Growth Trajectories Associated with Adult Obesity

Marie Françoise Rolland-Cachera • Sandrine Péneau

Nutritional Epidemiology Research Unit (UREN), INSERM U557, INRA U1125, CNAM, Paris 13 University, Sorbonne Paris Cité, CRNH IdF, Bobigny, France

Abstract
The influence of early life factors on later body weight and metabolic diseases has generated increasing interest in the recent years. Exposure to environmental factors during pregnancy and early life can exert long-lasting influence on health. Anthropometric indicators are of great value to investigate the early determinants of the development of obesity. Different indicators may be associated with different growth patterns and then may predict different risks. The adiposity rebound (AR) which corresponds to the second rise in BMI that occurs at around 6 years of age, predicts later body weight. An early rebound is a risk factor for later overweight. Many fat children stay fat but, by contrast, an early AR is not associated with overweight in early life. These observations point out the existence of various BMI patterns associated with adult obesity. Two main trajectories emerge: the trajectory of high BMI at all ages which reflects both high lean and fat body masses, and the trajectory of low or normal BMI followed by an early AR and a subsequent rise in BMI reflecting increased fat rather than lean body mass. The trajectory of always high BMI could correspond to the so-called 'metabolically healthy obese subjects' while the trajectory of low BMI followed by increasing fatness is associated with insulin resistance and coronary heart diseases. The very early rebound recorded in most obese subjects suggests that determinants of obesity have operated very early in life. The identification of growth trajectories is of great interest to investigate the factors promoting obesity and metabolic diseases and to improve prevention strategies which should start from early life.

The influence of early life factors on later body weight and metabolic diseases has generated increasing interest in the last two decades [1, 2]. The perinatal environment, particularly nutrition, affects growth and can have long-term health consequences. While high body fat in early life predicts adult overweight, by contrast, most obese adults were not overweight as children [3]. This clearly indicates that the
development of obesity may occur through different growth trajectories. The identifica-
tion of these trajectories is of great interest to identify the early determinants of 
the development of obesity. They will be described here and discussed in term of their 
prediction of later health risks.

**Body Mass Index Trajectories**

The BMI calculated as the weight/height\(^2\) has been selected to predict adiposity in 
children because it is highly correlated with weight and body fat, and weakly related 
to stature [4]. In the early 1980s, the first BMI reference charts [4] have been con-
structed throughout childhood (fig. 1). It appeared that the development of the BMI 
during growth parallels the development of more direct measures of body adiposity 
such as skinfolds. On average, a rapid 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. We named adiposity rebound 
(AR) [8] the point of minimal BMI value (the nadir of the BMI curve) preceding the 
second rise in BMI (fig. 1).

On average, AR takes place by the age of 6 years, but may occur earlier or 
later in individual cases [8, 9]. Several main patterns appear. Most fat infants in 
early life will have an average BMI after a late rebound (>6 years), while others 
will remain fat after an early rebound. Thin children can become average after 
an early rebound or remain thin after a late rebound. However, a number of thin 
children become fat after an early rebound. Their BMI curves cross the centile 
upward and reach overweight levels only several years after the AR [9]. This pat-
tern points out that in many cases overweight diagnosed at adolescence actually 
has its origin much earlier in life. The frequent changes in BMI level which are 
related to an early or late AR explain why adult fatness is poorly predicted by BMI 
before the AR [3].

**Lean and Fat Body Measurements Trajectories: Is the AR a Rebound in Lean or Fat 
Body Mass?**

All studies investigating the predictive value of the AR showed that an early AR 
is associated with later overweight [8–18]. However, whether an early AR reflects 
an increase in fat or in lean body mass has been questioned. In a study following 
children from birth to 21 years, we observed that an early adiposity rebound was 
significantly associated with higher BMI and subscapular skinfold at the age of 
21 years [9]. A study conducted in New Zealand found that changes in BMI dur-
ing the AR period were caused specifically by alteration in body fat assessed by 
DXA rather than by alteration in lean mass, and children undergoing early AR
gained fat at a faster rate than children who rebounded at a later age [15]. Later on, this observation was confirmed on a larger sample [16], showing that an early AR was associated with greater skinfold thickness, fat mass and fat mass index at the ages of 7, 9 and 11 years. In this study, the early AR was associated with higher BMI values, greater weight, and higher waist girths at age 26 years. Another study showed that the rebound reflected an increase in fat mass and fat-free mass in boys and fat mass in girls [17]. More recently, a study was conducted in children examined at 4 and 6.5 years of age. Their weight and length measures between 0 and 2 years were obtained from health records. This study showed that an early AR was associated with high body fat at 6.5 years, but also with high lean mass [18]. Finally, using data from the ELANCE longitudinal study [19], we examined the pattern of fat and lean compartments according to the age of AR. Figure 2a shows that an early AR predicted later high BMI, but was associated with lower BMI before the age of 4 years. To examine the contribution of lean and fat compartments in BMI trajectories, we used arm fat and muscle areas based on arm circumference and triceps skinfold measurements [20]. Children who had an early AR had higher arm fat areas from the age of 6 years, while except at the age of 8 years, there was not difference in muscle areas between the two groups of early and late rebound. In summary, most studies show that the AR mainly reflects an increase in fat rather than lean mass. These observations justify therefore using the term ‘adiposity rebound’ initially proposed [8] rather than BMI rebound proposed later on [14].
**Indicators Predicting Later Overweight: Early AR or High BMI at Rebound?**

**Assumptions Based on Cross-Sectional Observations**

The utility of the AR has been questioned by several authors. Based on centile curves constructed cross-sectionally, they reported that the age at AR was earlier on upper centiles than on lower centiles [21, 22]. For example, in figure 1, age at AR is 6 years on the median French reference curve, but ranges from 5 years on the 97th centile to 7 years on the 3rd centile and it occurs clearly earlier (3.5 years) on the +3 SD WHO curve. Following these observations, the authors [21, 22] suggested that an early rebound is a risk factor for later fatness because it identifies children whose BMI is high at rebound. However, BMI patterns based on a cross-sectional approach (centile curves) are very different from individual BMI trajectories.

**Individual BMI Trajectories Associated with an Early AR**

The assumption, based on a cross-sectional approach, that an early AR predicts later overweight because it is associated with a high BMI at AR does not take into account the individual BMI patterns. In longitudinal studies, an early AR is generally associated with either normal [7, 15, 17] or low [8, 9, 16, 23–26] BMI at or preceding the rebound. A BMI curve based on measurements recorded in the same subjects who were massively obese at adolescence is presented figure 1. The BMI curve attains high levels after an early AR, but BMI at the age of AR was close to the 50th centile of the reference population, showing that an early AR is not associated with high BMI values at rebound. Data from the ELANCE longitudinal study confirm this particular pattern. They show that children with an early AR have lower BMI before the rebound and higher values thereafter (fig. 2a).

**BMI Trajectories Associated with an Early AR or with a High BMI at 6 Years**

Several authors have proposed to use the BMI value at mean age at AR (by the age of 6 years) rather than evaluating the age at AR, because it is a more practical criterion for the determination of later risk [21, 22]. We then also examined the BMI trajectory associated with a high BMI at 6 years using data from the ELANCE study. By contrast with trajectories associated with an early AR, the trajectory associated with a high BMI at 6 years displays high BMI values at all ages (fig. 2b). Differences between the two trajectories start at birth. Age at AR is not associated with birth weight (r = –0.04; p = 0.75), while a high BMI at 6 years is associated with a high birth weight (r = 0.29; p = 0.01). Consequently, while both ‘BMI at 6 years’ and ‘age at AR’ predict later obesity, it clearly appears that the two indicators represent very different growth patterns, i.e. respectively high BMI at all ages starting from birth, and low BMI values followed by an early AR and increased fatness later on.
Fig. 2. Comparisons of trajectories associated with two indicators (age at AR and BMI at 6 years) using data of the ELANCE prospective study (n = 104 subjects) [19]. Two subgroups were constituted on the basis of the distribution of each indicator. a Early AR (<6 years): 23 boys and 12 girls; late AR (≥ 6 years): 38 boys and 31 girls. b Low BMI at 6 years (<15.25 in boys, n = 28) and (<14.85 in girls, n = 21); high BMI at 6 years (≥15.25 in boys, n = 33 and ≥14.85 in girls, n = 22). Legend: AR = Adiposity Rebound; BMI = Body Mass Index (kg/m²); UFE = Upper arm Fat area Estimate (cm²); UME = Upper arm Muscle area Estimate (cm²); n.s. = non significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001.
Body Composition Trajectories Associated with an Early AR or with a High BMI at 6 Years

Using data from the ELANCE study, we examined arm fat and muscle areas trajectories associated with a high BMI at 6 years. By contrast with the trajectories associated with an early AR described above (fig. 2a), a high BMI at 6 years was associated with both high fat and muscle areas at all ages (fig. 2b). The two indicators (AR and BMI at AR) then reflect different body composition trajectories, i.e. a high BMI at 6 years is associated with both high fat and muscle masses at all ages, while an early AR is associated with high fat mass after the AR and is weakly associated with muscle mass.

BMI Pattern in Massively Obese Subjects

Mean age at AR in the obese generally occurs as early as by the age of 2–3 years compared to 6 years in reference populations. In a study conducted in 62 obese children examined in a department of pediatric endocrinology in France, mean age at AR was 3.2 years [9]. None of the children had a late AR (>6 years), and more than half of them (55%) had an AR before the age of 3 years. More recently, we conducted a study in massively obese adolescents. Their BMI trajectory showed that mean age at AR was 2 years as compared to 6 years in the reference population (fig. 1). An early AR (<6 years) was reported in 97% subjects, and 65% had a rebound ≤2 years [7]. In summary, the two main characteristics of the BMI pattern in the obese are the very early AR and the median BMI value at the time of the AR, showing that generally obese subjects were not overweight in early childhood. These two elements are useful to be considered when investigating the origin of obesity development.

Discussion

It clearly appears that overweight in late childhood and adulthood could be attained through different growth patterns. Two main BMI trajectories emerge. On the one hand, children who are always overweight, starting with high birth weight, are more likely to have both high fat and lean body masses at all ages. On the other hand, children with an early AR are characterized by normal weight at birth, followed by normal or even low adiposity level by the ages of 1–3 years. Subsequently, from the time of AR, they become overweight, due to the development of fat mass rather than of lean mass. The two types of trajectories may be associated with different health risks. Overweight subjects with high birth weight followed by high lean body mass conferring increased metabolic activity, may have lower health risks [27]. They could correspond to the so-called ‘metabolically healthy obese subjects’ [28, 29]. By contrast, the trajectory of subjects who were thin in infancy and thereafter put on weight rapidly after an early AR is associated with insulin resistance and coronary heart diseases [24, 25, 30].
Several factors in early life could explain the different growth trajectories. A permanently high BMI seems to correspond to the trajectory associated with high energy intake in early childhood perhaps due to high muscle mass, while the trajectory associated with an early AR could correspond to early high intakes of proteins [19]. The low BMI values before the rebound could be explained by a negative energy balance as a consequence of the use of high protein-low fat diets, often reported in young children [11]. A mismatch between low fat intake in early life, followed by high-fat diets at later ages, may be responsible for the early low-later high BMI trajectories [11] which are particularly associated with later risks [24, 25, 30].

Conclusion

From studies investigating growth patterns, it clearly appears that different trajectories are associated with adult obesity. The ‘permanently high BMI’ and the ‘low BMI followed by an early AR and later high fatness’ trajectories do not reflect the same body composition and are probably not associated with the same health risks. The AR appears to be a useful indicator to predict adiposity for the use of pediatricians and researchers. The very early rebound recorded in most obese subjects suggests that determinants of obesity have operated very early in life. The identification of growth trajectories is of great interest to investigate the factors promoting obesity and to improve prevention strategies which should start early in life.

References

7 Péneau S, Thibault H, Rolland-Cachera MF: Massively obese adolescents were of normal weight at the age of adiposity rebound. Obesity (Silver Spring) 2009;17:1309–1310.