Anthropological Review • Vol. 88(4), 69–76 (2025)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.88.4.04

Assessment of the Internal Consistency of Two Polish References in Detecting Short Stature and Obesity in Children and Adolescents

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Abstract: In paediatric practice, growth references are used by doctors and nurses to evaluate a child's growth status. We present an assessment of the internal consistency of two Polish references in detecting short stature and obesity in children and adolescents. Key diagnostic thresholds, the 3rd percentile for height and the 95th for Body Mass Index (BMI), were selected for comparison. Percentiles were calculated for hypothetical heights 0.2 cm lower than the third percentile of specific references and 0.1 units lower than the 95th percentile of specific references, in the case of height and BMI references, respectively. The z-scores were calculated and converted to percentiles. MS Excel was used. Around the 3rd percentile of height and the 95th percentile of BMI, there is a discrepancy in the Warsaw growth reference for measured height and BMI, respectively, and the calculated percentile. In the case of the Polish 2010 and 2012 growth references, a hypothetical height 0.2 cm below the third percentile of height-for-age reference yielded percentiles below 3 for all ages in both sexes. The Polish 2010 and 2012 growth references for measurements 0.1 units below the obesity threshold yielded percentiles of 94.69–94.86 in boys and girls. The Polish 2010 and 2012 growth references provide consistent and coherent calculation results for the 3rd percentile of height and the 95th percentile of BMI for children and adolescents aged 3–18 years.

Keywords: growth references, children, z-score, percentile

Received: 1.08.2025; Revised: 2.12.2025; Accepted: 4.12.2025

Introduction

The growth of a child is a crucial indicator of health (WHO 1995; Gelander 2006). Monitoring growth to identify health- or nutrition-related problems is a vital task in many medical areas in primary health care (Ministry of Health 2023). Growth references have practical significance as doctors and nurses use them in relation to individual children part of medical assessments evaluating growth status. In Poland, growth references based on a representative national sample of children and adolescents were first developed during OLAF and OLA studies and reported as the Polish 2010 and 2012 growth references for school-aged and preschool children, respectively (Kułaga 2011; 2013). However, references from the years 1996–1999, based on measurements of children from Poland's capital city—hereinafter: "Warsaw growth references"/"Warsaw growth charts"—are still in use (Palczewska and Niedźwiedzka 2001). There are several key differences between the two reference systems, not only in the years of development (more recent vs older ones), population (whole country, including rural populations, vs capital city) but also the method of statistical elaboration (crude percentiles without accounting for data skewness vs LMS, which enables accounting for skew data distribution and smoothing reference curves) (Cole 1990). The biological data including anthropometry like weight, height, and Body Mass Index (BMI), often have asymmetric (skewed) distribution. Calculation of z-score, which is first step in determining the percentile is based on normal (Gaussian) distribution. This is why accounting for the skewed distribution of anthropometric data is crucial for creating accurate growth references. Table 1 provides a summary comparison of the two Polish growth reference systems.

Table 1. Summary characteristics of the Warsaw growth references and the Polish 2010 and 2012 growth references

	Warsaw growth references	Polish 2010 and 2012 growth references
Years of development	1996–1999	2007–2012
Reference population	urban population – Warsaw children and youth	urban and rural – whole country population
Method of study subjects drawing	random sampling	random sampling
Age range	0–18 years	3–18 years
Sample size	6,366	22,292
Statistical method of percentile development	Crude percentiles (calculation without accounting for skewness)	LMS method for constructing normalized growth standards (Cole 1990)
z-score calculation	Based on mean and standard deviation, which does not account for skewness	Based on LMS parameters, a Box-Cox power transformation was used to normalize the data at each age (Cole 1990)
Percentile	Based on the z-score normal distribution	Based on the z-score normal distribution

L = Box-Cox power; *M* = median; *S* = coefficient of variation.

Usually, a result of the measurement is marked on a growth chart (percentile chart). Medical calculators are becoming increasingly popular, and children's growth assessment with a mathematical formula is possible using hospital information systems and online calculators: https://antek.exploreit.io/pl, https://nauka.czd.pl/kalkulator-2/, https://www.jakicentyl.pl/. These calculators use parameters of a growth reference system to calculate percentiles: mean and standard deviation (SD) or LMS if the reference used is constructed according to the LMS method (Cole 1990). A precise calculation of height, weight and BMI percentile is required. The z-score is calculated for this purpose, and based on normal distribution, the percentile associated with the calculated z-score is derived. These approaches are also applicable in scientific analyses, which usually involve processing significant volumes of growth data. It is important to note that different growth reference systems yield different results, which may be of significance in particular cases. This paper aims to provide evidence regarding noteworthy differences in height-for-age and BMI-for-age percentile calculation resulting from the application of two Polish growth references.

Materials and Methods

The internal consistency of calculation percentile values was compared between two reference ranges: 1) the Warsaw growth reference (Palczewska and Niedźwiedzka 2001), 2) the Polish 2010 and 2012 growth references (Kułaga 2011; 2013). Key diagnostic thresholds, the 3rd percentile for height and the 95th for BMI, were selected for comparison. The height-for-age percentiles were calculated for hypothetical heights 2 mm lower than the third percentile of the specific reference. The BMI-for-age percentiles were calculated for a hypothetical BMI 0.1 units lower than the 95th percentile of specific reference (Jodkowska et al. 2007; Kułaga 2011; 2013). The 95th percentile of BMI-for-age is considered to indicate the obesity threshold in childhood and adolescence (Mazur et al. 2024). In the case of the Warsaw growth reference, the following formula was used to calculate the z-score (z):

$$z = \frac{measurement - mean}{standard\ deviation} \tag{1}$$

For the Polish 2010 and 2012 growth references, the formula for z-score calculation was:

$$z = \frac{\left[\frac{measurement}{M}\right]^{L} - 1}{LS} \tag{2}$$

where L = Box-Cox power; M = median; S = coefficient of variation.

Finally, the obtained z-scores were converted to percentiles based on normal distribution using the NORM.S.DIST function and tabulated according to age and sex. All calculations were done using an MS Excel spreadsheet (Microsoft Corporation).

Results

For the Warsaw growth reference, a hypothetical height below the 3rd percentile yielded a calculated percentile above 3.0 for numerous age groups in both boys and girls (Table 2). In the case of the Polish 2010 and 2012 growth references, a hypothetical height 0.2 cm below the third percentile of height-for-age reference yielded percentiles below 3 (2.54–2.90) for all ages in both sexes (Table 2).

Table 2. Height-for-age percentiles calculated for hypothetical height measurement 0.2 cm below the 3rd percentile with the use of the Warsaw growth reference and the Polish 2010 and 2012 growth reference. The values in bold signify a discrepancy around the 3rd percentile calculated for hypothetical height

The Warsaw growth reference						
	boys			girls		
Age (years)	The 3rd percentile (cm)	Hypothetical Height (cm)	Percentile calculated for hypothetical height	The 3rd percentile (cm)	Hypothetical Height (cm)	Percentile calculated for hypothetical height
3	89.8	89.6	2.24	90.0	89.8	**4.48**
4	96.5	96.3	1.90	96.6	96.4	**4.76**
5	103.6	103.4	**4.15**	102.4	102.2	**3.82**
6	109.7	109.5	**5.73**	107.5	107.3	**5.32**
7	115.0	114.8	**4.02**	113.0	112.8	**3.72**
8	119.5	119.3	**3.92**	118.8	118.6	1.69
9	124.3	124.1	1.63	123.9	123.7	2.99
10	128.5	128.3	2.84	128.0	127.8	**3.07**
11	133.7	133.5	**3.03**	134.1	133.9	2.95
12	139.5	139.3	1.87	140.1	139.9	2.60
13	144.5	144.3	**4.07**	146.5	146.3	1.85
14	151.0	150.8	**4.55**	150.0	149.8	2.54
15	158.0	157.8	2.31	151.8	151.6	2.75
16	164.5	164.3	**3.34**	153.0	152.8	2.16
17	166.4	166.2	2.89	153.5	153.3	1.39
18	166.7	166.5	**3.10**	154.0	153.8	2.78
The Polish 2010 and 2012 growth references						
	boys			girls		
3	90.5	90.3	2.60	89.1	88.9	2.74
4	97.2	97.0	2.67	95.8	95.6	2.54
5	103.3	103.1	2.88	101.9	101.7	2.90
6	109.0	108.8	2.68	107.6	107.4	2.82
7	115.0	114.8	2.69	113.3	113.1	2.72
8	120.1	119.9	2.70	118.7	118.5	2.81
9	125.0	124.8	2.82	123.6	123.4	2.77
10	129.3	129.1	2.79	128.3	128.1	2.79
11	133.7	133.5	2.81	134.1	133.9	2.84
12	138.6	138.4	2.84	141.0	140.8	2.84
13	144.8	144.6	2.83	146.9	146.7	2.77
14	152.1	151.9	2.85	150.6	150.4	2.74
15	158.5	158.3	2.78	152.4	152.2	2.77
16	162.8	162.6	2.84	153.1	152.9	2.75
17	165.2	165.0	2.76	153.6	153.4	2.79
18	166.7	166.5	2.81	154.0	153.8	2.84

In the case of children and adolescent BMI obesity threshold, the Warsaw growth reference yielded a percentile over the 95th for measurements 0.1 units below the threshold for most ages in boys and all ages in girls. The Polish 2010 and 2012 growth references for measurements 0.1 units below the obesity threshold yielded percentiles of 94.69–94.86 in boys and girls (Table 3).

Table 3. BMI-for-age percentiles calculated for hypothetical measurement of BMI 0.1 unit below the 95th percentile with the use of the Warsaw growth reference and the Polish 2010 and 2012 growth reference. The values in bold signify a discrepancy around the 95th percentile calculated for hypothetical BMI

The Warsaw growth reference						
	boys			girls		
Age (years)	The 95th percentile (kg/m²)	Hypothetical BMI (kg/m²)	Percentile calculated for hypothetical BMI	The 95th percentile (kg/m²)	Hypothetical BMI (kg/m²)	Percentile calculated for hypothetical BMI
6	18.3	18.2	91.59	18.5	18.4	**96.86**
7	19.0	18.9	**98.02**	20.2	20.1	**95.72**
8	21.0	20.9	94.15	21.3	21.2	**97.22**
9	22.2	22.1	**96.75**	22.2	22.1	**98.74**
10	23.3	23.2	**97.15**	22.8	22.7	**97.28**
11	24.0	23.9	**98.33**	23.5	23.4	**97.67**
12	24.8	24.7	**95.74**	24.1	24.0	**96.60**
13	25.4	25.3	**96.69**	24.5	24.4	**97.30**
14	25.7	25.6	**96.03**	24.9	24.8	**97.53**
15	25.7	25.6	**97.08**	25.4	25.3	**97.70**
16	25.7	25.6	**96.07**	25.7	25.6	**96.78**
17	25.8	25.7	94.60	25.9	25.8	94.57
18	26.3	26.2	**95.50**	26.1	26.0	**97.75**
The Polish 2010 and 2012 growth references						
	boys			girls		
6	19.8	19.6	94.73	19.6	19.4	94.69
7	20.6	20.4	94.77	20.2	20.0	94.73
8	21.6	21.4	94.80	21.1	20.9	94.76
9	22.7	22.5	94.83	22.0	21.8	94.79
10	23.8	23.6	94.85	22.9	22.7	94.81
11	24.7	24.5	94.86	23.9	23.7	94.82
12	25.4	25.2	94.86	24.7	24.5	94.82
13	25.8	25.6	94.85	25.3	25.1	94.82
14	26.2	26.0	94.84	25.8	25.6	94.82
15	26.6	26.4	94.83	26.1	25.9	94.81
16	27.1	26.9	94.82	26.3	26.1	94.80
17	27.6	27.4	94.81	26.5	26.3	94.80
18	28.1	27.9	94.80	26.7	26.5	94.80

Discussion

Routine monitoring of children's growth relies on age- and sex-specific reference intervals "where interest lies in the detection of extreme values, possibly indicating abnormality" (Wright and Royston 1997: 47). An example of such an abnormality is growth hormone deficiency, for which an auxological criterion, namely height below the third percentile for age and sex, is one of the requirements to qualify for the growth hormone programme in Poland (Ministry of Health 2024). From this perspective, the discrepancy between the results of height percentile calculations (percentile over 3) and the measurement result (below the third percentile), as presented in Table 2, is a major drawback, especially for systems using the Warsaw growth reference parameters (Palczewska and Niedźwiedzka 2001). A child could be wrongly disqualified from the growth hormone programme based on a height-for-age percentile calculated in this way. Fortunately, the more recent Polish growth reference system from 2010 and 2012 (Kułaga 2011; 2013) provides consistent and coherent results between height measurement below the third percentile and the result of percentile calculation.

The BMI by age and sex reference is currently the most widely used metric for estimating obesity among children and adolescents (Reilly et al. 2002). Monitoring a child's BMI in relation to population-based reference is crucial in the era of the childhood obesity pandemic (González-Álvarez et al. 2020). Overestimating BMI percentiles across all age ranges in girls and the majority of ages in boys is viewed as a critical limitation of the Warsaw growth reference: when applied, it would categorize as obese those children who are not obese according to the 95th BMI percentile.

Both height-for-age reference and BMI-for-age reference are tools used in child growth and development monitoring. The tools should be accurate, meaning that the result obtained by a tool is a true or accepted value. Our analysis provides evidence that the Warsaw growth reference system is not accurate enough around the third percentile of height and the 95th percentile of BMI, while the Polish 2010 and 2012 growth references are accurate.

One limitation of the Polish 2010 and 2012 growth references is the lack of parameters for children under 3 years of age. Nevertheless, it is important to note that growth reference based on measurements taken from children who were not optimally fed in infancy, i.e. exclusively breastfed for at least 4 months, is now not recommended (Woynarowska et al. 2012). In many countries, including Poland, there are no available national growth references for infants and toddlers optimally fed in infancy. To solve this problem, the World Health Organization (WHO) Child Growth Standards for Children aged 0–5 years were adapted and used in over 100 countries (Woynarowska et al. 2012; de Onis et al. 2006). In 2011, recommendations for implementing the WHO growth standards were signed by the Committee of Human Development and the Committee of Anthropology of the Polish Academy of Sciences, the Main Board of the Polish Anthropological Society, the Institute of Mother and Child, and the Institute of Food and Nutrition (Woynarowska et al. 2012).

Conclusions

Around the 3rd percentile of height and the 95th percentile of BMI, there is a discrepancy in the Warsaw references for measured height and BMI and the cal-

culated percentile. The Polish 2010 and 2012 growth references provide consistent and coherent calculation results for the 3rd percentile of height and the 95th percentile of BMI for children and adolescents aged 3–18 years. Therefore, to ensure accurate patient classification and avoid potential clinical errors, the Polish 2010 and 2012 growth references should be exclusively adopted in all clinical settings for children aged 3 to 18 years.

Acknowledgments

We thank the anonymous reviewer for valuable remarks and comments which improved the paper.

Author contributions

ZK designed the work, contributed to analysis, and interpretation of data, drafted the work. AK contributed to analysis, and interpretation of data and revised the manuscript critically for important intellectual content. All authors gave final approval of the version to be published.

Ethics statement

Not applicable.

Data availability statement

Data are available upon request from the corresponding author.

Financial disclosure

Not applicable.

Conflict of interest

The authors have no conflicts of interest to disclose.

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