HUMAN BiOLOGY AND PUBLiC HEALTH
JOURNAL OF THE AUXOLOGICAL SOCIETY

ISSN 2748-9957 | Vol. 1 2022 | pp. 1–9

The arithmetic dilemma when defining thinness, overweight and obesity in stunted populations

Michael Hermanussen[1] • Masiar Novine[2] • Christiane Scheffler[3] • Detlef Groth[2]

[1] Aschauhof 3, 24340 Eckernförde – Altenhof, Germany
[2] University of Potsdam, Bioinformatics, 14476 Potsdam-Golm, Germany
[3] University of Potsdam, Human Biology, 14469 Potsdam, Germany

Citation:

Hermanussen, M. et al. (2022). The arithmetic dilemma when defining thinness, overweight and obesity in stunted populations, Human Biology and Public Health 1.
https://doi.org/10.52905/hbph2022.1.21.

Received: 2021-10-11
Accepted: 2021-11-02
Published: 2022-08-24

Conflict of Interest:

There are no conflicts of interest.

Correspondence to:

Michael Hermanussen
email: michael.hermanussen@gmail.com

Keywords:

BMI, stunting, prevalence, thinness, obesity, misclassification, double burden of malnutrition

Abstract

Background Critical cut-off values of BMI-for-age z-scores (BAZ) are used to define "thinness", "overweight" and "obesity", but the validity of these cut-off values needs to be questioned in populations that are shorter or taller than the reference. We hypothesized that the prevalence of thinness, overweight, and obesity depends on population height and performed a random simulation.

Methods We created virtual child populations aged 2–10 years with normally distributed height expressed as height-for-age z-scores (HAZ) and weight expressed as weight-for-age z-score (WAZ), based on WHO growth standards and references, with a correlation r=0.7 between height and weight. We adjusted weight-for-height and calculated BAZ.

Results BAZ depends on height and age. In short children (mean HAZ=-2 to HAZ=-3), the prevalence of thinness falls to less than 1% in the youngest and rises up to 10% (mean HAZ=-2) and up to 13% (mean HAZ=-3) at age 10 years. The prevalence of obesity rises to up to 7% in the shortest and youngest and falls close to zero at age 10. Short young children and tall older children are more prone to be misclassified as overweight.

Conclusions The prevalence of thinness, overweight and obesity depends on height and age. The coexistence of being short and being overweight – currently referred to as "double burden of malnutrition" – needs consideration as to what extent this condition is a health issue or reflects calculation artefacts. The arithmetic dilemma particularly affects young children in short populations. We suggest abstaining from defining "thinness", "overweight", or "obesity" by BMI z-scores. Different states of under- and malnutrition should rather be classified by direct or indirect measures of body fat.

Take home message for students For arithmetic reasons, the prevalence of thinness, overweight and obesity when defined by z-scores for BMI strongly depends on average population height and age.

Abbreviations

BAZ BMI-for-age z-scores
BMI body mass index
HAZ height-for-age z-scores
LMIC Low and Middle Income Countries
SD standard deviation
WAZ weight-for-age z-score
WHO World Health Organization

Introduction

Short people tend to be lighter than tall people. The coefficient of correlation within same age cohorts of children slightly depends on age but for practical reasons may be considered close to r=0.7 (Mumm and Hermanussen 2021). This applies to both absolute height (cm) and weight (kg) as well as to height-for-age z-values (HAZ) and weight-for-age z-values (WAZ). Due to this association, many children in Low and Middle Income Countries (LMIC) are not only short (yielding an apparently high prevalence of stunting), but also tend to be low in weight (yielding an apparently high prevalence of underweight) when referred to WHO height and weight for age standards (WHO 2006) and references (WHO growth reference 2007; WHO Multicentre Growth Reference Study Group 2006). Stunting is conventionally attributed to poor nutrition, repeated infection, and inadequate psychosocial stimulation. The prevalence of stunting is often used in public health and medicine, by governmental and health organizations, and also by the United Nations agencies, as the common yardstick to assess and monitor child health and development (Zorlu 2011). Meanwhile, over 140 countries employ WHO growth standards and references.

Being short and light does not automatically imply a low body mass index (BMI, weight divided by the square of height). The BMI is commonly used as an indicator to define the nutritional status (CDC 2015). Yet, many stunted populations around the world are normal in BMI despite increasing prevalence of overweight and obesity in recent years (NCD Risk Factor Collaboration 2017). The BMI is a ratio and depends on both height and weight. This is trivial but it needs to be considered as changing either one of the two parameters affects this ratio. Critical cut-off values of BMI z-scores are used to define "thinness" (BMI-for-age z-values (BAZ) below -2SD) (Cole and Lobstein 2012), "overweight" (BAZ above +1 SD) and "obesity" (BAZ above +2 SD) also in children (de Onis and Lobstein 2010). As BMI depends on both height and weight, it is essential to clarify whether BMI cut-off values also apply for populations that are on average shorter or taller than the reference they are compared. For arithmetic reasons, being short or tall may affect the density distribution of the BMI and, thus, may lead to misclassification of the nutritional status.

We hypothesize that the prevalence of thinness, overweight, and obesity is not independent of the average height of the population.

Methods

Body height tends to follow a standard normal (Gaussian) distribution in a homogeneous, well-nourished population. This proposition, advanced by Quetelet in 1835 and established more systematically by Galton and Pearson half a century later (Tanner 1981), is largely accepted. We follow this notion and created an initial virtual population of girls and boys aged 2 – 10 years with standard normally distributed height expressed as height-for-age z-scores (HAZinit) based on WHO growth

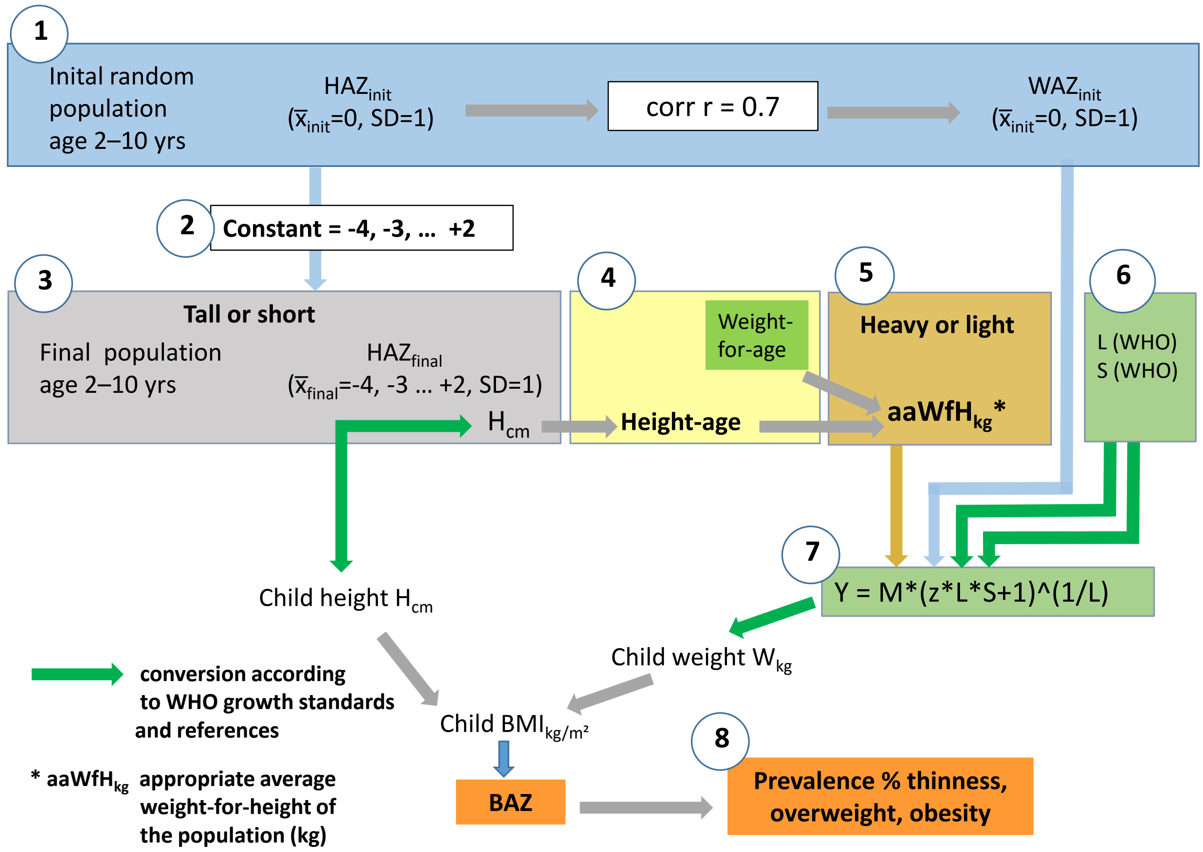

Figure 1 Flowchart of simulation. See description in the text.

standards and references. HAZinit has a standard normal distribution with x̄init=0, and SD=1. Each child was then assigned a weight-for-age z-score (WAZinit) that was related to HAZinit with r=0.7 (Mumm and Hermanussen 2021). WAZinit had a standard normal distribution with x̄init=0 and SD=1, too.

In a second step, the initial population was transferred into the final populations by adding an integer constant (-4, -3, ... +1, +2) to the HAZinit of each child. We considered this range relevant as it includes the average height of the shortest (Walker et al. 2006) and the tallest human populations (Fredriks et al. 2000). The final populations differed in mean height, but their density distributions still equaled the initial HAZinit distribution. One may do so as density distributions of height are quite independent of mean height, with very similar standard deviations in short and tall populations (Eveleth and Tanner 1990). Shifting the density distribution of height along the x-axis, thus, neither affects height variation nor the correlation between final HAZ (HAZfinal) and WAZinit.

Short people tend to be lighter than tall people. Creating populations of different height, thus, requires weight adjustment. Yet, as weight density distributions are skewed, linearly shifting z-score distributions of weight will lead to “shrinkage” or to “expansion” of the z-distributions, depending on whether shifting to the left or to the right.

Weight-for-height tables can solve the problem, but weight-for-height tables are not available for all ages. Thus, we introduced an auxiliary step and made use of the concept of height-age. Height-age is that age that corresponds to the child’s height when plotted at the 50th percentile. E.g. if a group of girls is on average 126.6 cm tall, the group is considered to have a "height-age" of 8 years irrespective of their calendar age. For 8-year-old girls, WHO weight-for-age references give a median weight of 25.0 kg suggesting that 25.0 kg is the "appropriate average weight-for-height" of a group of 126.6 cm tall girls.

The simulation (Figure 1) includes:

1. The blue box
   indicates the initial virtual population of boys and girls (cohort size N=10,000), aged 2, 3, 4, … 9, 10 years. Each child was assigned an initial height-for-age z-score (HAZinit), with $\bar{x}$init=0 and SD=1, and a weight-for-age z-score (WAZinit), with $\bar{x}$init=0 and SD=1, that correlated with HAZinit with r=0.7.
   At this step, neither height (Hcm) nor weight (Wkg) of these children has been determined.
2. A population specific constant (-4, -3, -2 … +1, +2)
   was added to HAZinit of each child, yielding the final populations of children. The final populations were on average shorter or taller than the initial population, with $\bar{x}$final=-4, -3, …. +1, +2. The variance remained the same with SD=1.
3. The grey box
   indicates the conversion of the individual HAZfinal into height in cm (Hcm), based on WHO growth standards and references (green arrow). This step yields mean height (cm) of the final populations.
4. The yellow box
   indicates the concept of height-age. Mean population height is used to assign the assumed appropriate age for height.
5. The brown box
   indicates the final assignment of an "appropriate average weight-for-height" in kg via the appropriate height-age.
6. Orange boxes
   indicate variables obtained from WHO growth standards and references (WHO 2006; WHO growth reference 2007). L, S, and the population specific "appropriate average weight-for-height" are used to calculate weight in kg (Wkg) for each child by:
7. LMS method
   as described by Cole's LMS formula (Cole 1990):
   Y = M*(z*L*S+1)^(1/L)
   Y individual weight (Wkg)
   M appropriate average population weight-for-height in kg
   z WAZinit
   L Box-Cox power to remove skewness (obtained from WHO weight-for-age tables)
   S coefficient of variation (obtained from WHO weight-for-age tables)
   This approach guarantees that in the final populations, individual height and weight still corresponded with the correlation r=0.7, regardless of average population height.
8. Brown boxes:
   Individual BMI (kg/m^2) was calculated from individual height (Hcm) and weight (Wkg), and converted into BMI-for-age z-scores (BAZ) according to WHO growth standards and references (WHO 2006; WHO growth reference 2007). The critical cut-off values of "thinness" (BAZ below -2 SD), "overweight" (BAZ above +1 SD) and "obesity" (BAZ above +2 SD) in the final short and tall populations defined the prevalence of thinness, overweight and obesity.

Simulation, analysis and graphics were handled with the programming language R (Goodreau et al. 2008; Handcock et al. 2008). R is Free Software under the terms of the Free Software Foundation's GNU General Public License in source code from the R Foundation (The R Founda-

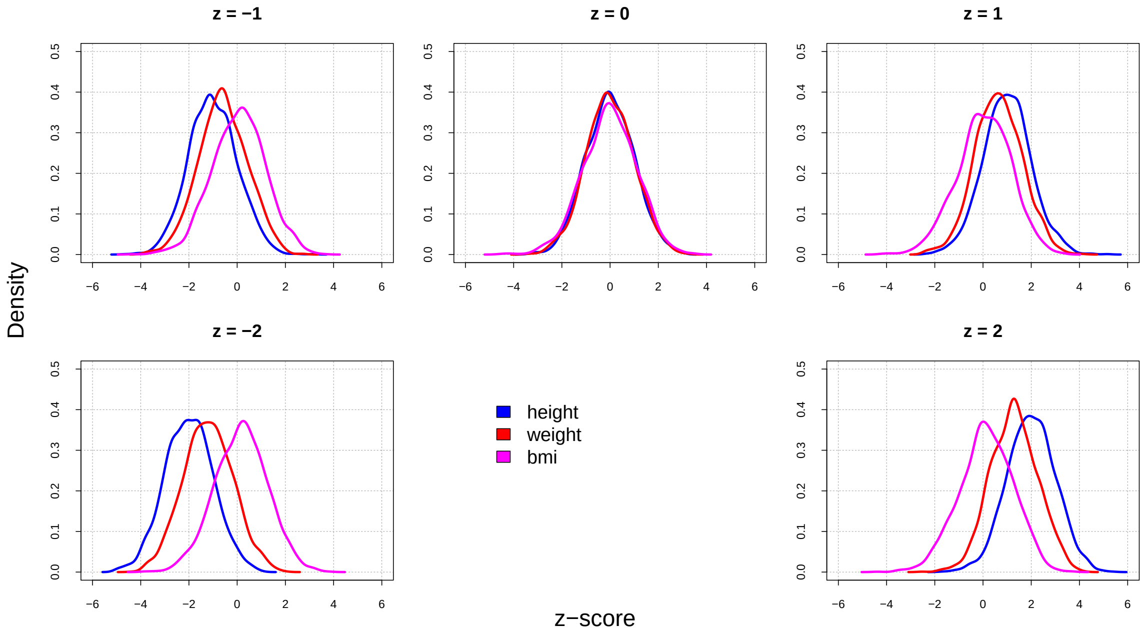

Figure 2 Density distributions of mean height-for-age z-scores (HAZ), mean weight-for-age z-scores (WAZ), and mean BMI-for-age z-scores (BAZ) in 10,000 simulated 5-year-old boys. HAZ, WAZ, and BAZ overlap in populations with median HAZ=0. The density distributions disintegrate when HAZ≠0.

tion 2022). For the 3D plots the R package plot3D was used (Soetaert 2021).
For details see supplementary material.

Results

The density distributions of mean height-for-age z-scores (HAZ), mean weight-for-age z-scores (WAZ), and mean BMI-for-age z-scores (BAZ) overlap in populations with mean HAZ=0 (Figure 2). The density distributions disintegrate when HAZ≠0. Density distributions of WAZ and, to a lesser extent, of BAZ shift to the left with decreasing HAZ and to the right with increasing HAZ.
BAZ depends on HAZ and WAZ. Short and heavy children have higher BAZ than tall and light children, the association, however, is not linear. The surface graphs (magic carpets) indicate that children with the same HAZ and WAZ appear increasingly thin when they get older (Figure 3). This is particularly relevant for tall children.
The age dependence of BAZ becomes more apparent when relating BAZ to age and HAZ (Figure 4). In a “normal” population, the prevalence of thinness is expected to be 2.3% (BAZ < -2), the prevalence of obesity 2.3% (BAZ > +2), and the prevalence of overweight plus obesity 15.9% (BAZ > +1). This should be true regardless of age and average population height. The magic carpets (surface graphs) should be horizontal without bumps and twists. However, this is not the case. Only populations with mean HAZ = 0 (“normal populations”) show the expected prevalences of thinness, overweight and obesity. Magic carpets get strongly twisted when HAZ≠0 (Figure 4).

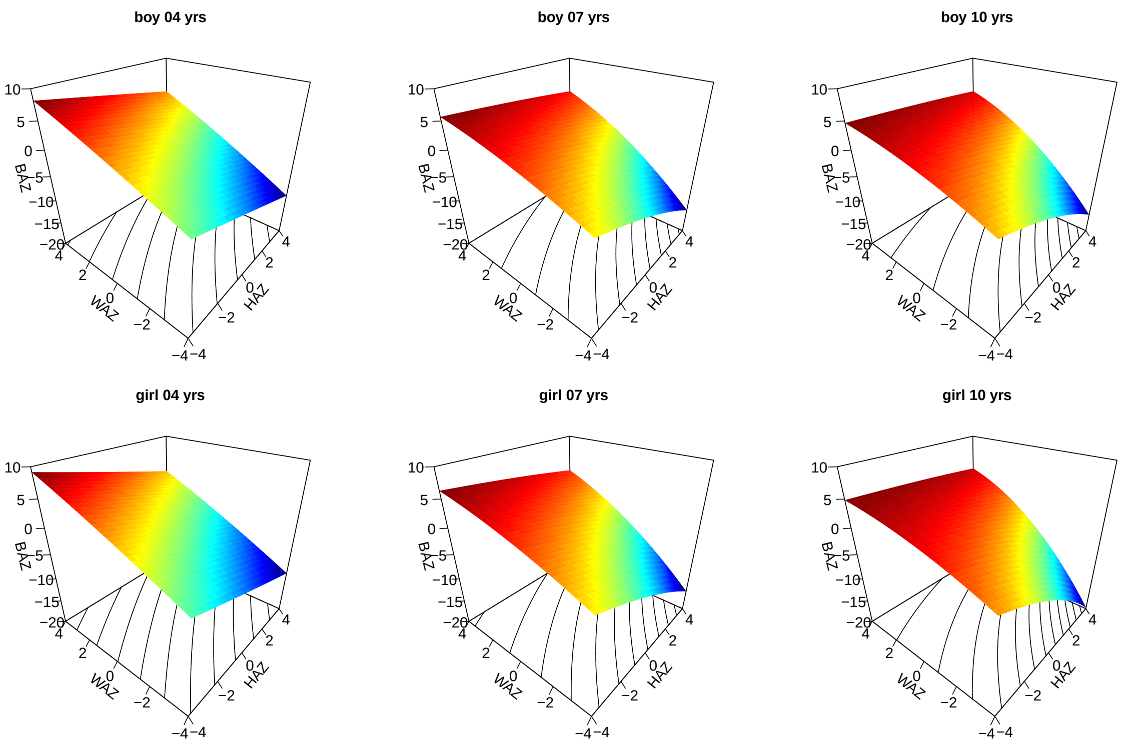

Figure 3 Surface graphs (magic carpets) of BMI-for-age z-scores (BAZ) in simulated child populations at age 4, 7, and 10 years. BAZ depends on age with highest curvature in both sexes at age 10 years.

In short girls (mean HAZ=-2 to HAZ=-3), the prevalence of thinness falls to less than 1% in the youngest and rises to 10% (mean HAZ=-2) and to 13% (mean HAZ=-3) at age 10 years. Very similar results were obtained in the boys. On the other hand, the prevalence of obesity rises to up to 7% in the shortest and youngest and falls close to zero at age 10 years. Short young children and tall older children are more prone to be misclassified as overweight than short older children and tall younger children, simply for arithmetic reasons.

Discussion

Short children are usually lighter than tall children, but the association between height and weight is not linear. The body mass index (BMI) depends on age and its density distribution is skewed. To account for sex dependence and skewness, modern references for BMI provide z-scores for BMI (BMI-for-age z-scores, BAZ) according to Cole's LMS method (Cole 1990). BAZ are considered an appropriate tool for assessing the nutritional state. Critical cut-off values for BAZ define "thinness" (Cole and Lobstein 2012), "overweight" and "obesity" (de Onis and Lobstein 2010). In a "normal" population, thinness is expected to have a prevalence of 2.3%, obesity 2.3%, and overweight plus obesity 15.9%. These cut-off values are used by international health organizations (UNICEF 2020).

The present study confirms our hypothesis that the prevalence of thinness, overweight, and obesity is not independent of the average height of the population. This is particularly relevant in very short populations. Short young children are relatively too often misclassified as overweight, short older children too often as thin. The present findings coincide with recent observations published by Ricardo and co-workers (Ricardo et al. 2021) who showed that "the overall prevalence of overweight declined with age from 6.3% for infants (aged 0–11 months) to 3.0% in 4 years olds" in children of Low and Middle Income Countries.

The coexistence of being short and being overweight is often observed and currently referred to as "double burden of malnutrition" (WHO 2016). It is considered a major public health challenge in many developing countries and has prompted hundreds of publications, including a recent meta-analysis in 595,975 children under five years from 65 LMICs (Akombi et al. 2019). We do not question that this combination does exists, but claims for "urgent need to strengthen existing policies on child malnutrition to integrate and scale up opportunities for innovative approaches which address the double burden of malnutrition in children under five years in LMICs" (Akombi et al. 2019) need careful reconsideration and differentiation as to what extent the "double burden of malnutrition" is a health issue and to what extent it reflects calculation artefacts.

On purpose, we limited the present study to the age range from 2 to 10 years as the rapid height and weight changes during infancy and puberty might unnecessarily complicate the simulation. Thus, we cannot form an opinion on statements referring to adolescents such as those published by Guedes and co-workers (Guedes et al. 2013) who wrote that "the low body weight/thinness for girls raised from 2.7% (7–10 years old) to 5.5% (15–17 years old); the body weight excess (overweight and obesity) decreased from 30.1 to 16.2% for the same age groups". Nevertheless, it appears suggestive to assume that also these results may partially reflect the arithmetic dilemma when using global references for stunted populations.

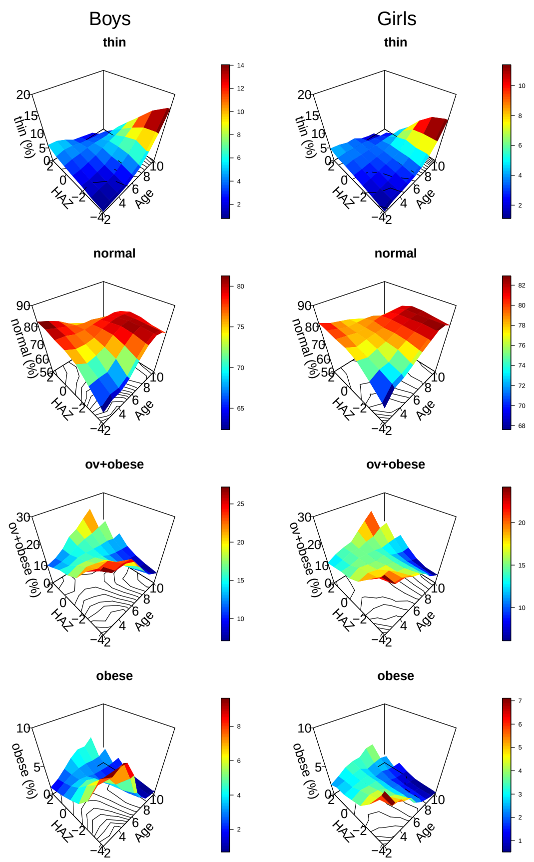

Figure 4 Magic carpets (surface graphs) depicting the prevalence of the normal state, thinness, overweight+obesity, and obesity alone in simulated tall, normal and short child populations. Colors indicate percent. The shape of the magic carpets depends on age and mean population height. Short young and tall older children are more prone to be misclassified as overweight and obese than short older and tall young children.

Conclusion

The prevalence of thinness, overweight, and obesity when defined by z-scores for BMI, depends on average population height and age. The coexistence of being short and being overweight – currently referred to as "double burden of malnutrition" – is frequently observed but needs careful consideration as to what extent this condition is a health issue or reflects calculation artefacts. The arithmetic dilemma particularly affects young children in short populations. We therefore suggest abstaining from defining "thinness", "overweight", or "obesity" by BMI z-scores. Different states of under- and malnutrition should rather be classified by direct or indirect measures of body fat, of which mid-upper arm circumferences (Hai et al. 2020) and other anthropometric variables and indices (Duggleby et al. 2009) have been suggested.

Acknowledgements

We greatly appreciate the help of Dr. Rebekka Mumm, Potsdam, and Prof. Christian Aßmann, Bamberg. Parts of this analysis were performed at the International Student Summer School on "Human Growth and Development", Gülpe, Brandenburg, Germany, July 18th to 24th. The study was supported by the Auxological Society (Deutsche Gesellschaft für Auxologie, DGA).

References

Akombi, B. J./Chitekwe, S./Sahle, B. W./Renzaho, A. M. N. (2019). Estimating the double burden of malnutrition among 595,975 children in 65 low- and middle-income countries: a meta-analysis of demographic and health surveys. International Journal of Environmental Research and Public Health 16 (16), E2886. https://doi.org/10.3390/ijerph16162886.

CDC (2015). Growth chart training | DNPAO | CDC. Available online at https://www.cdc.gov/nccdphp/dnpao/growthcharts/index.htm (accessed 3/21/2022).

Cole, T. J. (1990). The LMS method for constructing normalized growth standards. European Journal of Clinical Nutrition 44 (1), 45–60.

Cole, T. J./Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. Pediatric Obesity 7 (4), 284–294. https://doi.org/10.1111/j.2047-6310.2012.00064.x.

de Onis, M./Lobstein, T. (2010). Defining obesity risk status in the general childhood population: Which cut-offs should we use? International Journal of Pediatric Obesity 5 (6), 458–460. https://doi.org/10.3109/17477161003615583.

Duggleby, S. L./Jackson, A. A./Godfrey, K. M./Robinson, S. M./Inskip, H. M. (2009). Cut-off points for anthropometric indices of adiposity: differential classification in a large population of young women. The British Journal of Nutrition 101 (3), 424–430. https://doi.org/10.1017/S0007114508012245.

Eveleth, P. B./Tanner, J. M. (1990). Worldwide variation in human growth. Cambridge, Cambridge University Press.

Fredriks, A. M./van Buuren, S./Burgmeijer, R. J./Meulmeester, J. F./Beuker, R. J./Brugman, E./Roede, M. J./Verloove-Vanhorick, S. P./Wit, J. M. (2000). Continuing positive secular growth change in the Netherlands 1955–1997. Pediatric Research 47 (3), 316–323. https://doi.org/10.1203/00006450-200003000-00006.

Goodreau, S. M./Handcock, M. S./Hunter, D. R./Butts, C. T./Morris, M. (2008). A statnet tutorial. Journal of Statistical Software 24 (1), 1–26. https://doi.org/10.18637/jss.v024.i09.

Guedes, D. P./Almeida, F. N./Neto, J. T. M./Maia, Maria de Fátima de M./Tolentino, T. M. (2013). Low body weight/thinness, overweight and obesity of children and adolescents from a Brazilian region of low economic status. Revista Paulista de Pediatria 31, 437–443. https://doi.org/10.1590/S0103-05822013000400004.

Hai, T. T./Bardosono, S./Wiradnyani, L. A. A./Hop, L. T./Ngan, H. T. D./Phuong, H. N. (2020). The optimal mid-upper-arm circumference cutoffs to screen severe acute malnutrition in Vietnamese children. AIMS Public Health 7 (1), 188–196. https://doi.org/10.3934/publichealth.2020016.

Handcock, M. S./Hunter, D. R./Butts, C. T./Goodreau, S. M./Morris, M. (2008). statnet: Software tools for the representation, visualization, analysis and simulation of network data. Journal of Statistical Software 24 (1), 1548–7660. https://doi.org/10.18637/jss.v024.i01.

Mumm, R./Hermanussen, M. (2021). A short note on the BMI and on secular changes in BMI. Human Biology and Public Health 2. https://doi.org/10.52905/hbph.v2.17.

NCD Risk Factor Collaboration (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet 390 (10113), 2627–2642. https://doi.org/10.1016/S0140-6736(17)32129-3.

Ricardo, L. I. C./Gatica-Domínguez, G./Crochemore-Silva, I./Neves, P. A. R./dos Santos Vaz, J./Barros, A. J. D./Victora, C. G. (2021). Age patterns in overweight and wasting prevalence of under 5-year-old children from low- and middle-income countries. International Journal of Obesity, 1–6. https://doi.org/10.1038/s41366-021-00911-5.

Soetaert, K. (2021). plot3D: Plotting multi-dimensional data version 1.4 from CRAN. Available online at https://rdrr.io/cran/plot3D/ (accessed 9/28/2021).

Tanner, J. M. (1981). A history of the study of human growth. Cambridge, Cambridge University Press.

The R Foundation (2022). The R Foundation. Available online at https://www.r-project.org/foundation/ (accessed 8/18/2022).

UNICEF (2020). Malnutrition in children. Available online at https://data.unicef.org/topic/nutrition/malnutrition/ (accessed 10/10/2021).

Walker, R./Gurven, M./Hill, K./Migliano, A./Chagnon, N./de Souza, R./Djurovic, G./Hames, R./Hurtado, A. M./Kaplan, H./Kramer, K./Oliver, W. J./Valeggia, C./Yamauchi, T. (2006). Growth rates and life histories in twenty-two small-scale societies. American Journal of Human Biology 18 (3), 295–311. https://doi.org/10.1002/ajhb.20510.

WHO (2006). WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development. Available online at https://www.who.int/publications/i/item/924154693X (accessed 9/25/2021).

WHO (2016). The double burden of malnutrition: policy brief. Available online at https://apps.who.int/iris/handle/10665/255413 (accessed 8/19/2022).

WHO growth reference (2007). Growth reference data for 5–19 years. Available online at https://www.who.int/toolkits/growth-reference-data-for-5to19-years (accessed 8/19/2022).

WHO Multicentre Growth Reference Study Group (2006). WHO Child Growth Standards based on length/height, weight and age. Acta Paediatrica Suppl. 450, 76–85. https://doi.org/10.1111/j.1651-2227.2006.tb02378.x.

Zorlu, G. (2011). New WHO child growth standards catch on. Bulletin of the World Health Organization 89 (4), 250–251. https://doi.org/10.2471/BLT.11.040411.