History and Meaning of the Body Mass Index. Interest of Other Anthropometric Measurements

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Summary

The definition of obesity in children was originally based on the definition used for undernutrition. Weight-for-age and weight-for-height indices are still recommended to define overweight in children. The use of skinfold and circumferences is also recommended. For many reasons, the use of the body mass index (BMI) is increasing. It is based on weight and height which are easily available and reliable measurements. It is closely correlated with total and percent body fat assessed by more fundamental measures of body composition. As in adults, BMI in children is associated with morbidity and mortality. Several BMI references are available. The correct use of these various references is essential. It will facilitate comparisons between studies and populations and help identify factors responsible for the high prevalence of childhood obesity.

Introduction

Nutritional status in children is assessed on the basis of body composition and growth parameters. Undernutrition and obesity are defined as a deficit or excess of body fat. Objective criteria are necessary to identify grades of nutritional status. Defining underweight and obesity consists of choosing a suitable measure of body fat, and a suitable cut-off. In contrast to adulthood for which there is a general agreement for the cut offs defining grades of nutritional status, in children several definitions are available. Their description and ECOG recommendations for their use were recently released (1). Nutritional status is generally assessed using the body mass index (BMI). In adults, cut-off points to define grades of thinness were validated by measurements of basal metabolic rate (2) and grades of overweight were based on the association between BMI and mortality (3, 4). Children grow in size, so that anthropometric cut-offs need to be adjusted for age. Grades of nutritional status refer to population distributions for each age and gender. Weight status, in children as in adults, is associated with morbidity. Then, the clinical validity of the BMI should also be considered in children. The differences between the various references lie on the population and the methods used to construct cut offs (1). Given the difficulty raised by the plethora of definitions, it is important to clarify their origin, the method used to define categories and the directions for their use. Description of BMI and other anthropometric measurements were previously developed in an ECOG book (5). Here, we will present the steps toward the current methods used and the scientific evidence for selecting these methods.

Anthropometric Measurements to Define Nutritional Status

Direct measures of total body fat, e.g. underwater weighing, dual energy X-ray absorptiometry (DEXA), computer tomography or magnetic resonance imaging (MRI) give accurate values of body fat, but are inappropriate for routine clinical practice because of the lack of available retrospective data, high cost and technical difficulties. However, these techniques are useful to validate methods based on anthropometric measurements. Anthropometry is the single universally applicable, inexpensive and non-invasive method available to assess, the size, shape and composition of the human body. It reflects both health and nutrition and predicts performance, risk factors and survival (6). The most widely used anthropometric measurements to predict fatness are skinfolds, circumferences and weight and height.

Skinfolds, circumferences and weight and height

- Skinfold measurements

They assess subcutaneous fat thickness but predict total and percentage body fat (7). In children, the triceps skinfold is better than the subscapular to predict percent body fat, while the subscapular skinfold is better than the triceps to predict total body fat (8). Body fatness can be predicted from equations based on skinfolds. They were first established for adults and then adapted for children (9). However, they are population specific and may not apply to all individuals, especially those with abnormal growth. Regional fat distribution can be assessed from trunk (e.g. subscapular) and extremity (e.g. triceps) skinfolds. The relationship between skinfolds and intra abdominal adipose tissue (IAAT) as assessed by DEXA was examined in children (10). Skinfolds, particularly those recorded at the trunk site, are better predictors of IAAT than the trunk/extremity skinfold ratio. Similarly, skinfolds, particularly those recorded at the trunk site, are better predictors of cardiovascular risk factors than the trunk/extremity skinfold ratio (11). In addition, trunk skinfolds rather than skinfold at the triceps site are more sensible to nutritional interventions (12).

- Circumferences

They are currently used to assess nutritional status in the field of undernutrition (3). This measurement is particularly useful because it requires inexpensive device and is a good proxy for muscle mass at the arm site and of visceral adipose tissue at the waist site (13, 14). Formulae based on arm circumference and arm skinfolds have been developed by Gurney and Jelliffe (15). They calculate arm areas assuming that the arm and its constituents are cylindrical. Arm fat areas are not better than the corresponding skinfolds for estimating percentage body fat, but they are systematically better than skinfolds for estimating body fat mass (16). The advantage of this method is that it assesses both lean and fat compartments. However, this traditional method underestimates fat (17). Later on, another more simple formula based on the same principle and measurements has been developed (18). This method gives more precise assessment of body fat, particularly in the obese. Measurements of circumferences at the waist, hip and thigh sites are used to predict body fat distribution. In children, both waist and hip circumferences are good predictors of IAAT (10). This may explain why the waist/hip ratio (WHR) is a poor predictor of IAAT in children. Here again, single measures (waist or hip circumferences) are better predictors of cardiovascular risk factors than WHR (11). In children, hip circumference is positively associated with cardiovascular risk factors (11). This finding is quite different from the results found in adults, for which hip circumference is associated with lower risks. The trunk/extremity skinfold seems to be better than the WHR in predicting cardiovascular risk factors or hyperinsulinemia in children and adolescents (11, 19). The waist-to-height ratio predicting central adiposity (DEXA) (20) is a valuable index for selecting children at risk of cardiovascular diseases. Another advantage is that a cut off of 0.5 identifies children at risk whatever their age or gender (21,22).

- Weight and height measurements

Weight and height are widely available. These measurements are easily acceptable to the subject and more reproducible than skinfolds. In children, the use of weight-for-age is recommended by the

World Health Organisation WHO (3, 23) to assess nutritional status. As weight is strongly associated with age, the more specific weight-for-height indicator can be used. Weight-for-age and weight-for-height tables and charts were originally used to assess undernutrition and are still used to assess stunting and wasting (23). The weight-for-height reference values have the advantage of not using age which is often unknown in developing countries. However, the methods based on weight-for-age ignoring height, or weight-for-height ignoring age, are less precise than weight for height indices taking all together weight, height and age into account.

Units used for expressing measurements

Adjusted anthropometric values are expressed in different ways: percentage of the median, centiles and Z-scores.

- The percent of median is 100 times the measurement divided by the median or mean reference value for the child's age (or in the case of weight-for-height, weight divided by the median for the child's height). This method does not take into account changes in the extent and skweness of the BMI distribution by age and sex. This limit is important for assessing overweight but less for undernutrition.

- For centiles, the measurement is plotted on a growth centile chart and the child's centile interpolated from the growth curves.

- Z-scores are closely related to centiles, and indicate the number of standard deviations the child's measurement lie above or below the mean or median reference value.

Percent of the median is the simplest of the three forms to calculate, and has been in use the longest. Centiles are easy to read off the chart, and are well understood by parents. If the measurement is normally distributed centiles and Z-scores are interchangeable. Otherwise, the LMS smoothing method which takes the characteristics of the distributions into account should be used (24).

Body mass indices: the Body Mass index

Correlations with height and body fat

Adjustment of weight for both height and age can be achieved using power indices of the form weight/heightn. The selection of indices was first based on low correlations with height, and high correlations with weight and body fat. As a rule, weight/height2, the Quetelet index or BMI, shows the lowest correlation with height, except at adolescence in boys, where W/H3 shows lower correlation with height (25, 26) and the first BMI charts have been constructed throughout childhood (25) (Figure 1a). As opposed to weight/height which increases steadily, or weight/height3 which decreases steadily, BMI has both ascending and descending phases (25,26) which are similar to the development of subscapular skinfold thickness (27) (Figure 1b). The similarity between the development of BMI and more direct measures of fatness is a major argument to promote BMI over other indices.

Figure 1: Development of the Body Mass Index (BMI) (25), subscapular skinfold (27) and muscle mass assessed by upper arm muscle area index (18) in girls (3rd, 25th, 50th 75th and 97th centiles). Data from the French reference study (27).

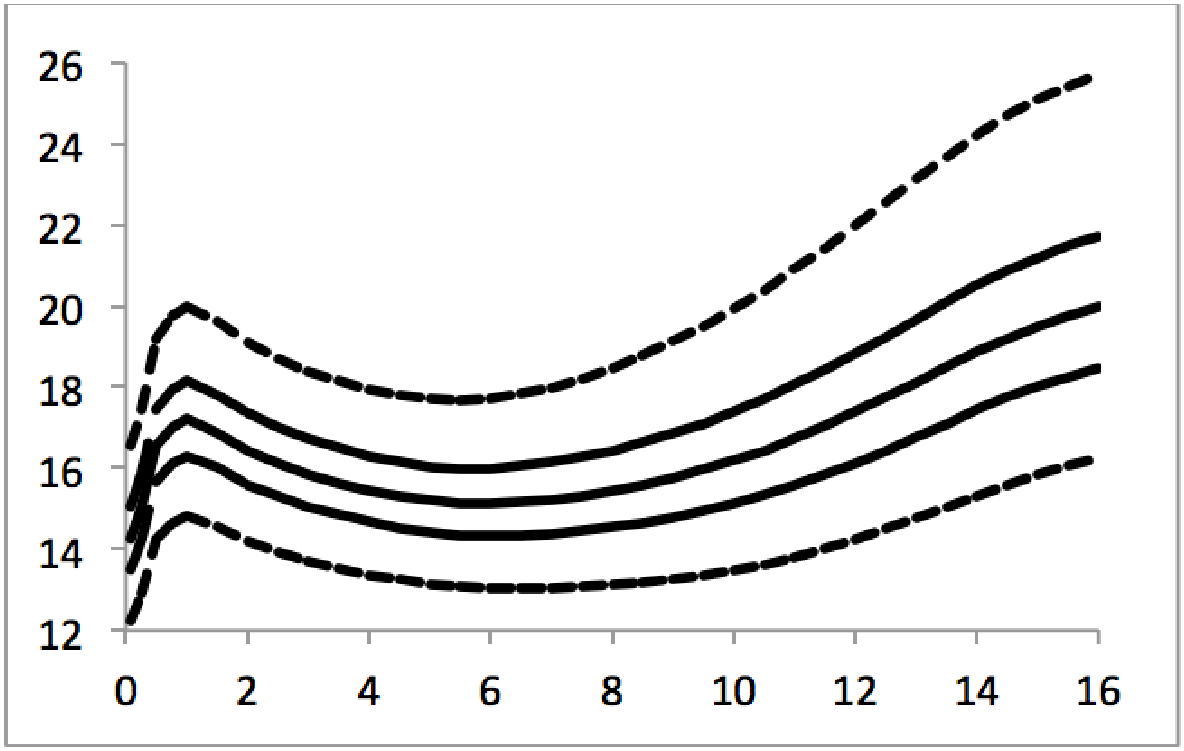

Figure 1a: Body Mass Index (kg/m2)

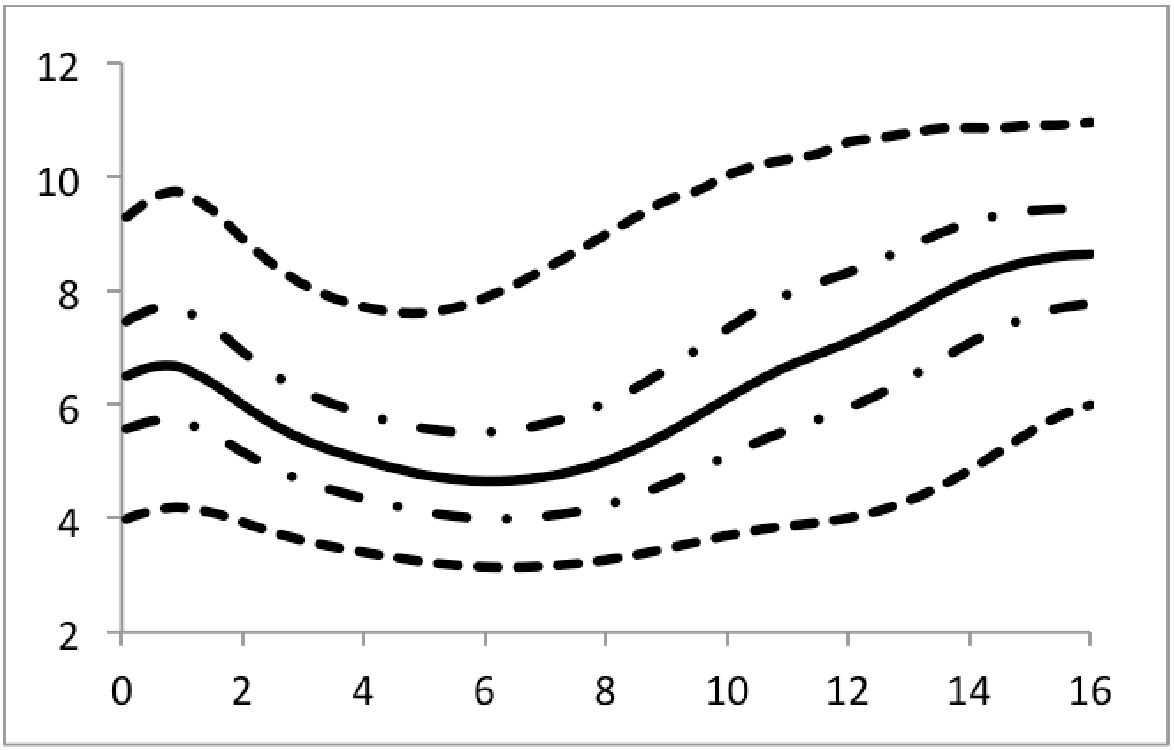

Figure 1b: Subscapular Skinfold (mm)

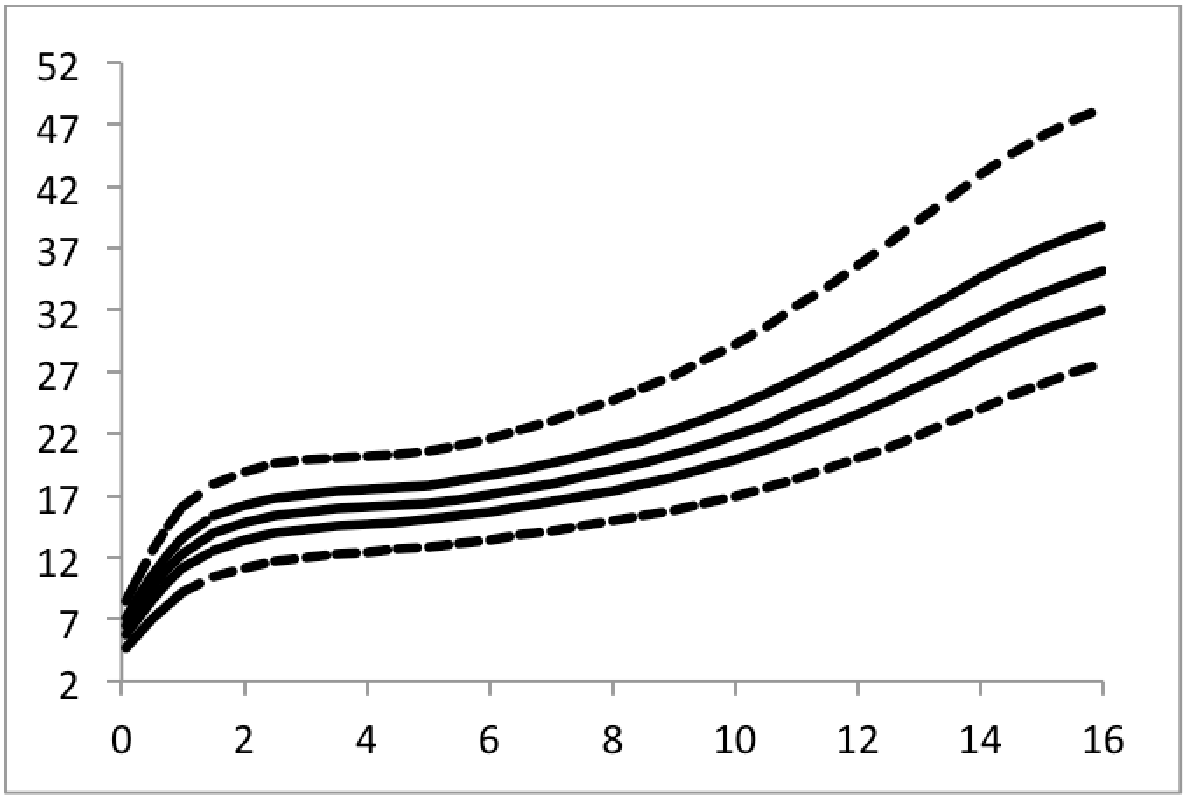

Figure 1c: Upper arm Muscle Area (UMA) (cm2)

Validity in an index of fatness refers to its association with body composition (28). BMI was found to be better than other indices in predicting body fat (29). It was highly correlated with percent body fat assessed by DEXA (30, 31). For all these reasons, the BMI is now used internationally for children.

Clinical validity of the BMI

The validity of indicators of body composition and nutritional status should also be based on their associations with current or future morbidity and mortality rates. There have been several studies relating weight-for-height to subsequent mortality in children (26). The optimal power of height in the weight/heightn indices for assessing the risk of death was also determined in the context of malnourished children. The BMI was preferred over other indices and over weight-for-height Z-score (32).

The BMI is associated with morbidity and mortality rates in adults (33). In children and adolescents, associations have been demonstrated between BMI, or changes in BMI, and increased blood pressure, adverse lipoprotein profile, non-insulin-dependent diabetes mellitus and early atherosclerosis lesions (34). The association between childhood BMI and adult mortality has been examined in two follow-up studies. In the Harvard Growth study, overweight girls and boys had an increased risk of obesity-associated morbidity when compared to their lean adolescent peers (35). In another study based on the Boyd Orr cohort, subjects who as children were above the 75th centile for BMI had higher risks of ischemic heart disease mortality than subjects whose BMI was between the 25th and 49th centiles (36). In addition, this study showed a nonlinear (J-shaped) relation

between BMI and mortality. Subjects who were underweight in childhood were also at increased risk of all-cause mortality compared to those with average weight. This growth pattern is consistent with the increased mortality associated with both low and high BMI previously described in adults (33).

Characteristics associated with obesity

In addition to high body fat stores, obese children display other characteristics. Compared with non-obese children, they have increased stature and muscle mass (37), early maturation (38), android body fat distribution (39), and obese girls have early menarche (40). These parameters should be borne in mind, as they may help to explain the mechanisms promoting obesity. Like obesity, they are associated with increased health risks (19, 41).

Tracking

Many studies have examined the persistence (tracking) of fatness from childhood to adulthood. The likelihood that childhood obesity will persist into adulthood depends on the age of initial assessment. Individual development in adiposity is characterized by low tracking from early childhood to adulthood, while at later ages, the fattest adolescents have a high risk of obesity in adulthood (42-44). In addition, retrospective studies have shown that most obese adults were not overweight in early life (42). The magnitude of tracking is an important aspect to consider when defining obesity in children. It must be taken into account for treatment or prevention strategies.

The Adiposity rebound

Definition

On the average, a rapid BMI increase occurs during the first year of life. The BMI subsequently declines and reaches a minimum around the age of 6 years, before beginning a sustained increase up to the end of growth (Figure 1a). This development is similar with other fatness patterns such as skinfolds (Figure 1b), but clearly differs from the development of lean mass which steadily increases with age (Figure 1c). The point of minimal BMI value (the nadir of the BMI curve) preceding the second rise in BMI was named the adiposity rebound (AR) (45).

The low tracking between early and late childhood can be better understood by examining individual BMI curves (Figure 2). On average, AR takes place by the age of 6 years, but in individual cases, it may occur earlier or later (43, 45). Several main patterns appear. Most fat infants in early life will join average BMI after a late rebound (>6 years), while others will remain fat after an early rebound. Thin children can join average after an early rebound or remain thin after a late rebound. However, a number of thin children become fat after an early rebound (case 3 Figure 2). Their BMI curves cross centile upward and join overweight levels only several years after the AR. This pattern points out that in many cases, overweight diagnosed at adolescence actually has its origin much earlier in life.

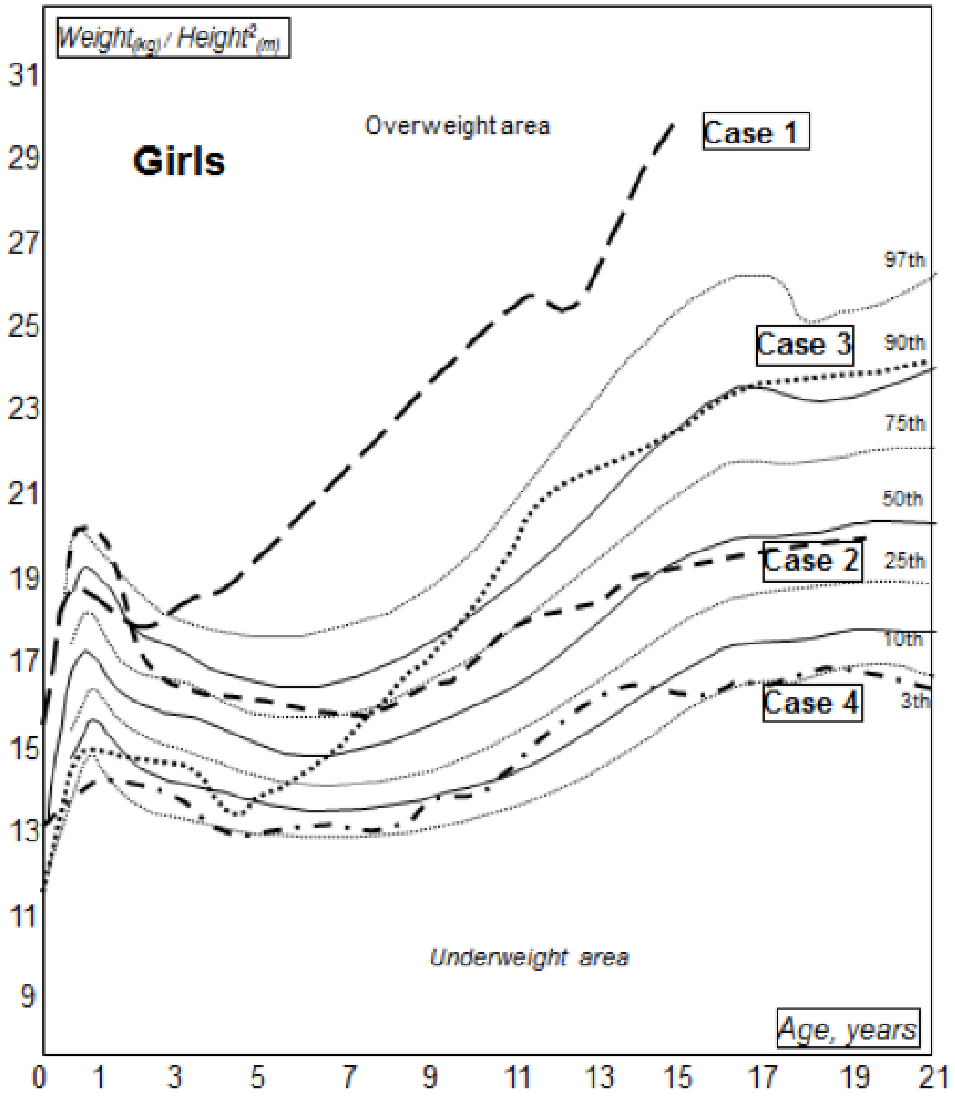

Figure 2: *Four examples of Body Mass Index development: Case 1, fat child at one year, remained fat after an early adiposity rebound (2 years); case 2, fat child at one year, did not stay fat after a late adiposity rebound (8 years); case 3, lean child at one year, became fat after an early adiposity rebound (4.5 years); case 4, lean child at one year, remained lean after a late adiposity rebound (8 years), (After Rolland-Cachera (43)).*

The frequent changes in BMI level throughout growth explain why adult fatness is poorly predicted by BMI level before the age at AR (42, 43). An early AR is also associated with advanced bone age reflecting accelerated growth (45). This indicator of fatness development is a useful tool to predict future adiposity and to investigate early determinants of adult obesity.

Individual BMI trajectories associated with an early or late AR

BMI trajectories are important to consider because BMI patterns rather than BMI level, are associated with later metabolic risks (46-48).

Based on centile curves constructed cross sectionally, it has been suggested (49, 50) that an early rebound is a risk factor for later fatness because it identifies children whose BMI is high at rebound. (for example the nadir of the BMI curves takes place earlier on the 97th than on the 3rd BMI centile Figure 1a), However, longitudinal studies examining BMI patterns associated with an early AR (51) show that BMI level at or before an early AR is either normal (52-55) or more generally low (43,45-48,55-58). Data from the ELANCE longitudinal study (59) confirm this particular pattern. Children with an early AR have lower BMI before the rebound and higher values thereafter (Figure 3a). This pattern is associated with later metabolic risks (46-48, 55). By contrast, trajectories exhibiting high BMI throughout growth likely reflect both high lean and fat body mass and are likely not associated with the same metabolic risks (51). Then, based on all studies examining BMI patterns, it is clear that an early adiposity rebound occurs in the absence of elevated concurrent or earlier BMI (51, 58) and previous suggestions (49,50) that an early rebound predicts later overweight because BMI is high at rebound are not scientifically founded.

Figure 3: Development of the body mass index (BMI), Upper arm fat area estimate (UFE) and Upper arm muscle area estimate (UME) (18) according to the age at adiposity rebound in 40 males and 33 females from the ELANCE French longitudinal study (51,59) (early AR <6 y; late rebound ≥ 6 y).

For comparisons between early and late rebound groups (ANOVA), all values were converted into Z-scores tacking gender into account (Statistical differences between early and late rebound groups were: P<0.001 since 6 y for BMI, P<0.001 since 8y for UFE and P<0.05 at 10 – 14 y for UME).

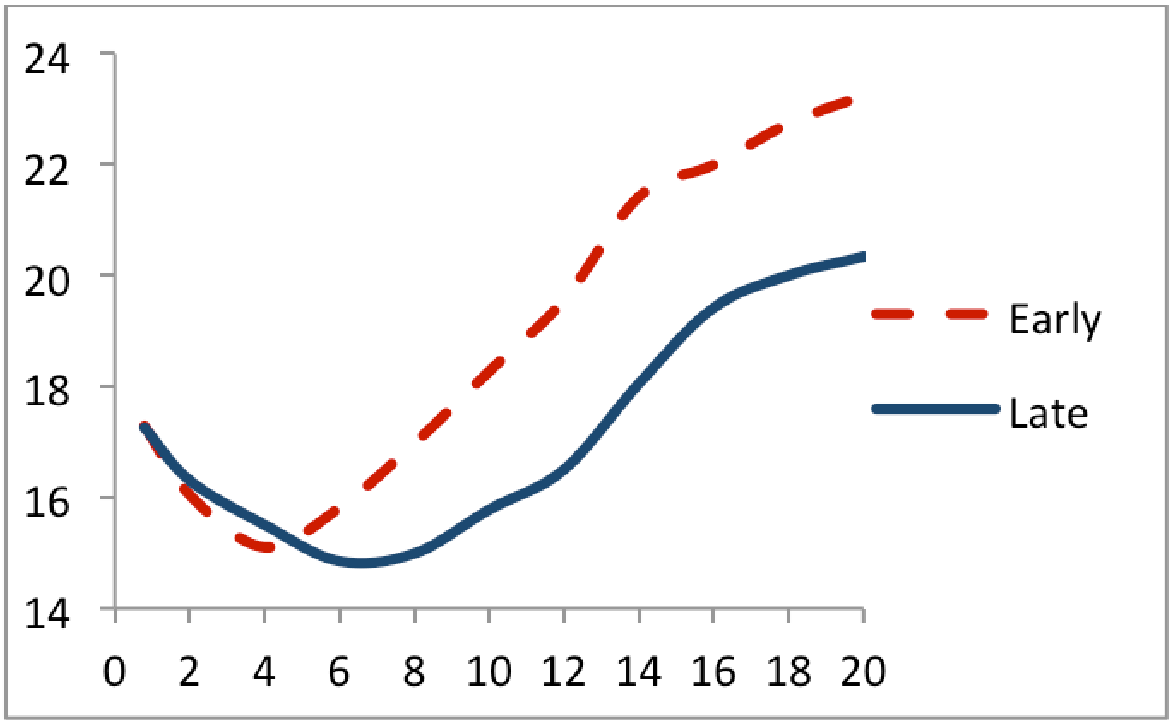

Figure 3a: Body Mass Index BMI (kg/m2) according to age at AR

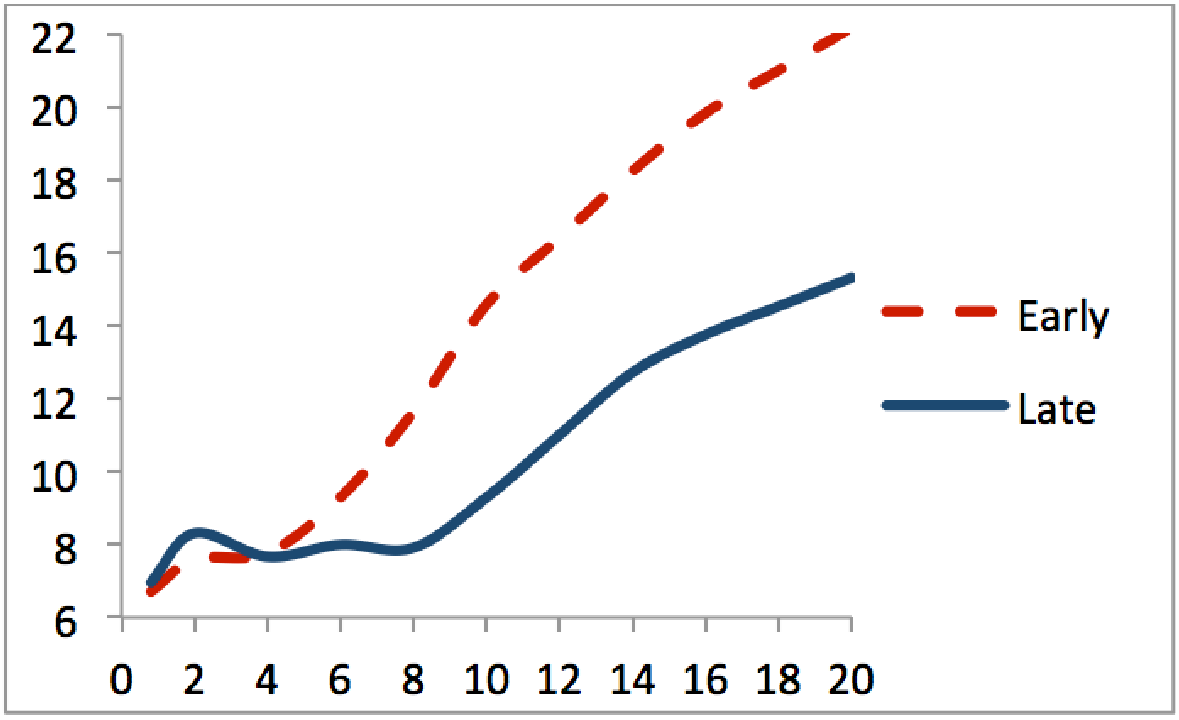

Figure 3b: Arm fat area estimate UFE (cm2) according to age at AR

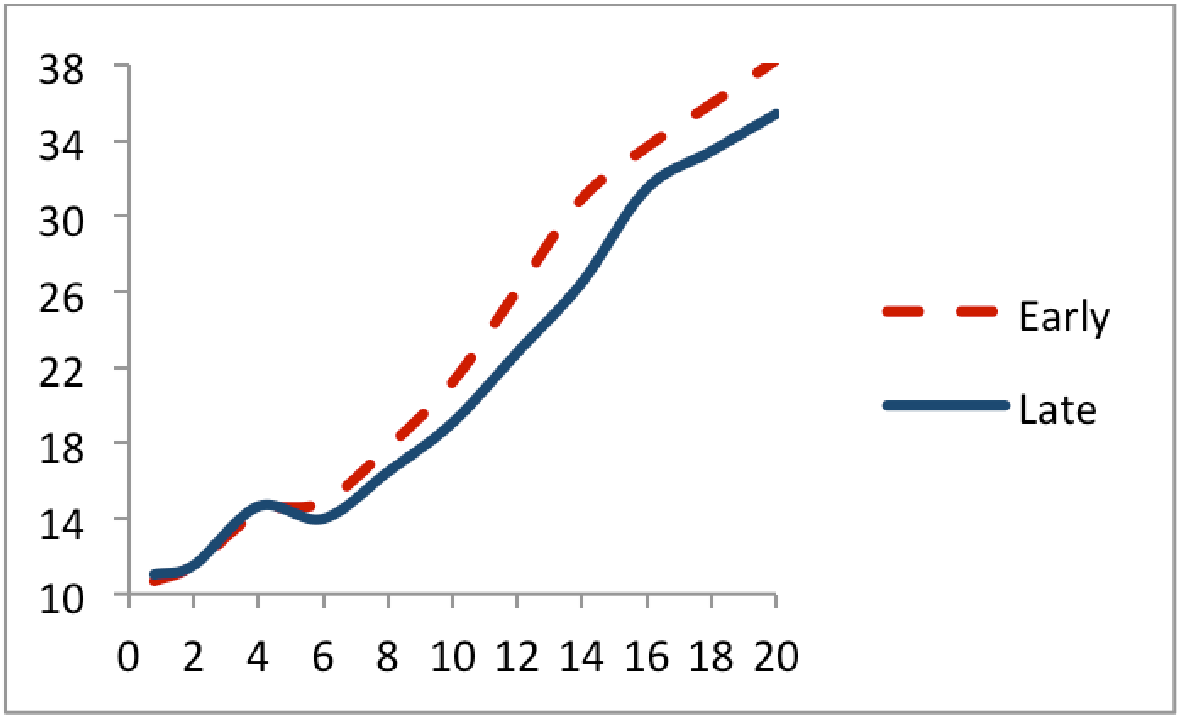

Figure 3c: Arm muscle area estimate UME (cm2) according to age at AR

Is the Adiposity Rebound a rebound in lean or fat body mass?

A large number of studies investigating the predictive value of the AR showed that an early AR is associated with later overweight (43-61). However, whether an early AR reflects an increase in fat or in lean body mass has been questioned. A study following children from birth to 21 years showed that an early AR was significantly associated with higher BMI and subscapular skinfold at the age of 21 years (43). Several studies have shown that changes in BMI during the AR period were caused specifically by alteration in body fat rather than by alteration in lean mass, (53, 62) but other studies found that an early rebound was also associated with lean mass (54, 63). Finally, using data from the ELANCE longitudinal study of subjects followed from birth to 20 years of age (59, 64), the pattern of fat and lean compartments according to the age at AR were examined. Figure 3a shows that an early AR is associated with higher BMI values between the ages of 6 to 20 years. To examine the contribution of lean and fat compartments, arm fat and muscle arm areas based on arm circumference and triceps skinfold measurements were used (18). Children who had an early AR had higher arm fat areas from the age of 8 years ($P<0.001$) (Figure 3b). Muscle area was significantly higher at the age of 10 and 14 years in subjects with an early rebound ($p<0.05$) (Figure 3c). In summary, as a rule, increased BMI at the time of the AR mainly reflects an increase in fat rather than lean mass. These observations justify therefore using the term "adiposity rebound" initially proposed (45).

Current definition of childhood obesity

Different growth references

Several growth curves are available to define grades of nutritional status (1), mainly the IOTF (65), and Cole et al. (66) WHO (67, 68), CDC (69). The WHO growth curves are described in another chapter in the present book.

Clarification on the definitions of nutritional status in children was published by the ECOG in 2011 (1). The following recommendations were proposed: 1. Use IOTF and WHO definitions to assess the prevalence of childhood overweight and obesity and use Cole et al. 2007 and WHO definitions for the prevalence of thinness; 2. Additional definitions (CDC and national references) could also be used in order to provide more opportunities of comparisons of prevalence between studies; 3. Use WHO standards (0-5years) and references (5-19 years) in clinical studies involving growth assessment to improve comparability between results; 4. Always state explicitly the definition used and use the exact terms corresponding to each definition, clearly stating whether or not the term overweight includes obesity and specify which definition is used to assess weight deficit; 5. Whenever possible, perform additional body measurements, including arm and waist circumferences, skinfolds and bioelectrical impedance analysis; 6. Perform anthropometric measurements according to standardized procedures.

Note that since the ECOG recommendations were published (1), the IOTF cut-offs for overweight (65) and Cole et al. for thinness (66) have been gathered together in a recent publication (70).

Terminology

A consensus for the use of a single reference seems difficult to obtain, but there is another important issue which could be more easily solved. ECOG recommends using the exact terms corresponding to each definition. Because of the inconsistency of existing terminologies for defining levels of overweight, ambiguous information is frequently encountered in the literature. It is generally agreed that according to IOTF criteria, the estimated prevalence of overweight in European children is about 20% (71). This prevalence includes all children with a BMI greater than the centile curve that matches the value of 25 at 18 years. However, as it may be confused with CDC terminology, the range between the IOTF centiles 25 and 30 is often inappropriately termed "overweight", thereby providing uncertain information. Following previous suggestion (72), we could agree to simplify the language and like for adults (3), use for all definitions the common terminology "Grade 1" and "Grade 2" overweight in children (Table 1). In a second stage, terms such as "at risk of overweight" or "obesity" could be used in different contexts. This would be particularly useful in the clinician's office where the terminology could be adapted to the age of the child and possibly other health or familial parameters, avoiding judgment or stigmatization (73). The universal use of "Grade 1" and "Grade 2" overweight for children would improve communication, provide clarity to the different definitions and be particularly useful for international comparisons.

	Current terminologies for children				Proposed commun terminology for children (as for adults)*	
BMI levels corresponding to adult cut offs[a]	**IOTF and Cole[b]**	**WHO <5 y[c]**	**WHO ≥ 5y[d]**	**CDC[e]**	**1st step terminology***	
<18.5 Thinness	**All thinness categories (< Centile-18.5)**	Nutrition condition based on Height/age, Weight/age or Weight/Height	**All thinness categories (<-2SD)**	**Underweight (<5th centile)**	**All thinness categories (Grades 1 to 3)**	
<16	Grade 3 Thinness					Grade 3 Thinness
16-17	Grade 2 Thinness		Severe thinness (<–3 SD)			Grade 2 Thinness
17-18.5	Grade 1 Thinness		Thinness (-2<BMI < –3 SD)			Grade 1 Thinness
18.5-25 Normal range					**Normal range**	**Grade 0 Nutritional status**
≥ 25 Overweight (OW)	**OW (≥Centile-25)**	**Possible risk of OW (≥+1DS)**	**OW (≥+1DS)**	**OW + Obesity (≥85th centile)**	**Overweight (all grades)****	
25-30	OW-non obese (C-25 to C-30)	Possible risk of OW-non OW (+1 to +2DS)	OW-non obese (+1 to +2DS)	OW (85-95th centile)		Grade 1 OW
≥ 30	Obesity (≥ Centile-30)	OW (≥+2DS)	Obesity (≥+2DS)	Obesity (≥95th centile)		Grade 2 OW (or obesity)

Table 1: Definition of nutritional status: terminologies used by IOTF, WHO and CDC and proposition of a common definition (72).

**In a second step, other terms like "at risk of overweight" etc… can be used according to the context (clinical, epidemiological…)*

***Other grades like grade 3 OW (30<BMI<40 for massive obesity) etc… can be added*

OW: overweight

[a]*World Health Organisation. WHO Technical Report 1995 (3)*

[b]*Cole TJ, Lobstein T. Pediatr Obes 2012 (70)*

[c]*WHO Child Growth Standards (67)*

[d]*WHO Growth Reference for school-aged children and adolescents (68)*

[e]*Kuczmarski et al. CDC growth charts Adv Data 2000 (69)*

Conclusion

Assessment of nutritional status is essential for clinical, epidemiological and research purposes. Precise methods of body composition such as DEXA become more commonly used, but a suitable method to define grades of nutritional status should use indicators based on more easily available measurements. They also must predict body fat and risk factors. With respect to these different aspects, the BMI appears to be a good indicator of adiposity in children. However, using additional methods to assess body composition is recommended to improve the interpretation of BMI measurements. Growth references are necessary for defining nutritional status in children. A single reference should be desirable, but in the absence of such consensus it is particularly important to be informed on the suitable indicators to be selected, the instruction for their use and for their interpretation. Improvement of knowledge of the definition of nutritional status will make inter-study comparisons more valid, and help identify factors responsible for the high rate of childhood obesity.

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