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Is body mass index an appropriate proxy for body fat in children?

Colleen M. Doak [a,*], Daniel J. Hoffman [b], Shane A. Norris [c], Maiza Campos Ponce [a], Katja Polman [a,d], Paula L. Griffiths [c,e]

[a] Department of Health Sciences, VU University Amsterdam, The Netherlands
[b] Department of Nutritional Sciences, Rutgers, the State University of New Jersey, USA
[c] MRC/Wits Developmental Pathways for Health Research Unit, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[d] Department of Biomedical Sciences, Institute of Tropical Medicine, Antwerp, Belgium
[e] Centre for Global Health and Human Development, School of Sport, Exercise and Health Sciences, Loughborough University, Leicestershire, United Kingdom

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ABSTRACT

As the global prevalence of childhood overweight and obesity spreads to low and middle income countries, there is an increasing need for researchers to assess overweight and obesity in populations where child undernutrition still prevails. Although BMI (body mass index) cutoffs are widely used in research and project evaluations, they have only recently been included in WHO definitions for overweight and obesity in children. This review describes the history of how and why BMI was introduced as a proxy for adiposity in children, the scientific evidence and examples from epidemiological studies. Overall, BMI continues to be a valuable measure in children if the underlying assumptions of the criteria and cut-off values are considered. However, where BMI is associated with height, in children, we recommend using weight for height *z*-scores.

1. Introduction

Standing height and weight are relatively easy and inexpensive measures to perform in most field settings (WHO Expert Committee on Physical Status, 1995), and consequently, are used as the basis for multiple indicators of nutritional status. In low and middle income countries (LMICs), measures of height and weight have long been used to identify acute and chronic undernutrition (WHO Working Group, 1986; WHO Expert Committee on Physical Status, 1995; World Health Organization, 2008). As the emerging epidemic of childhood overweight and obesity spreads throughout developed and developing countries, the need to measure and monitor childhood obesity has increased. Initially, overweight and obesity (WHO Working Group, 1986; WHO Expert Committee on Physical Status, 1995) were defined using weight for height for age *z*-scores (WHZ) to identify the heaviest children for a given height and age. These classifications continue to be used in the literature as a more sensitive indicator of obesity than body mass index (BMI) (Stanojevic et al., 2007). However, WHZ has proved challenging to implement in clinical settings since, there is no single chart that can be used to identify WHZ for children of all ages. Furthermore, weight for height *z*-scores are not used for adults and are less familiar than BMI. A single measure, or index, adjusted for height is preferable, and researchers and clinicians have used BMI to meet this criterion (Fig. 1).

Although BMI cutoffs are widely used in definitions of child overweight and obesity in the literature, they have only recently been included as such by the WHO. Table 1 shows the World Health Organization (WHO) definitions for thinness, overweight and obesity for children 0–5 years of age and ≥ 5 years of age. Namely, the *z*-score definitions were chosen to reflect the SD cutoffs most closely related to the International Obesity Task Force (IOTF) measures (Cole et al., 2007; Cole and Lobstein, 2012). The choice to use different cut-offs for the under 5 years age group is related to potential misclassification in children under age 5 years as overweight or obese (de Onis and Lobstein, 2010). This concern is particularly relevant in a context of transitioning LMICs (Ke-You and Da-Wei, 2001). Given the potential implications for interventions, it is vital to critically evaluate the use of BMI to identify overweight and obesity in children (2–18 years of age).

This review considers the use of BMI from the perspective of the LMIC context. Specifically, we will underline the methodological complexities of using BMI to explore both sides of malnutrition in a comprehensive way. Given that most research on the use of BMI has focused on overweight/obesity, we begin with an historical perspective, describing how and why BMI was introduced as an index of child adiposity (Section 2). In Section 3, we review evidence for whether BMI accounts for height differences

* Correspondence to: VU University, Faculty of Earth and Life Sciences, Department of Health Sciences, Section of Infectious Disease, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands. Tel.: +31 20 598 3502; fax: +31 20 598 6940.
E-mail addresses: c.m.doak@vu.nl, colleen.doak@gmail.com (C.M. Doak).

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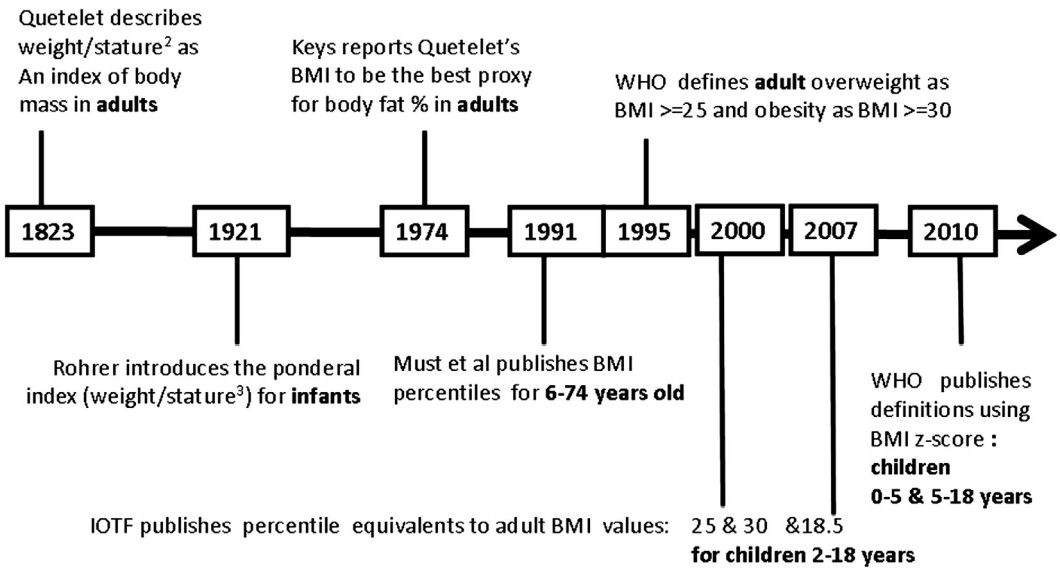

Fig. 1. shows the timeline of key events in the main events in the development and application of BMI. The application of BMI in children relates to the history of the use of BMI in adults. Although the Quetelet index was first described in 1823, it was nearly 100 years later (1921) that an index was developed to account for the dimensions of infants. The WHO adopted BMI cutoffs to define overweight and obesity in adults in 1995, however it was not until 2010 that de Onis and Lobstein (2010) published the the WHO definitions for overweight and obesity using BMI for children.

Table 1
BMI cut-offs used to define thinness, overweight and obesity in children.

	WHO (de Onis and Lobstein, 2010) <5 years of age	WHO (de Onis and Lobstein, 2010) ≥ 5 years of age	Must et al. (1991) ≥ 5 years	IOTF (Cole et al., 2000; Cole et al., 2007)
Thinness	<-2SD BMI	<-2 SD BMI	<5th percentile BMI	Percentile equivalent <18.5
Overweight	>2 SD BMI	>1 SD BMI	>85th percentile BMI	Percentile equivalent of adult BMI >25
Obesity	>3 SD BMI	>2 SD BMI	>95 percentile BMI	Percentile equivalent of BMI >30

in individual children or in populations. Next, Section 4 reviews the evidence describing population differences in results when using BMI based outcomes as compared to other measures of adiposity. Finally, Section 5 will weigh up the policy and program related issues of using BMI based cut-offs in children. In conclusion, we use the above results to formulate recommendations for the use of BMI in children and to articulate future directions in both research and policy.

2. The history of the use of BMI in children

The Quetelet body mass index (weight/stature^2) was first described by Adolphe Quetelet in 1832 as an index of body mass, adjusted for height (Eknoyan, 2008). The Quetelet index was designed to allow for comparisons of weight between adults of different heights. In 1974, Ancel Keys popularized the term body mass index (BMI) in his seminal paper in which he showed the Quetelet index to be the best proxy for body fat percentage in adults (Ashwell, 2011). However, it is widely recognized that Quetelet's BMI cannot be used in children under the age of 2 years, given differences in body proportions between infancy and adulthood. In 1921, to account for the problems of using the index in infants, Rohrer (1921) introduced the ponderal index (weight/stature^3) with stature cubed as a more appropriate adjustment for height because of the different dimensions of infants. As with adults, the formulation of the denominator (stature^3) was chosen to adjust for stature, such that weights from infants of different lengths could be directly compared. Although it was widely agreed that the Quetelet body mass index was most appropriate for adults and Rohrer's ponderal index was most appropriate for infants, it was not clear what formula to apply in toddlers, young children or adolescents.

Since the mid-1980s, BMI has been used to classify overweight and obesity globally in adults. During the 1980s, a number of studies compared the Quetelet index (weight/stature^2) to the Rohrer's index (weight/stature^3) in children. These studies concluded weight/stature^2 to be preferable in children over the age of 5. For example, Michielutte et al. (1984) found Quetelet's BMI was better correlated with triceps skinfolds than Rohrer's ponderal index in 5–12-year-old children in North Carolina. However, the authors also noted that neither index was ideal. In fact, the correlation between BMI and triceps skinfold was low in 5-year-old boys ($r=0.24$). Furthermore, the authors noted that neither index was consistent by race, age or income (Michielutte et al., 1984). For example, the strongest correlations with triceps skinfolds were in girls from the lowest income census tract whereas in boys there was no pattern by income group. Another study by Roche (1981) compared the BMI to the ponderal index and triceps skinfold measures to total body fat in children and adults, from 6 to 49 years, as measured by underwater weighing. While the authors recommended weight/stature^2 as an indicator of total body fat for girls, they noted subscapular skinfold thickness was a better indicator for boys.

In a study of 6–74-year-old, Must et al. (1991) found BMI to be correlated with triceps skinfolds across the age spectrum, providing justification for the use of a BMI-based reference in children over 5 years old. Additionally, Must et al. (1991) provided smoothed 85th and 95th percentiles of BMI for 6–74-year-old, with results reported by race, sex and age for the NHANES I