countries, growth during the first 5 years hardly changed over the last two generations, but there was a clear tendency towards increased height from pre-pubertal ages.

The comparison between our curves and those established by the WHO shows that children in Switzerland are taller from the second year of birth until adulthood. Our 3rd percentile (similar to those of our neighbouring countries Germany and Austria) lies up to 4 cm above the 3rd WHO percentile. This is of clinical relevance. Normally, paediatricians only become concerned when the level of a child's growth falls below the 3rd percentile. Consequently, diagnoses may be missed or diagnosed late, especially as a greater proportion of children with diseases that influence growth are found within the lower percentiles (Christesen et al. 2016).

The comparison with recent growth curves from our neighbouring countries, Germany and Austria, shows only small differences over the whole age range between the median percentile curves. Children of northern/central Italy are comparable with their Swiss, Austrian and German peers until 12 years (girls) and 14 years (boys). Thereafter, the differences increase as a result of an earlier cessation of growth and shorter final height.

By examining the impact of immigrant children on height, we found that children from Swiss parents differed only marginally from the overall growth curve and, therefore, we included all children in our sample regardless of their national origin. There was an exception at age 10–11 for girls with both parents being Swiss; these children were 1.3 cm smaller than the overall median. We assume that this is caused by a slight delay in the onset of puberty.

As expected for a society with relatively low socioeconomic differences among the various sections of the population, we also did not observe any relevant differences in height between poor and rich socioeconomic areas in Switzerland.

Weight and BMI

BMI, as well as the prevalence of being overweight and obese, has increased in many countries over the last decades (Coombes 2014; Mayer et al. 2015). We also observed an increase in BMI when comparing the median BMI of the Prader longitudinal study (unpublished data) with our median BMI curve, which is close to those of our neighbouring countries. Today, median BMI is about 2 kg/m^2 higher in 18-year-old boys and 1.4 kg/m^2 higher in 18-year-old girls than two generations before.

Further analysis of BMI in Switzerland reveals that boys and girls from parents originating from countries of southern Europe (including Turkey and the Balkan region) have a 2.5-fold higher risk of becoming overweight over children with both parents of Swiss origin. This risk depends mainly on the area of origin and is only minimally influenced by the residential socioeconomic situation. The prevalence of becoming overweight or obese for children when only one parent is Swiss is almost identical with the children who have both parents of Swiss origin. The origin seems to have the greatest influence on BMI, possibly through genetic and/or cultural eating habits.

Compared with the WHO standard/references, the 50th BMI percentiles in boys and girls are similar compared to our new Swiss sample. This is remarkable given that many children sampled for the WHO cohort were born within the same period as the Prader study subjects who had a significantly lower BMI. However, the course of the 97th BMI percentile WHO curve differs and extends well below the 97th percentile of our new Swiss curve as well as below those of Germany and Austria. This is explained by the fact that the WHO excluded so-called 'unhealthy weights'. All weight-for-height values that deviated more than ±3 standard deviations (SD) from the median from the longitudinal sample and more than −3 SD or +2 SD from the median from the cross-sectional sample were removed before the percentiles were calculated. This leads to a decrease in the gender-specific 97th empirical percentiles (Flegal et al. 2012). By applying this process to our data, this would equate to excluding about 670 boys and 500 girls because they were considered too heavy for their height in addition to the outliers we identified. Consequently, this results in a decrease of the gender-specific 97th percentiles by about 1 kg/m^2 at the age of 5 years, 2 kg/m^2 at the age of 13 years and 3.5 kg/m^2 at the end of growth. The 90th percentile also decreased by 1.7 kg/m^2 at the end of growth.

To date, there is no unanimously accepted definition for overweight and obesity in children based on age- and sex-specific BMI. Standard definitions for overweight and obesity were published in 2000 by the IOFT (Cole et al. 2000) and have since been widely used. German and Austrian working groups calculated cut-offs for overweight and obesity based on the IOTF methodology and by using their own local data (Schaffrath Rosario et al. 2010; Mayer et al. 2015). Nevertheless, Schaffrath Rosario et al. (2010) proposed the continued use of 90th and 97th percentiles from the older German reference (Kromeyer-Hauschild et al. 2001) to ensure a comparable estimate of the prevalence of overweight and obesity over a longer observation period for German children. Mayer et al. (2015), on the other hand, recommend the use of IOTF criteria based on their own national data to classify overweight and obesity in Austria. In Switzerland, the 90th and 97th percentiles of the WHO standards/references are generally applied in conjunction with German reference values (Kromeyer-Hauschild et al. 2001).

Depending on the cut-off definition used, the prevalence of overweight and obesity in our sample varies considerably. Prevalence of overweight is highest when using the percentiles which correspond to 25 kg/m^2 at the age of 18 as the cut-off throughout childhood. Prevalence of obesity rates are highest when using the WHO 97th percentile as the cut-off.

There are some study limitations to consider. Our prospective data collection was done by 62 paediatricians in 34 practices as well as by our own staff in schools. In addition, we included three retrospective data sources, each of which generated additional measurements. Therefore, we cannot make any appraisal concerning the degree of the inter-rater reliability of our measurement data. We assume that the quality of the prospective measurements was high, since all staff were specifically trained according to the study protocol. They were also highly motivated to obtain precise measurements for contemporary national growth curves. In addition, our data quality analysis (results not shown) shows that the differences among the main data sources are small in terms of standardised height values. A second limitation is that the prospective data collection was localised to central and eastern Switzerland, which might not be representative for the entire country. Panczak et al. (2017) described area variation of height among all young military conscripts aged 18.5–20.5 years in Switzerland: 76% were from the German speaking part and their mean height of 178.4 cm is nearly identical with the median final height of our male sample; 20% were from the French speaking part of Switzerland with a mean height of 177.8 cm; and 4% were from the Italian speaking part with a mean height of 177.1 cm. There are no recent growth references available for our western neighbouring country, France, but the difference between French vs Swiss-German speaking conscripts is small (0.6 cm). The Italian speaking population in Switzerland is ~ 8%; even if we had included an adequate number of measurements from this particular group, we believe our results would not be substantially different.

For the construction of cut-off values for overweight and obesity with the IOTF method, it is important to ensure realistic sampling of 18-year-olds because their BMI distribution defines the cut-off percentile used for all ages. It is a strength that our study includes children and adolescents from birth to 18 and 20 years for girls and boys, respectively, with a representative quotum of different educational levels, particularly at the end of growth. For the 18-year-old male population, we included not only participants attending a wide variety of schools, but also data stemming from male recruits who come from all social classes and parts of Switzerland. For our 18-year-old girls, we took great care to ensure that no more than 30% were high school students, with the remaining 70% enrolled in a wide variety of vocational training courses in different Swiss regions.

Conclusion

We established new growth curves for Switzerland for which growth deviates from the WHO standard/references, especially regarding the 3rd percentile of height and the 97th percentile of BMI. Further medical clarification is usually only undertaken by a paediatrician when a child's height falls below the 3rd percentile. The 97th BMI percentile is important because it can be used as the cut-off value for obesity.

These contemporary height-, weight- and BMI-for-age reference data can be used as a valuable instrument for paediatricians in assessing individual growth of children in Switzerland.

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Data availability statement

Data supporting the findings of this study are available from the corresponding author upon request.

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