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Body mass index percentiles for children and adolescents in Germany based on a nationally representative sample (KiGGS 2003-2006)

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Abstract

Objective: To present body mass index (BMI) percentiles representative for children in Germany and to compare them with currently used percentiles by Kromeyer-Hauschild (KH) and international percentiles of the World Health Organisation (WHO) and the International Obesity Task Force (IOTF).

Methods: Representative examination survey of 17,641 children and adolescents aged 0 to 17 years living in Germany (KiGGS 2003-2006 study, response rate 67%) with standardised measurement of height and weight.

Results: Generally, BMI in KiGGS was higher than in the reference populations from previous decades. KiGGS shows an asymmetric upward shift of the BMI distribution from about age 6 years and an earlier adiposity rebound compared to KH. The BMI peak in the first year of life is shown by KiGGS and WHO but much less by KH. The cut-offs for overweight and obesity determined with the IOTF methodology in KiGGS (percentiles corresponding to BMI 25 and 30 kg/m^2 at age 18) were similar to IOTF cut-offs from age 18 to 10 but systematically lower for younger children.

Conclusions: The KiGGS BMI percentiles appear more valid for Germany than current alternatives and should be used for population monitoring. Despite their methodological limitations, the general shape of the older German KH references is confirmed by KiGGS for the ages 2-17 years. In order not to obscure the increase in obesity rates in the last decades, we therefore propose to continue using KH for individual diagnosis of overweight and obesity and prevalence estimation in this age range.

Keywords: body mass index; centiles; overweight; childhood; adolescence; reference values

Introduction

In children as well as in adults, body mass index (BMI) is the most widely used indicator for defining obesity (Bellizzi and Dietz 1990, Hall and Cole 2006, Himes and Dietz 1994, Must et al 1991a, Must et al 1991b). In children however, due to growth-related changes in body proportions, the cut-off cannot be the same for all ages. There is general agreement on using age-specific percentiles for defining obesity and overweight. However, there is less agreement on the most appropriate reference population, and studies suited for reference value development are remarkably scarce (Bellizzi and Dietz 1990, Cole et al 2000). Frequent limitations include selection bias, lack of measurement standardisation, use of both self-reported and measured BMI, limited statistical power and modelling techniques.

Two different sets of cut-off points for international use have been developed: The International Obesity Task Force (IOTF) proposed cut-offs defined by the specific percentiles which at age 18.0 correspond to the adult cut-off points for overweight and obesity of 25 kg/m² and 30 kg/m² (Cole et al 2000). However, the reference population consisted of six studies (1963-1993) from countries with widely differing prevalence rates for obesity and probably also with differences in pubertal timing. The World Health Organisation (WHO) chose a new prescriptive approach for children under age five by using a selective multi-country reference population (1997-2003) of exclusively breast-fed healthy babies from comparable affluent backgrounds (WHO Multicenter Growth Reference Study Group 2006a, WHO Multicenter Growth Reference Study Group 2006b). For older children and adolescents, the new WHO reference values for BMI are derived from data collected in 1971-1974 in the United States (de Onis et al 2007). Such international reference values have the advantage of allowing cross-national comparisons, but it is not clear how well they fit child populations whose data were not included in the reference population.

Reference values from national studies have been developed in some countries (Cacciari et al 2002, Cole et al 1995, Del-Rio-Navarro et al 2007, Lindgren et al 1995, Luciano et al 1997, Moreno et al 2006, Must et al 1991a, Rolland-Cachera et al 1991). In Germany for example, national reference values for BMI in children are based on the best available data at the time (1985-1999). These reference values by Kromeyer-Hauschild et al. (KH) (Kromeyer-Hauschild et al 2001), however, have serious limitations such as use of both measured and parent-reported height and weight, use of non-representative data from regions and time periods with different prevalences of obesity, heterogeneity of sampling and measurement methods and limited statistical power in certain age groups (Kromeyer-Hauschild et al 2001).

As a first step towards a more valid national monitoring of childhood obesity with methods reproducible over time, the KiGGS 2003-2006 study is a nationally representative study of children aged 0 to 17 years living in Germany, with standardised measurements of height and weight (Kurth et al 2008). We present KiGGS BMI percentiles smoothed with the LMS method (Cole and Green 1992) and compare them to the IOTF and WHO international reference values as well as to the older German KH percentiles in order to learn more about type and magnitude of differences between available BMI reference value systems.

METHODS

Study population

The German Health Interview and Examination Survey for Children and Adolescents (KiGGS) is a population-based, nationally representative cross-sectional study carried out from May 2003 to May 2006 with 17,641 participants (8985 boys, 8656 girls) aged 0- to 17-years living in Germany (response rate 66.6%) (Kurth et al 2008). Sampling involved random selection of 167 communities stratified by federal state, community type and size, followed by random selection of an equal number of children per birth year from local population registries. KiGGS includes 17 % of children with a two-sided migration background, migrants from Turkey and from the former Soviet Union being the two largest groups (Kurth et al 2008). The girls' median age at menarche was 12.8 years, the boys' voice started changing/reached a deep voice at a median of 13.5/15.1 years (Kahl et al 2007). The survey was approved by the Federal Office for Data Protection and by the Charité University Medicine ethics committee. Written informed consent was obtained from all parents or caregivers as well as from participants aged 14 years or older. A computer-assisted personal interview by a study physician included questioning on current and past medical conditions and medication within the seven days preceding the interview.

Body height was measured by trained staff according to a standardised protocol to the nearest 0.1 cm using portable devices (supine length with Harpenden infantometer for ages 0-1 years and standing height with Harpenden stadiometer for ages 2-17, and age 1 year if lying measurement was not tolerated; Holtain Ltd., Crymych, UK). Body weight was measured in underwear to the nearest 0.1 kg with a calibrated scale (SECA, Birmingham, UK) (Kurth et al 2008). Measurement procedures were subject to internal and external quality control measures. BMI was calculated as the ratio of weight (in kg) by height/length (in m^2) and rounded to three digits.

KiGGS includes only very few children under the age of 3 months, therefore only data of children aged 3.0 months to under 18 years were used in the analysis (the oldest child was aged 17.98 years). Percentiles are presented for ages 4.0 months to 17.5 years. Of all KiGGS participants, 3.6% of boys and 3.1% of girls were excluded from the reference population. Height or weight measurements were missing or invalid in 147 children (ranging from 2.3% among 0-2 year olds to <1% among older children). Other reasons for exclusion from the reference population were chronic conditions or intake of medication that can influence growth and weight development: premature birth (only for 0-1 year olds), severe infections (only for 0-1 year olds or if infection had occurred during the past 4 weeks), chronic renal or gastrointestinal diseases, Down’s syndrome, cystic fibrosis, pubertas praecox, micro- or hydrocephalus, tuberculosis, rheumatic diseases and arthritis (because of the associated intake of corticosteroids), cancer or congenital heart defects with impairment of physical fitness; current intake of growth hormones, corticosteroids or medication for attention deficit hyperactivity disorder.

Statistical analysis

The LMS method (Cole and Green 1992) was used to model the age-specific percentile curves. It is based on three parameters: L, which is related to the skewness, M, the median, and S, the coefficient of variation of the original data. L, M and S are taken to be smooth curves of exact age and modelled as cubic splines. The ($100\cdot\alpha$)-percentile at age *a*, $P_\alpha(a)$, is given by

$$P_\alpha(a) = M(a)\cdot\left(1 + L(a)\cdot S(a)\cdot z_\alpha\right)^{1/L(a)}$$ for **Fehler! Textmarke nicht definiert.** $L(a) \neq 0$

with z_α the α-quantile of a standard normal distribution. These percentiles are shown in Tables 2 and 3 and Figure 1. The z-score or standard deviation score (SDS score) for an individual BMI of *x* kg/m² at age *a* can be calculated from the tables as

$$SDS(x;a) = \frac{\left(x/M(a) \right)^{L(a)} - 1}{L(a) \cdot S(a)}$$ for **Fehler! Textmarke nicht definiert.** $L(a) \neq 0$.

The goodness-of-fit was examined via Q-Tests (Pan and Cole 2004, Royston and Wright 2000) and wurmplots (van Buuren and Fredriks 2001), by a graphical comparison of the smoothed with the unsmoothed percentiles and by examining the percentage of the data outside the smoothed percentiles. In order to stabilize the model at the lower end of the age range, parent-reported data on length and weight at birth were used in the fitting process. Use of the birth data was restricted to under 2-year-olds in order to avoid possible secular trends, and to minimize recall bias. Six outlying values in boys and 13 in girls were excluded. It was not possible to fit the percentile curves for the entire age range 0-17 years in one single model. In particular, the age at which the maximum BMI occurs in the first year of life moved downwards (from 1.2 to 0.8 years) when the degrees of freedom were increased, but then the M-curve was very wiggly for the older ages. Therefore, the curves were fit separately for the age range 0-4 years (model A) and 1-17 years (model B) and then combined by fitting a cubic spline to the L, M and S values resulting from model A and model B.

The LMS model was fitted using the programme lmsChartMaker Pro (version 2.2; Medical Research Council, UK, 2006). All other calculations were carried out in SAS (version 9.2; SAS Institute Inc., Cary, NC, USA, 2008). Sampling weights were used to account for unequal sampling probabilities and to reflect the distribution of the population in Germany with respect to age, sex, living in East- vs. West-Germany vs. Berlin and German/non-German nationality (Kurth et al 2008).

RESULTS

The reference population consisted of 8645 boys and 8378 girls with 405 to 528 children per age and sex group (see Table 1). Figure 1 and Tables 2 and 3 show the smoothed BMI percentiles for boys and girls aged 4 months to 17.5 years. The BMI values in Tables 2 and 3 are tabulated at exact ages. Therefore, when used for prevalence estimations of BMI by one-year age groups, the mid-year value gives an unbiased estimate, e.g. for the 5.0 to 5.99 year group the BMI cut-off tabulated for age 5.5 years should be used (see also (Cole et al 2000)). For individual children, the BMI values for tabulated ages bordering the exact age of the child will be relevant, e.g. the values for ages 5.0 and 5.5 for a child aged 5 years and one month (and the correct cut-off will be closer to the value tabulated for 5.0 than to the one for 5.5).

From age 4 months, all KiGGS BMI percentiles run almost parallel until the age of adiposity rebound. There is a strong BMI increase during the first year of life, with the maximum reached at about 9 months, then an almost linear decrease until the age of the adiposity rebound, when BMI increases again. The adiposity rebound occurs earlier in the higher percentiles, e.g. at 5.2 years for both boys and girls in the median curve, but 6 months to two years earlier in P90 and P97. The subsequent increase in BMI is also more pronounced in the higher percentiles. From age 10 onwards, starting in the upper percentiles, girls have slightly higher BMI values than boys. By age 18, BMI percentiles of boys and girls are largely similar.

Compared to the currently used German KH percentiles and the WHO percentiles, the KiGGS percentiles show an upward shift of the BMI distribution, becoming most evident in the upper percentiles and starting from about age 6 years (Figure 2). The stronger upward shift in the upper percentiles is also apparent after a transformation to standard deviation scores (SDS) according to the KH reference (plots not shown). For example, P50 for boys at age 16.0 is by 0.22 SDS higher than KH, P90 by 0.34 and P97 by 0.42 SDS. For girls, the difference for P50 is 0.26 SDS, for P90 0.42 and for P97 0.60 SDS. An small increase is also seen in the lower percentiles (P3 – plots not shown – and P10), mostly in adolescent girls. The general shape is more similar between KiGGS and KH than between KiGGS and the WHO reference. As an exception to this, the BMI peak in the first year of life, which can be seen in the KiGGS percentiles as well as in the WHO percentiles (KiGGS about 1-2 months later than WHO), almost doesn't exist in the KH percentiles (Figure 2).

In analogy to the method used for obtaining the IOTF cutpoints for overweight and obesity (Cole et al 2000), we determined the KiGGS percentiles which, at age 17.98, correspond to the adult cut-offs for overweight and obesity, i.e. 25 and 30 kg/m^2. The specific KiGGS percentiles thus defining overweight and obesity were lower than the corresponding IOTF percentiles: P76.7 and P95.0 for boys and P80.1 and P95.5 for girls. The two sets of cut-offs are in good accordance, especially among boys, starting at age 8–10 years, but differ considerably in the younger children (Figure 3). At age 2 years, the IOTF cut-offs for overweight even approach the KiGGS percentiles defining obesity.

Discussion

The KiGGS 2003-2006 study provides the first nationally representative, population-based, standardised BMI measurements of a large sample of children and adolescents living in Germany. Based on these data, we present BMI percentiles smoothed with the LMS method for boys and girls aged 4 months to 17.5 years and we compare them to percentiles based on older German KH and international WHO and IOTF reference populations.

Generally, BMI is higher in KiGGS than in the three other reference populations and there are age-dependent differences in the shape of the percentiles. Compared to the currently used German KH percentiles, which are based on pooled data from 17 regional and methodologically heterogeneous German studies from 1985 to 1999 (Kromeyer-Hauschild et al 2001), the KiGGS percentiles show an upward shift of the BMI distribution from around age 6 years upwards, which is more pronounced in the upper percentiles. This population-wide asymmetric BMI increase in the last decades is in accordance with results from other German regional studies (Apfelbacher et al 2008, Herpertz-Dahlmann et al 2003, Kalies et al 2002, Kromeyer-Hauschild and Zellner 2007, Meigen et al 2008, Moss et al 2007, von Kries 2004, Zellner et al 2004). Of note, compared to KH, KiGGS has a very similar height distribution (SDS analysis, not shown here). This confirms previous reports of a levelling-off of the secular increase in height (Zellner et al 2004).

Overall, despite methodological limitations of the KH references, the general shape of KH is confirmed by KiGGS for almost the entire age range. A notable exception, however, is the age range 0 to 2 years, where KH almost doesn’t show the peak in the first year of life that can be seen in both KiGGS and WHO and which has recently been reported to predict later BMI (Silverwood et al 2009). There are many differences between these reference populations. For example, WHO included only breastfed children while in KiGGS 40% of children under five were not fully breastfed until the fourth month. However, major reasons for the resemblance of KiGGS and WHO, but not KH percentiles under the age of two are likely to be the separate modelling of data for younger children as well as sampling and measurement issues like shorter time intervals and standardised measurements in both

KiGGS and WHO, but not in KH. In fact, our initial modelling of the KiGGS data over the entire age range of 0 to 17 years did not show this peak known from the WHO reference (WHO Multicenter Growth Reference Study Group 2006a). Not unexpectedly, for older children, the KiGGS BMI data show an even more pronounced upward shift in comparison with the WHO percentiles for children over 5 years, which are based on data from the United States from 1971-1974 (de Onis et al 2007).

To our knowledge, this is the first analysis that applies the IOTF approach to another reference population, i.e. that reports the specific percentiles that equal the adult cut-offs for overweight and obesity at age 18 years and compares the age-related distribution of these specific percentiles in different data-sets. These specific percentiles that define overweight and obesity by the IOTF method in the 2003-2006 KiGGS dataset from Germany are lower than the ones found in the six IOTF data sets 1963-1993 (Cole et al 2000): overweight boys KiGGS P76.7, IOTF P81.9- P95.3; overweight girls KiGGS P80.1, IOTF P83.5-P93.5; obesity boys KiGGS P95.0, IOTF P96.7-P99.9; obesity girls KiGGS P95.5, IOTF P96.0-P99.7. The resulting cut-offs are in good accordance only in adolescence while for younger children the KiGGS cut-offs are lower. This shows that good accordance between reference systems at age 18 does not necessarily imply good accordance at other ages, and it suggests that the IOTF cut-offs may not be universally applicable in younger children.

Major strengths of the KiGGS study are its large and nationally representative sample size and the standardised measurements of height and weight. The large number of about 500 observations per age and sex group results in curves with stable outer percentiles. Compared to the older German KH percentiles, that partly used screening examination data that are performed at fixed intervals and by multiple observers, KiGGS has

standardised measurements for narrow time intervals. In addition, the separate modelling of data for younger and older children allowed us to better capture the rapidly changing rate of BMI in the first year of life, as confirmed by the greater resemblance of the KiGGS percentiles with the WHO BMI curves at this age. KiGGS also has detailed information on the socioeconomic background of the children and can therefore be used to monitor trends in socio-economic disparities in childhood overweight and obesity. In England for example, despite a stabilized overall prevalence of childhood overweight and obesity, children from lower socio-economic strata have not benefited from this tred (Stamatakis et al 2009).
A possible limitation of KiGGS is selection bias. However, the response rate was good (67%) and two thirds of non-responders answered a short questionnaire including self-reported height and weight. For comparison, height and weight of participants was not only measured but also self-reported (before the measurement). Self-reported BMI of responders and non-responders by age and sex was not significantly different (Kurth and Schaffrath Rosario 2007), which is rather reassuring with respect to selection bias. An additional limitation is that KiGGS has no data for children less than 3 months of age, but the model was stabilized by including self-reported data on weight and length at birth.

In summary, the KiGGS BMI percentiles appear more valid for Germany than current alternatives and should be used for population monitoring. They may also serve as a reference for the evaluation of regional German studies. Participants of the KiGGS study 2003-2006 will be followed over time by regular telephone interviews and follow-up examinations including measurement of height and weight. This KiGGS cohort has the potential of linking BMI cut-offs to prospectively measured health risks and outcomes and could contribute to an improved definition of overweight and obesity in childhood. However, KiGGS percentiles should not be used for a percentile-based redefinition of the cut-offs for overweight and obesity in Germany, as this would fail to capture the obesity epidemic or any success in overcoming it (Wright et al 2002). We therefore propose to continue using the older German KH reference values for the age group 2 to 17 years for individual diagnosis and estimation of the prevalence of overweight and obesity. These percentiles have methodological limitations, but a comparison with KiGGS has not revealed unacceptable deficiencies for this age group. WHO and IOTF reference systems are useful for international comparisons but seem less appropriate for national use.

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References

Apfelbacher CJ, Cairns J, Bruckner T, Mohrenschlager M, Behrendt H, Ring J *et al* (2008). Prevalence of overweight and obesity in East and West German children in the decade after reunification: population-based series of cross-sectional studies. *J Epidemiol Community Health* **62:** 125-130.

Bellizzi MC, Dietz WH (1990). Workshop on childhood obesity: summary of the discussion. *American Journal of Clinical Nutrition* **70:** 173-175 S.

Cacciari E, Milani S, Balsamo A, Dammacco F, De Luca F, Chiarelli F *et al* (2002). Italian cross-sectional growth charts for height, weight and BMI (6-20 y). *Eur J Clin Nutr* **56:** 171-180.

Cole TJ, Green P (1992). Smoothing reference centile curves: The LMS method and penalized likelihood. *Statistics in Medicine* **11:** 1305-1319.

Cole TJ, Freemann J, Preece M (1995). Body mass index reference curves for the UK, 1990. *Archives of Disease in Childhood* **73:** 25-29.

Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* **320:** 1240-1246.

de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* **85:** 660-667.

Del-Rio-Navarro BE, Velazquez-Monroy O, Santos-Preciado JI, Lara-Esqueda A, Berber A, Loredo-Abdala A *et al* (2007). Mexican anthropometric percentiles for ages 10-18. *Eur J Clin Nutr* **61:** 963-975.

Hall DM, Cole TJ (2006). What use is the BMI? *Arch Dis Child* **91:** 283-286.

Herpertz-Dahlmann B, Geller F, Bohle C, Khalil C, Trost-Brinkhues G, Ziegler A *et al* (2003). Secular trends in body mass index measurements in preschool children from the City of Aachen, Germany. *Eur J Pediatr* **162:** 104-109.

Himes JH, Dietz WH (1994). Guidelines for overweight in adolescent preventive services: recommendations from an expert committee. The Expert Committee on Clinical Guidelines for Overweight in Adolescent Preventive Services. *Am J Clin Nutr* **59:** 307-316.

Kahl H, Schaffrath Rosario A, Schlaud M (2007). [Sexual maturation of children and adolescents in Germany. Results of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS)]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* **50:** 677-685.

Kalies H, Lenz J, von Kries R (2002). Prevalence of overweight and obesity and trends in body mass index in German pre-school children, 1982-1997. *Int J Obes Relat Metab Disord* **26:** 1211-1217.

Kromeyer-Hauschild K, Wabitsch M, Kunze D, Geller F, Geiß H, Hesse V *et al* (2001). Perzentile für den Body-mass-Index für das Kindes- und Jugendalter unter Heranziehung verschiedener deutscher Stichproben. *Monatsschrift Kinderheilkunde* **149:** 807-818.

Kromeyer-Hauschild K, Zellner K (2007). Trends in overweight and obesity and changes in the distribution of body mass index in schoolchildren of Jena, East Germany. *Eur J Clin Nutr* **61:** 404-411.

Kurth BM, Schaffrath Rosario A (2007). [The prevalence of overweight and obese children and adolescents living in Germany. Results of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS)]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* **50:** 736-743.

Kurth BM, Kamtsiuris P, Holling H, Schlaud M, Dolle R, Ellert U *et al* (2008). The challenge of comprehensively mapping children's health in a nation-wide health survey: design of the German KiGGS-Study. *BMC Public Health* **8:** 196.

Lindgren G, Strandell A, Cole T, Healy M, Tanner J (1995). Swedish population reference standards for height, weight and body mass index attained at 6 to 16 years (girls) or 19 years (boys). *Acta Paediatr* **84:** 1019-1028.

Luciano A, Bressan F, Zoppi G (1997). Body mass index reference curves for children aged 3-19 years from Verona, Italy. *Eur J Clin Nutr* **51:** 6-10.

Meigen C, Keller A, Gausche R, Kromeyer-Hauschild K, Bluher S, Kiess W *et al* (2008). Secular trends in body mass index in German children and adolescents: a cross-sectional data analysis via CrescNet between 1999 and 2006. *Metabolism* **57:** 934-939.

Moreno LA, Mesana MI, Gonzalez-Gross M, Gil CM, Fleta J, Warnberg J *et al* (2006). Anthropometric body fat composition reference values in Spanish adolescents. The AVENA Study. *Eur J Clin Nutr* **60:** 191-196.

Moss A, Wabitsch M, Kromeyer-Hauschild K, Reinehr T, Kurth BM (2007). [Prevalence of overweight and adiposity in German school children]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* **50:** 1424-1431.

Must A, Dallal GE, Dietz WH (1991a). Reference data for obesity: 85th and 95th percentiles of body mass index (wt/ht2) and triceps skinfold thickness. *Am J Clin Nutr* **53:** 839-846.

Must A, Dallal GE, Dietz WH (1991b). Reference data for obesity: 85th and 95th percentiles of body mass index (wt/ht2)- a correction. *Am J Clin Nutr* **54:** 773.

Pan H, Cole TJ (2004). A comparison of goodness of fit tests for age-related reference ranges. *Stat Med* **23:** 1749-1765.

Rolland-Cachera MF, Cole TJ, Sempe M, Tichet J, Rossignol C, Charraud A (1991). Body Mass Index variations: centiles from birth to 87 years. *Eur J Clin Nutr* **45:** 13-21.

Royston P, Wright EM (2000). Goodness-of-fit statistics for age-specific reference intervals. *Stat Med* **19:** 2943-2962.

Silverwood RJ, De Stavola BL, Cole TJ, Leon DA (2009). BMI peak in infancy as a predictor for later BMI in the Uppsala Family Study. *Int J Obes (Lond)*.

Stamatakis E, Wardle J, Cole TJ (2009). Childhood obesity and overweight prevalence trends in England: evidence for growing socioeconomic disparities. *Int J Obes (Lond)*.

van Buuren S, Fredriks M (2001). Worm plot: a simple diagnostic device for modelling growth reference curves. *Stat Med* **20:** 1259-1277.

von Kries R (2004). Adipositas bei Kindern in Bayern - Erfahrungen aus den Schuleingangsuntersuchungen. *Gesundheitswesen* **66, Sonderheft 1:** 80-85.

WHO Multicenter Growth Reference Study Group (2006a). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatr Suppl* **450:** 76-85.

WHO Multicenter Growth Reference Study Group (2006b). Enrolment and baseline characteristics in the WHO Multicentre Growth Reference Study. *Acta Paediatr Suppl* **450:** 7-15.

Wright CM, Booth IW, Buckler JM, Cameron N, Cole TJ, Healy MJ *et al* (2002). Growth reference charts for use in the United Kingdom. *Arch Dis Child* **86:** 11-14.

Zellner K, Jaeger U, Kromeyer-Hauschild K (2004). Height, weight and BMI of schoolchildren in Jena, Germany--are the secular changes levelling off? *Econ Hum Biol* **2:** 281-294.

Table 1: BMI reference population, KiGGS 2003-2006 study, Germany

Age (years)	% excluded[a)]	N included	BMI: Mean (kg/m²)	BMI: SD[b)] (kg/m²)	% excluded[a)]	N included	BMI: Mean (kg/m²)	BMI: SD[b)] (kg/m²)
		Boys				*Girls*		
0.25–0.99	9.9 %	427	17.08	1.30	9.3 %	415	16.54	1.31
1.00–1.99	9.8 %	409	16.59	1.32	10.8 %	415	16.33	1.27
2.00–2.99	3.0 %	467	16.28	1.42	5.3 %	443	15.94	1.22
3.00–3.99	2.7 %	447	15.94	1.17	2.5 %	459	15.80	1.36
4.00–4.99	1.1 %	475	15.70	1.57	3.1 %	490	15.73	1.57
5.00–5.99	0.7 %	489	15.66	1.59	1.4 %	452	15.61	1.60
6.00–6.99	1.7 %	508	16.04	2.03	1.0 %	485	15.88	1.77
7.00–7.99	2.1 %	517	16.56	2.50	1.2 %	490	16.25	2.19
8.00–8.99	3.0 %	499	17.05	2.74	1.3 %	515	16.85	2.38
9.00–9.99	4.0 %	528	17.51	2.57	2.0 %	508	17.66	2.82
10.00–10.99	5.4 %	512	18.40	3.00	3.1 %	467	18.27	3.29
11.00–11.99	3.9 %	519	19.13	3.28	1.6 %	509	19.10	3.73
12.00–12.99	5.9 %	485	19.59	3.62	3.1 %	481	20.11	3.96
13.00–13.99	5.2 %	510	20.30	3.81	1.3 %	466	20.72	4.08
14.00–14.99	2.6 %	523	21.00	4.24	3.2 %	451	21.46	4.46
15.00–15.99	2.8 %	490	21.59	4.22	1.6 %	457	22.01	4.78
16.00–16.99	3.5 %	435	22.23	4.34	3.6 %	441	22.28	4.16
17.00–17.98	1.2 %	405	22.54	4.62	3.5 %	434	22.57	4.54
Total	3.6 %	8645	18.53	3.83	3.1 %	8378	18.55	4.01

[a)] percent of total population (8985 boys, 8656 girls)

[b)] SD = standard deviation

Table 2: Smoothed BMI percentiles for boys, KiGGS 2003-2006 study, Germany

Age (years)	L	S	P3	P10	P25	P50 (M, median)	P75	P90	P97
4.0 months	0.069	0.094	13.66	14.46	15.31	16.314	17.38	18.39	19.44
6.0 months	-0.011	0.092	14.27	15.08	15.95	16.971	18.06	19.10	20.19
8.0 months	-0.092	0.091	14.50	15.30	16.16	17.175	18.26	19.30	20.40
10.0 months	-0.172	0.089	14.60	15.38	16.22	17.226	18.30	19.34	20.42
1.0 years	-0.251	0.088	14.54	15.30	16.12	17.092	18.14	19.16	20.23
1.25	-0.374	0.086	14.44	15.16	15.95	16.887	17.90	18.89	19.95
1.5	-0.500	0.084	14.30	14.99	15.75	16.650	17.63	18.60	19.63
1.75	-0.630	0.082	14.20	14.87	15.59	16.464	17.42	18.36	19.38
2.0	-0.763	0.081	14.15	14.79	15.49	16.336	17.27	18.20	19.20
2.5	-1.042	0.078	14.06	14.65	15.31	16.124	17.03	17.93	18.92
3.0	-1.329	0.077	13.97	14.53	15.16	15.942	16.82	17.72	18.72
3.5	-1.609	0.076	13.88	14.42	15.03	15.787	16.66	17.56	18.58
4.0	-1.865	0.077	13.77	14.29	14.89	15.642	16.52	17.44	18.50
4.5	-2.087	0.079	13.64	14.16	14.75	15.515	16.41	17.37	18.52
5.0	-2.268	0.082	13.53	14.06	14.66	15.444	16.38	17.41	18.67
5.5	-2.405	0.086	13.47	14.01	14.63	15.454	16.46	17.58	18.99
6.0	-2.498	0.092	13.45	14.01	14.66	15.529	16.61	17.85	19.47
6.5	-2.546	0.098	13.46	14.04	14.72	15.653	16.83	18.21	20.08
7.0	-2.552	0.105	13.48	14.09	14.82	15.814	17.10	18.64	20.80
7.5	-2.519	0.112	13.52	14.16	14.93	16.000	17.39	19.11	21.57
8.0	-2.455	0.118	13.57	14.25	15.07	16.211	17.72	19.60	22.37
8.5	-2.367	0.125	13.66	14.37	15.24	16.457	18.08	20.12	23.18
9.0	-2.265	0.131	13.77	14.52	15.45	16.738	18.47	20.66	23.97
9.5	-2.156	0.136	13.90	14.70	15.67	17.041	18.88	21.21	24.73
10.0	-2.049	0.141	14.04	14.88	15.91	17.357	19.29	21.75	25.45
10.5	-1.948	0.145	14.20	15.08	16.16	17.677	19.71	22.28	26.12
11.0	-1.859	0.149	14.36	15.28	16.41	17.992	20.11	22.78	26.75
11.5	-1.784	0.152	14.52	15.48	16.65	18.299	20.50	23.26	27.32
12.0	-1.726	0.155	14.70	15.69	16.90	18.601	20.87	23.71	27.86
12.5	-1.684	0.156	14.89	15.91	17.16	18.904	21.23	24.13	28.36
13.0	-1.656	0.157	15.10	16.15	17.42	19.212	21.59	24.54	28.83
13.5	-1.640	0.157	15.34	16.40	17.70	19.522	21.93	24.93	29.26
14.0	-1.632	0.157	15.59	16.67	17.99	19.834	22.27	25.30	29.65

Age (years)	L	S	P3	P10	P25	P50 (M, median)	P75	P90	P97
14.5	-1.628	0.156	15.86	16.95	18.29	20.149	22.61	25.65	29.99
15.0	-1.626	0.154	16.14	17.24	18.59	20.466	22.94	25.98	30.30
15.5	-1.625	0.152	16.43	17.54	18.90	20.786	23.26	26.29	30.58
16.0	-1.624	0.150	16.72	17.84	19.21	21.104	23.58	26.60	30.83
16.5	-1.624	0.148	17.01	18.14	19.52	21.416	23.89	26.89	31.07
17.0	-1.626	0.146	17.30	18.44	19.82	21.723	24.19	27.17	31.29
17.5	-1.628	0.144	17.59	18.74	20.12	22.025	24.49	27.45	31.52

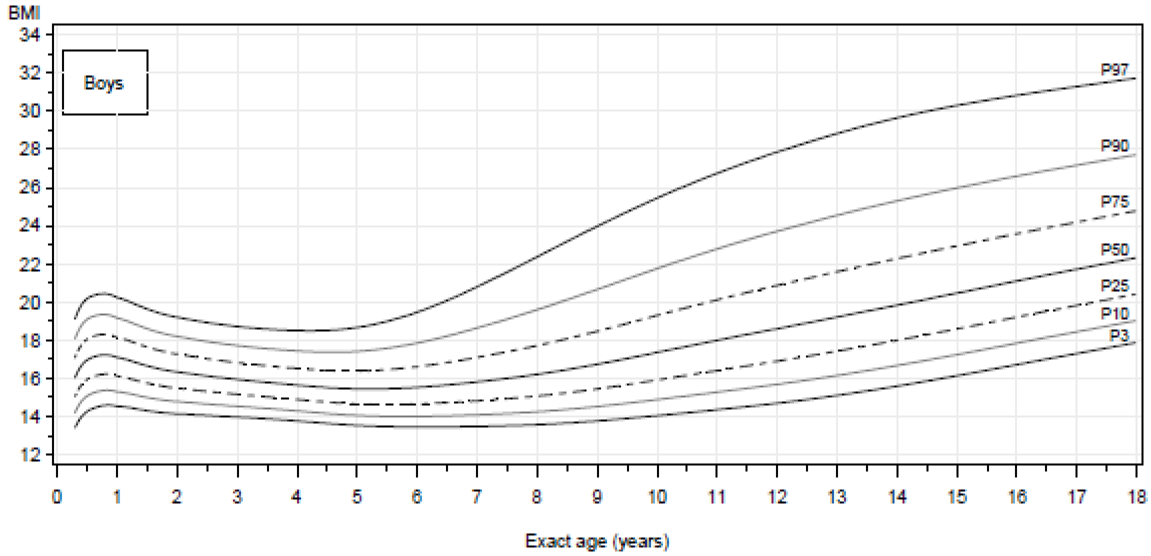
Table 3: Smoothed BMI percentiles for girls, KiGGS 2003-2006 study, Germany

Age (years)	L	S	P3	P10	P25	P50 (M, median)	P75	P90	P97
4.0 months	0.070	0.092	13.22	13.97	14.78	15.725	16.73	17.68	18.67
6.0 months	-0.065	0.090	13.90	14.67	15.49	16.462	17.50	18.49	19.53
8.0 months	-0.200	0.089	14.20	14.95	15.77	16.735	17.78	18.78	19.84
10.0 months	-0.334	0.088	14.26	15.00	15.79	16.744	17.77	18.77	19.83
1.0 years	-0.466	0.086	14.25	14.96	15.73	16.663	17.68	18.66	19.72
1.25	-0.661	0.084	14.17	14.85	15.59	16.484	17.47	18.44	19.49
1.5	-0.848	0.083	14.05	14.69	15.40	16.261	17.22	18.18	19.22
1.75	-1.026	0.082	13.95	14.57	15.25	16.091	17.03	17.98	19.02
2.0	-1.192	0.081	13.90	14.50	15.16	15.985	16.91	17.86	18.91
2.5	-1.485	0.080	13.81	14.39	15.03	15.834	16.76	17.71	18.79
3.0	-1.720	0.081	13.71	14.27	14.91	15.708	16.64	17.62	18.76
3.5	-1.897	0.083	13.61	14.16	14.79	15.600	16.55	17.57	18.77
4.0	-2.024	0.085	13.50	14.05	14.69	15.510	16.49	17.54	18.82
4.5	-2.107	0.088	13.41	13.96	14.61	15.444	16.45	17.55	18.91
5.0	-2.153	0.090	13.33	13.90	14.55	15.410	16.45	17.61	19.04
5.5	-2.170	0.094	13.28	13.86	14.53	15.421	16.50	17.72	19.25
6.0	-2.164	0.098	13.27	13.86	14.56	15.486	16.63	17.92	19.57
6.5	-2.139	0.102	13.28	13.90	14.63	15.602	16.81	18.20	20.00
7.0	-2.100	0.108	13.30	13.95	14.72	15.753	17.05	18.56	20.55
7.5	-2.049	0.115	13.32	14.01	14.83	15.936	17.34	18.99	21.21
8.0	-1.990	0.122	13.36	14.09	14.96	16.154	17.68	19.50	21.98
8.5	-1.926	0.130	13.42	14.19	15.12	16.405	18.06	20.07	22.86
9.0	-1.860	0.138	13.50	14.32	15.31	16.685	18.48	20.69	23.80
9.5	-1.795	0.146	13.59	14.46	15.52	16.989	18.93	21.33	24.78
10.0	-1.735	0.152	13.71	14.63	15.75	17.307	19.38	21.97	25.72
10.5	-1.680	0.158	13.87	14.82	16.00	17.641	19.83	22.58	26.60
11.0	-1.635	0.162	14.06	15.05	16.28	17.996	20.29	23.18	27.40
11.5	-1.601	0.164	14.30	15.33	16.60	18.374	20.75	23.74	28.11
12.0	-1.579	0.165	14.59	15.65	16.95	18.772	21.21	24.27	28.73
12.5	-1.571	0.164	14.91	15.99	17.31	19.174	21.65	24.75	29.24
13.0	-1.576	0.162	15.25	16.34	17.69	19.566	22.06	25.17	29.67
13.5	-1.594	0.160	15.60	16.70	18.06	19.943	22.45	25.55	30.02
14.0	-1.625	0.157	15.95	17.06	18.41	20.295	22.79	25.88	30.32

Age (years)	L	S	P3	P10	P25	P50 (M, median)	P75	P90	P97
14.5	-1.667	0.154	16.29	17.39	18.74	20.619	23.10	26.17	30.58
15.0	-1.719	0.150	16.60	17.70	19.04	20.907	23.37	26.42	30.79
15.5	-1.778	0.147	16.89	17.98	19.31	21.159	23.60	26.62	30.97
16.0	-1.843	0.144	17.15	18.23	19.55	21.374	23.79	26.79	31.12
16.5	-1.912	0.141	17.38	18.45	19.74	21.552	23.95	26.92	31.25
17.0	-1.983	0.139	17.58	18.63	19.91	21.699	24.07	27.03	31.36
17.5	-2.056	0.137	17.76	18.80	20.06	21.828	24.18	27.12	31.46

Figure legends

Figure 1: Smoothed BMI percentiles, KiGGS 2003-2006 study, Germany



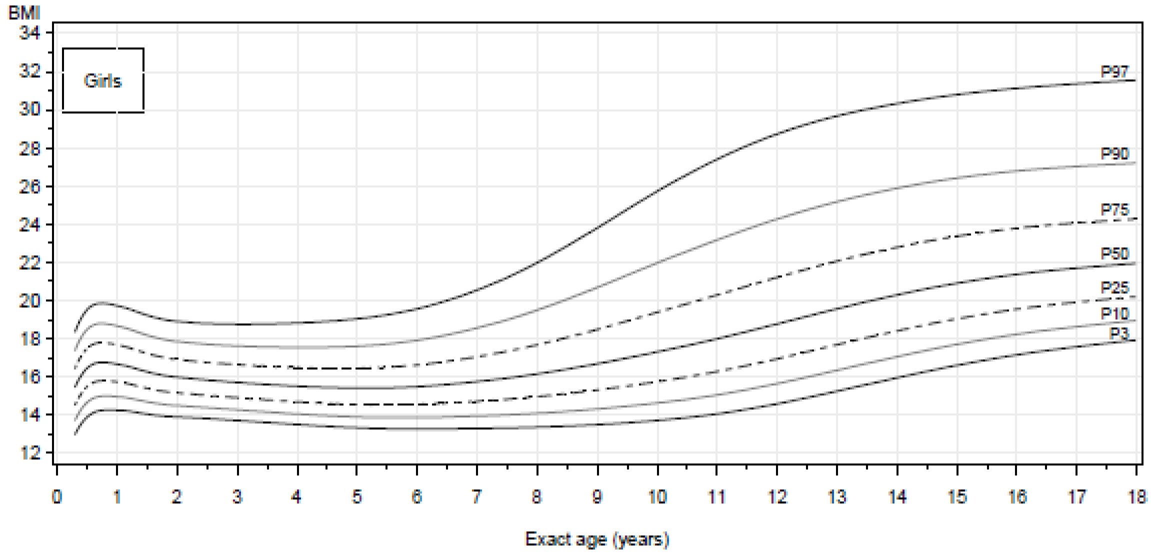


Figure 2: KiGGS BMI percentiles (P10, median P50, P90) compared to the German KH reference and the WHO reference, left panel: 4-24 months, right panel: 2-17 years

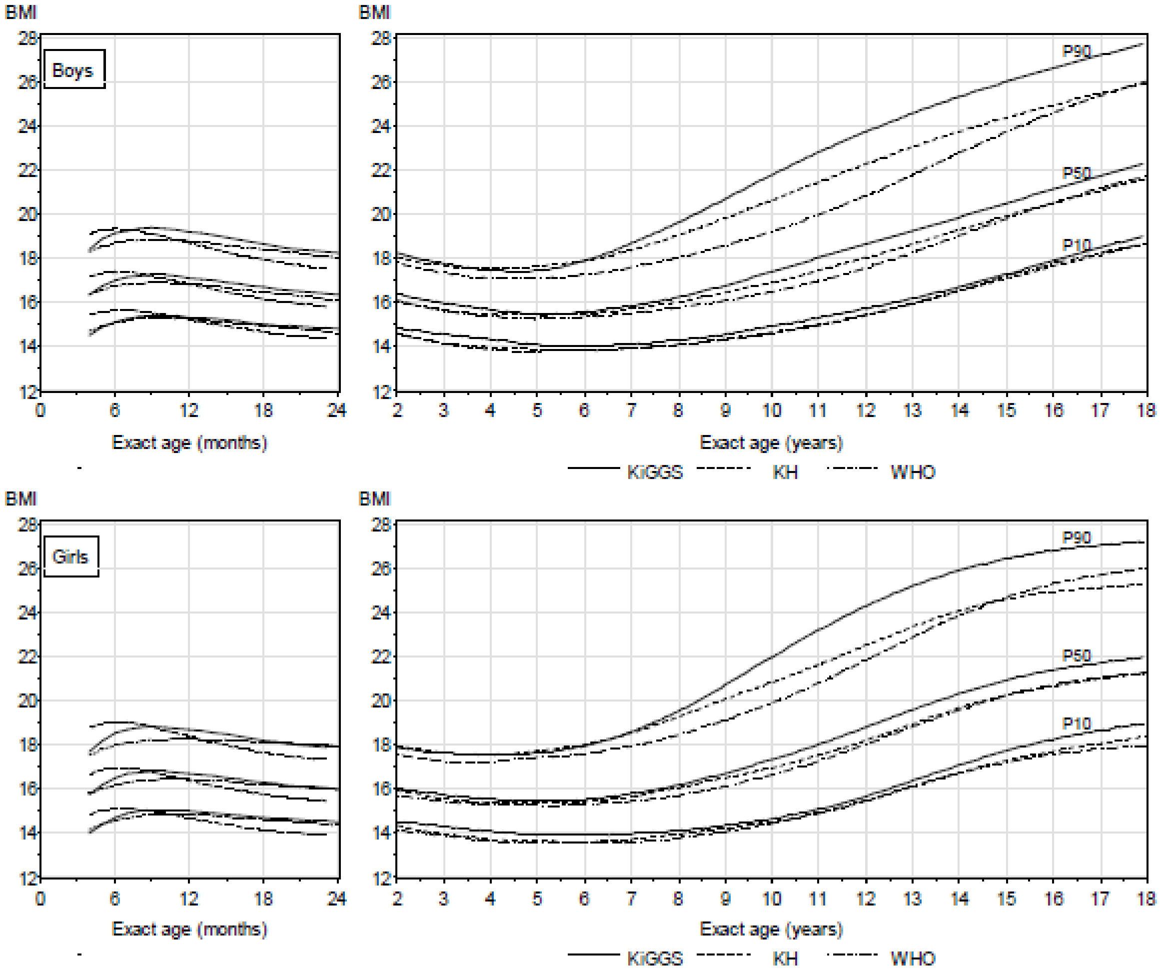


Figure 3: BMI percentiles defining overweight and obesity by the IOTF method in the IOTF and KiGGS dataset