WHAT IS THE BEST MEASURE OF ADIPOSITY CHANGE IN GROWING CHILDREN: BMI, BMI %, BMI Z-SCORE OR BMI CENTILE?

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Running title: Adiposity change in growing children.

Abstract

Background: Weight control programs for obese children monitor change in body mass index (BMI) adjusted for age. However change can be measured in several ways: raw (kg/m^2) units, percentage, z-scores or centiles. The suitability of the different measures is not known.

Aim: To identify the optimal BMI measure for change, whose short-term variability is most consistent for children across the spectrum of adiposity.

Setting: An Italian kindergarten.

Subjects: 135 (66 female) children aged 29-68 months at baseline, with BMI measured 3 times over a 9-month period.

Methods: Each child's short-term variability in adiposity was summarised by the standard deviation (SD) of BMI and BMI % adjusted for age, and BMI z-score and BMI centile. The SDs were then compared in obese and non-obese children, and also correlated with each child's baseline BMI z-score.

Results: The within-child SDs of BMI z-score and BMI centile were significantly smaller in obese than non-obese children, while the SDs of BMI and BMI % were similar in the two groups. Also the within-child SDs of z-score and centile, and to a lesser extent BMI %, were significantly inversely correlated with baseline z-score, whereas the SD of BMI was not. The changes in adiposity over time, as assessed by the four measures, were very highly correlated with each other, particularly for BMI with BMI %.

Discussion: Even though BMI z-score is optimal for assessing adiposity on a single occasion it is not necessarily the best scale for measuring change in adiposity,. A better scale is BMI itself, adjusted for age, whereas the within-child variability over time is largely independs on the child's level ofent of adiposity. Better alternatives are BMI itself or BMI %.

In conclusion, ourOur results underlineunderscore the importance of using an appropriatea relatively stable method to assess adiposity change when following children at risk of obesity.This has implications for the design of paediatric weight control programs.

Key words: child obesitypediatrics, body composition, body mass index, obesity, weight prevention, growthvariability

Introduction

Child obesity is now a serious public health concern worldwide, and many clinical programs have been developed to treat obese children. Many of them focus on weight gain prevention rather than weight loss, allowing the child to become thinner over time as they grow in height. To this end, it is often necessary to assess *short-term* weight changes in growing children (Barlow et al, 2002). For example, investigators may wish to test the initial 6-month effects of a weight gain-prevention program for children at-risk for obesity.

Weight reflects health and nutrition status and adjusted for height it is a useful tool to predict fatness (Zemel et al, 1997, Ellis KJ, 2000). However, weight changes with age during childhood (Ellis KJ, 2000) and, therefore, weight needs to be adjusted to compare an individual child with others of the same age. Thus, although Ttreatment effectiveness is usually monitored with serial measures of weight and height (Barlow et al, 2002),. Bbody mass index (BMI=weight/height^2) is a useful proxy measure of adiposity (Zemel et al, 1997, Ellis KJ, 2000), and can be converted to a centile or z-score adjusted for age and sex using the US CDC 2000 growth reference (Kuczmarski et al, 2000). Changes in adiposity over time can, thus, be based on the change in BMI, or the proportional (percentage) change in BMI, or the change in BMI z-score or centile. So researchers and clinicians interested in treatment response have four distinct ways of measuring the change in adiposity: BMI, BMI %, BMI z-score and BMI centile (Maynard et al, 2001; Zannolli et al, 1996, Pietrobelli et al, 1998).

To our knowledge, no report has yet compared the short-term variability of the four measures in individual children, or related it to their adiposity status. There are several reasons why such a relation might be important and why differences might be expected. Percentage change in BMI is larger in BMI units for fat obese children than for thin children. Also the centile curves on the BMI chart (Kuczmarski et al, 2000) are further apart for higher centiles, due to the skewness of the BMI distribution. Among boys aged 7 for example, the

90th-97th centile channel is 2.0 kg/m^2 wide while the 3rd-10th centile is 0.5 kg/m^2 wide, a quarter as much. In addition, changes on the centile scale correspond to much larger BMI changes in the tails of the distribution than at the median. For boys aged 7, seven centile points near the median (i.e. the 46.5th-53.5st centile) cover a BMI range of 0.25 kg/m^2, half that for 3rd-10th centile and an eighth that for 90th-97th centile.

To find out which is the most appropriate way of measuring change in adiposity, we need to know how BMI varies over time in normally growing children. An important principle is that the measure's within-child short-term variation should be the same whatever the child's adiposity, and this principle can be used to identify the best measure of change. This principle clearly does not apply to all the measures here – the BMI % and BMI z-score scales attenuate BMI change in fatter children, and the centile scale attenuates BMI change in both fat and thin children. The attenuation effectively shrinks the variability of the measure, which biases one part of the distribution relative to others.

It was our study aim Tto compare the performance of the different measures of BMI was measured longitudinally in a group of kindergarten children over a 9-month period. This issue has implications for short-term studies targeting the prevention of weight gain in children at-risk for obesity or the treatment of children who are already obese. These studies require the use of an outcome measure that is equally stable for non-obese and obese children, as intervention either attempts to prevent children from moving across these categories (prevention studies) or attempts to move children across these categories (treatment studies).

Methods

The study subjects were 135 (66 female) Italian pre-school children aged 29-68 months at baseline. They were recruited in a Verona kindergarten after excluding those with disorders affecting growth. Obesity was defined as baseline BMI on or above the 85th centile

(Kuczmarski et al, 2000) and 17 boys and 16 girls were obese (24%). Height and weight were measured three times for each child by the same trained observer, at baseline, 4 and 9 months.

BMI was calculated from weight and height, and BMI z-scores and centiles for sex and age were derived against the US CDC 2000 reference (Kuczmarski et al, 2000). In addition BMI was adjusted for age by subtracting the sex-age-specific median BMI (Kuczmarski et al, 2000), and BMI % was similarly defined as 100 $\log_e$(BMI / median BMI). This is effectively the percentage difference from median BMI (Cole TJ, 2000). So there are four sex-age-adjusted measures of adiposity: BMI, BMI %, BMI z-score and BMI centile.

To quantify within-child variability over time in the four measures, the standard deviation (SD) of each child's three measurements was calculated for each measure in turn. For analysis purposes the SDs were square root transformed to remove skewness, and the means compared in obese and non-obese children adjusted for sex and age using ANCOVA. Comparing the medians using Mann-Whitney gave very similar results. In addition children's SDs for each measure were (after square root transformation) correlated with their baseline BMI z-score. Adjusting for sex and age with multiple regression made no difference, and Spearman correlations were similar to Pearson correlations. Finally changes in the four adiposity measures over time were assessed with Pearson correlations.

The study was approved by the local ethics committee, and parents/guardians gave written consent for their children to participate.

Results

The mean age at baseline was 50 (SD 11) months. Table 1 shows the mean and SD of the four BMI adiposity measures by measurement occasion and sex. As a group the children were slightly fatter heavier than the US reference, with mean BMI 3-4% above the median, around the 57th centile. Adiposity changed little over time.

Figures 1-3 show the patterns of adiposity change over time in individual children, as measured by BMI, BMI z-score and BMI centile respectively. Figure 2 shows a suggestion of less variability for children in the upper part of the graph. In Figure 3 the fattest heaviest and thinnest children change very little in centile compared to the other children.

Figures 4 and 5 present the same data in a different way, comparing the first and third measurements of BMI (Figure 4) and BMI z-score (Figure 5) in individual children. BMI is adjusted for age. Both figures show high correlations (0.90 for BMI and 0.82 for BMI z-score), indicating strong tracking over time. In Figure 4 the scatterplot is of similar width throughout the range while in Figure 5 it narrows with increasing fatness and is pointed at the top. The width of the plot indicates the within-child variability of the measure, so the variability for BMI is fairly constant across the range whereas for BMI z-score it is reduced in fat children.

Table 2 summarises the within-child variability in the four BMI adiposity measures over time, giving the SDs overall and for obese and non-obese children separately. The SDs are surprisingly large, e.g. 0.4 kg/m^2 for BMI and 0.3 for BMI z-score. There was no difference in variability between the groups for BMI or BMI %, but a highly significant difference for BMI z-score and BMI centile. This shows that the latter two measures are less variable among obese children than non-obese.

Table 3 extends Table 2 to look for a more general association between variability and adiposity status, where each child’s four measures of BMI variability (analysed as the square root of the SD) are correlated with baseline BMI z-score. The variability in BMI z-score and BMI centile, and to a lesser extent in BMI %, was significantly inversely correlated with BMI z-score, so these measures rated fat children as appreciably less variable than thin children. By contrast the variability in BMI was unrelated to mean BMI z-score, indicating that BMI itself is a neutral – and hence optimal - measure of adiposity change. Figures 4 and 5 show the correlations for BMI and BMI z-score.

Yet it is not clear to what extent the four adiposity measures actually differ in their assessment of change over time. Table 4 focuses on adiposity change from measurement 1 to measurement 3 as judged by the four measures, and gives the correlations between them. Somewhat surprisingly the correlations are all very high ($r > 0.9$), particularly the change in BMI with the change in BMI %, implying that in practice the two measures can be used interchangeably. Restricting the table to the obese group of children reduces the correlations slightly but does not alter the conclusion.

Discussion

The study investigated changes in adiposity over a 9-month period in 135 Italian pre-school children. It foundThe principal finding of our study was that for certain BMI-based measures of adiposity, variability in adiposity depended on baseline adiposity status, while for other measures it did not. Specifically, variability in BMI was unrelated to baseline adiposity whereas variability in BMI z-score and BMI centile, measured in terms of the within-subject standard deviation, was highly significantly and inversely related to adiposity status. Expressed in percentage terms, variability in BMI was weakly inversely related to adiposity status. This was shown by comparing variability in obese and non-obese children (Table 2), and by looking at trends in variability across the spectrum of adiposity as defined by baseline BMI z-score (Table 3). These results suggest that short-term changes in adiposity are best evaluated by changes in BMI units.

Our results should be interpreted in the light of the age ranges that we studied and the length of follow-up. We studied children undergoing adiposity rebound, a period of dynamic changes in body composition. We believe these transitions make this period an essentialimportant one for addressing our research question. That is, comparing the stability of the BMI, BMI percentiles, and BMI raw score is arguably most important for dynamic stages of development rather than periods of limit limited growth. With respect to the short-term duration of our follow-up, most treatment studies for childhood overweight last approximately four to six months, ascertaining one baseline and one post-treatment evaluation of weight status. Our study duration and results therefore are pertinent for the evaluation of “short-term” weight prevention in children. The modest sample size canwas also be a representative of sample sizes often seen in real world clinical trials with children within this age range.

However, at the same time, thosethese factors that we addressed above also serve as limitations to the studyare also study limitations. Again, theThe number of subjects (135) iswas modest, the children arewere relatively fat while thin children arewere under-represented (Table 1 and Figure 3), and the age range (29-68 months) and period of follow-up (9 months) arewere limited. For these reasons the study needs to be replicated with different ages and follow-up periods. So oOur study findings may be relevant only for the evaluation of only short-term interventions in obese children with the particular age ranges of our study sample.

With respect to methodological issues concerning the dependence of variability of adiposity measures onand initial weightobesity status, Wwhy does the association – or lack of itthereof – between adiposity variability and adiposity status matter? Statistical methods like ANOVA use the variability of a variable (its SD or variance) to assess the significance of group mean differences, which requires the variability to be similar in the different groups. Longitudinal studies of child adiposity, particularly in obesity treatment programs, need to measure changes in adiposity on a scale where the variability is essentially the same irrespective of the child’s adiposity status. So Thus, ourthe findings have important implications for the choice of scale on which to measure adiposity change. The results clearly show that iIf the amount of variability is to be unrelated to the level of adiposity, as it should be, then the investigator should measure changes in adiposity on the BMI scale.

BMI centile is useful for classifying children's adiposity but poor at quantifying change in adiposity. Figure 3 shows it is sensitive to changes in the middle of the adiposity range but insensitive to changes at the extremes. Tables 2 and 3 confirm that BMI centile variability is significantly reduced in obese compared to non-obese children. So BMI centile is not suitable for measuring change, which is hardly surprising given that the centile scale is known to be inappropriate as a summary statistic, being bounded between 0 and 100. The centile scale is drastically foreshortened in the tails of the distribution, so that obese children inevitably change less than non-obese children in centile terms (and the same applies to very thin children, who are under-represented in the current cohort – see Figure 3).

Like BMI centile, BMI z-score is useful for assessing adiposity cross-sectionally. Furthermore, unlike BMI centile, it can be summarised across subjects for research purposes. So the change in BMI z-score is a logical choice to measure adiposity change over time, just as for height z-score change to measure height velocity (Cole TJ, 1997). Yet it turns out to be less than ideal as a measure of adiposity change, as – its variability gets progressively smaller the fatter the child (Tables 2 and 3). The z-score scale is foreshortened in the upper part of the distribution because of the skewness of the BMI distribution, so that the lower centiles are closer together than the upper centiles. This means that a given change in BMI corresponds to a smaller z-score change the higher the centile in the distribution.

The percentage change in BMI is another obvious choice of scale for measuring adiposity change, and it performs better than BMI z-score or centile (Table 2). Yet Hhere it is clearly appears inferior to BMI (Table 3), which is somewhat surprisingbut in practice adiposity change over time is virtually equivalent whether measured by BMI or BMI % (Table 4), so the two can be used interchangeably.

The practical clear conclusion implication of this study is that adiposity change should be measured in BMI (kg/m^2) or BMI (%) units. The BMI change can be adjusted for sex and age in the same way as used here, that is, by subtracting from each child's observed BMI change score the change in sex-age-specific median BMI for the same time period. But this conclusion needs to be qualified, as the adiposity measures for change over time are all highly correlated (Table 4), and the advantage of BMI or BMI % over BMI z-score is small.

In conclusion, our results underline the importance of using looking for an appropriate method to assess adiposity change when following children at risk of obesity (Power et al, 1997). It is also important to underline that oOur results couldshould be interpreted in light of the fact that it is fundamental to use the best measurement available when excessive weight gain relative to linear growth is recognized. Of the measures discussed here BMI centile is not at all suitable.; nor are BMI z-score is less than ideal or BMI % as their its variability depends on adiposity status, but in practice it is highly correlated with the alternative measures. Overall the best measures is are the change in BMI and BMI %. This conclusion needs testing with larger samples over different age ranges and periods of follow-up, in order to develop practical recommendations about how best to assess adiposity change in treatment programs for childhood obesity.

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Table 1. Mean (SD) of four measures of BMI by sex over the three occasions.

	Boys (N = 69)			Girls (N = 66)		
Measure	1	2	3	1	2	3
BMI	16.3 (1.9)	16.1 (1.8)	16.2 (1.9)	16.0 (1.7)	15.9 (1.7)	16.0 (1.9)
BMI %	3.1 (11)	2.8 (11)	3.5 (11)	3.7 (10)	3.7 (10)	4.4 (11)
BMI z-score	0.25 (1.3)	0.21 (1.2)	0.28 (1.2)	0.27 (1.0)	0.25 (1.0)	0.29 (1.1)
BMI centile	56 (32)	55 (30)	57 (29)	57 (30)	57 (29)	59 (29)

Table 2. Median (inter-quartile range) of the within-child SD across occasions for four measures of BMI change by obesity status, adjusted for sex and age.

Measure	Overall (N=135)	Obese (N=33)	Non-obese (N=102)	p-value*
BMI	0.39 (0.35)	0.42 (0.41)	0.38 (0.36)	0.2
BMI %	2.3 (2.3)	2.1 (1.7)	2.5 (2.4)	0.9
BMI z-score	0.29 (0.31)	0.20 (0.19)	0.34 (0.34)	0.004
BMI centile	6.5 (10)	2.3 (3.4)	8.9 (11)	<0.0001

* calculated by 2-sample t-test with square root transformation

Table 3. Correlations between adiposity variability, measured by within-child SD, and adiposity status, measured by baseline BMI z-score. for four BMI adiposity measures.

Measure	Correlation*	p-value
BMI	-0.01	0.9
BMI %	-0.16	0.06
BMI z-score	-0.44	< 0.0001
BMI centile	-0.48	< 0.0001

* calculated after square root transformation of SD

Table 4. Correlations between the change from measurement 1 to 3 for four measures of BMI adiposity change.

	Change in BMI	Change in BMI %	Change in BMI z-score	Change in BMI centile
Change in BMI	1			
Change in BMI %	0.995	1		
Change in BMI z-score	0.93	0.96	1	
Change in BMI centile	0.91	0.92	0.92	1

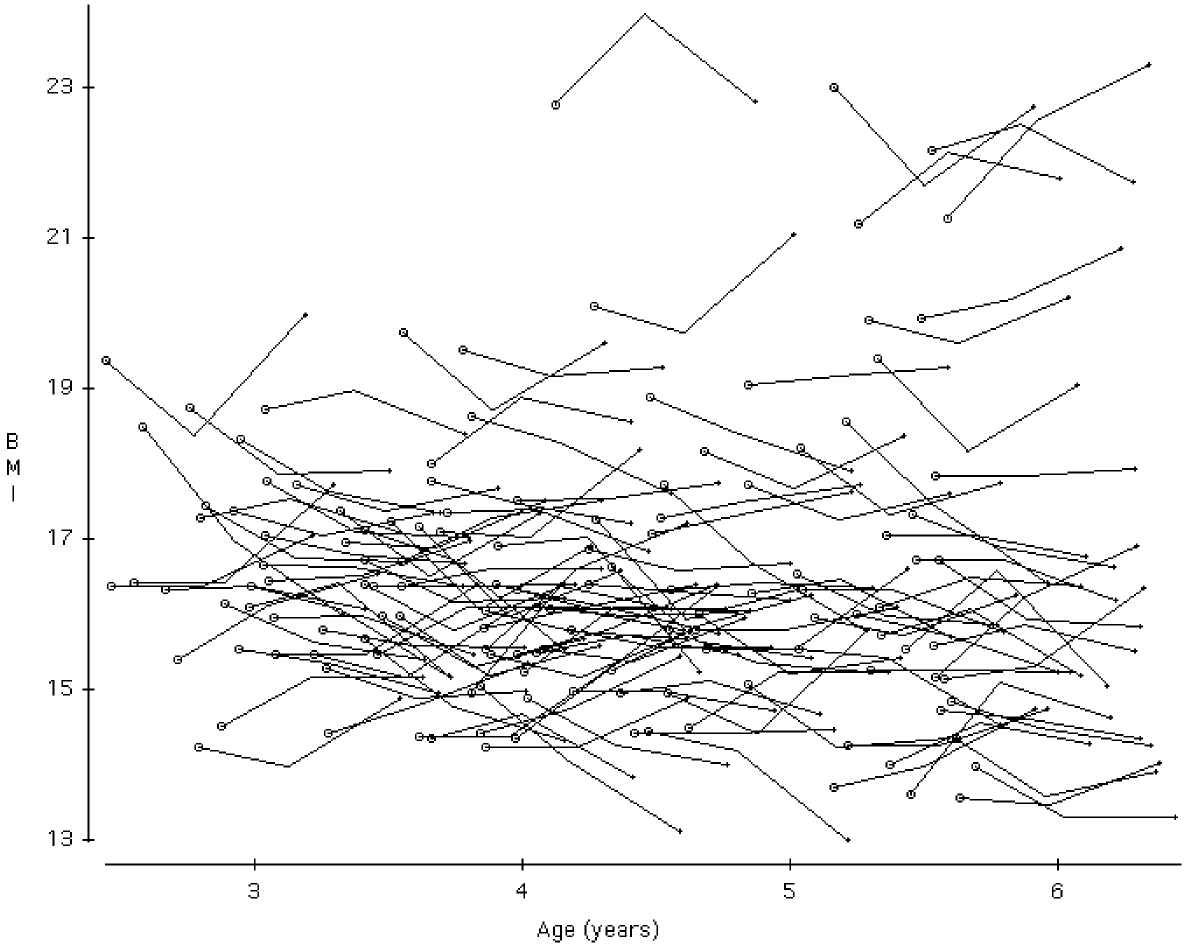


Figure 1. BMI plotted against age over 3 occasions in 135 subjects.

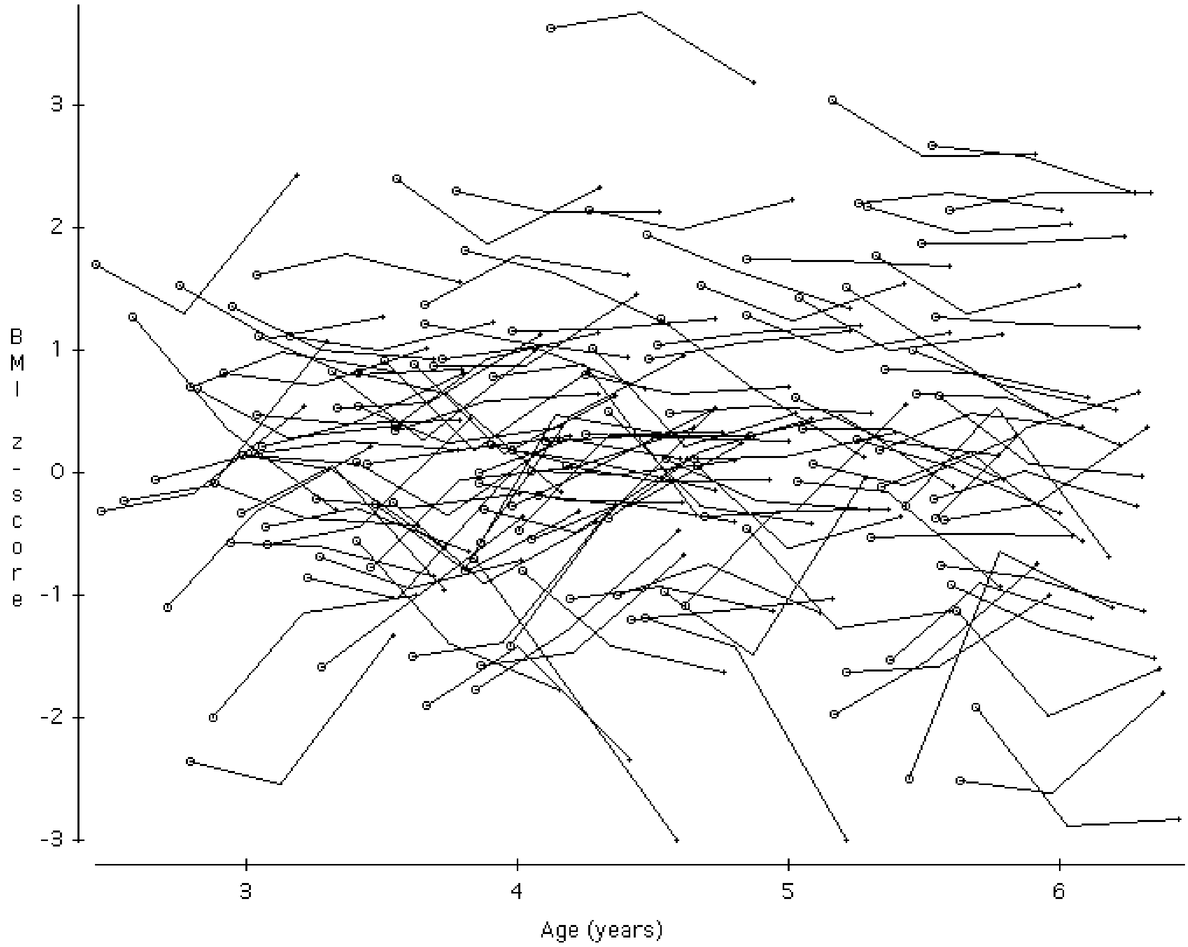


Figure 2. BMI z-score plotted against age over 3 occasions in 135 subjects.

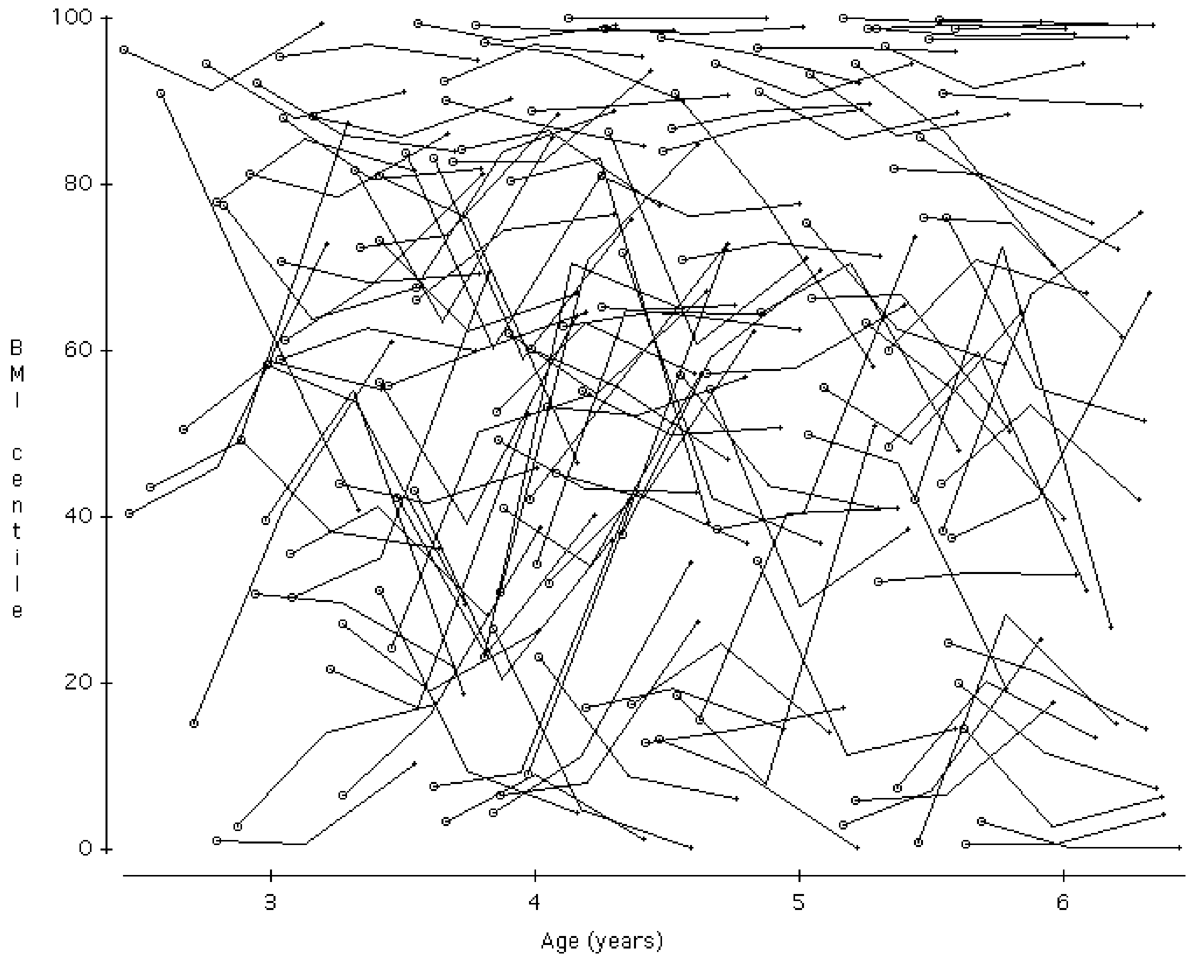
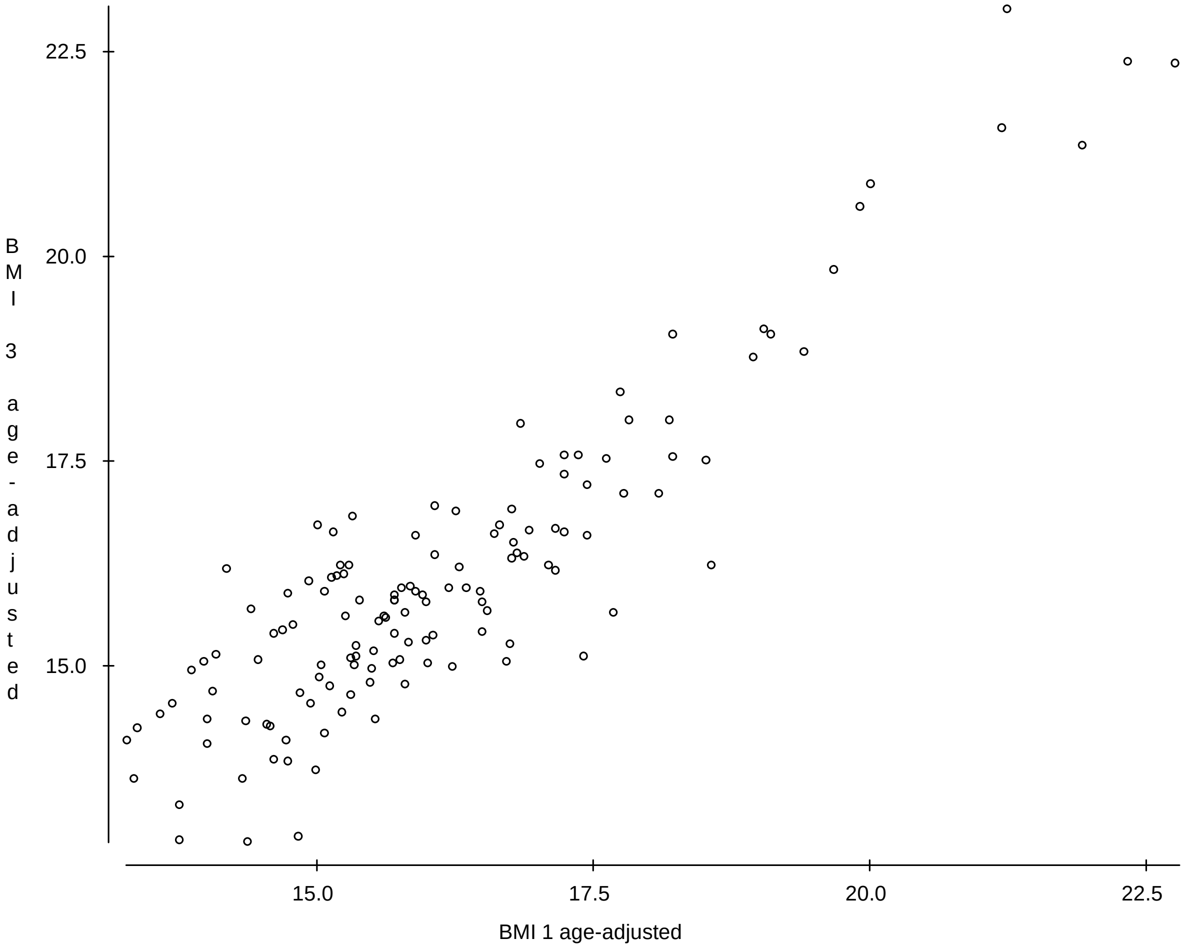


Figure 3. BMI centile plotted against age over 3 occasions in 135 subjects.


22.5
20.0
17.5
15.0
BMI 3 age-adjusted
15.0
17.5
20.0
22.5
BMI 1 age-adjusted

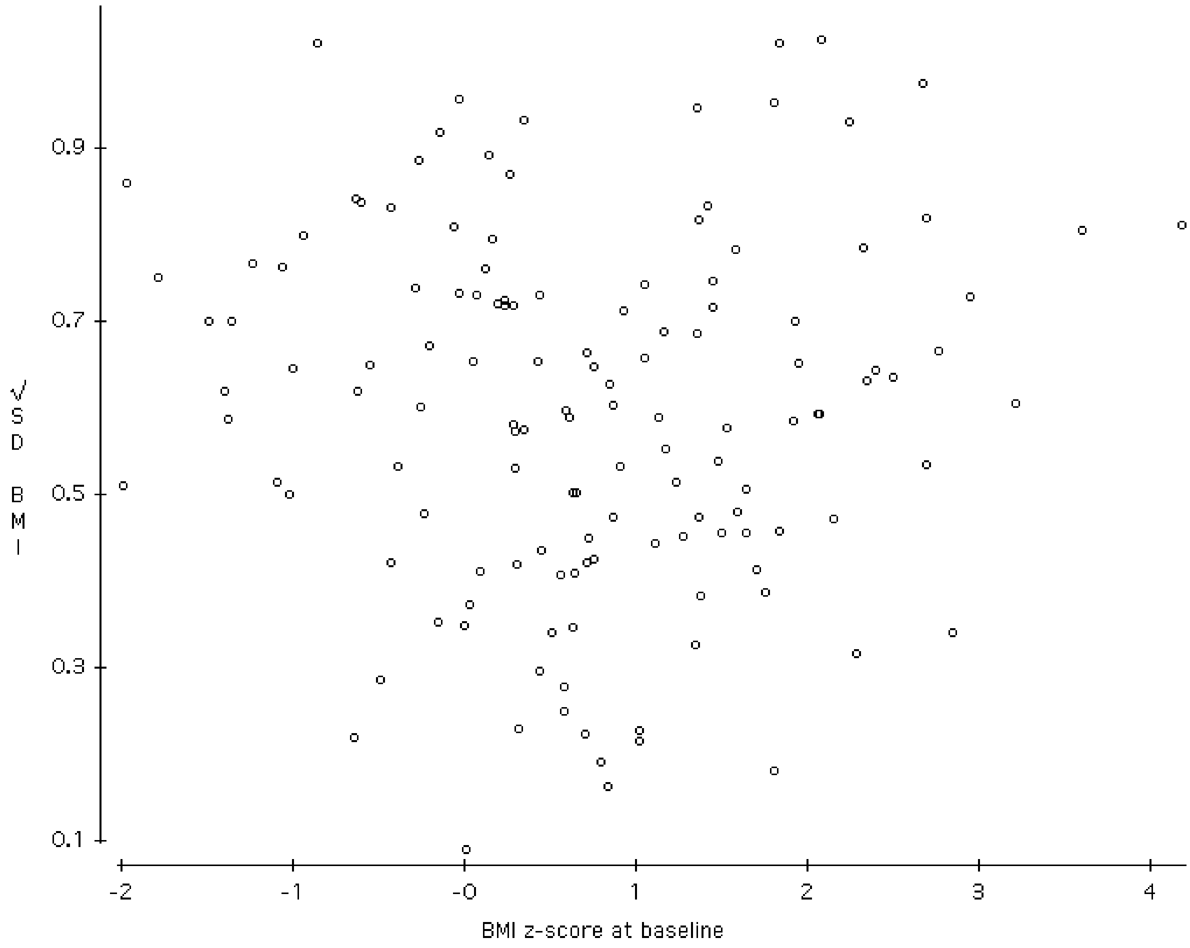
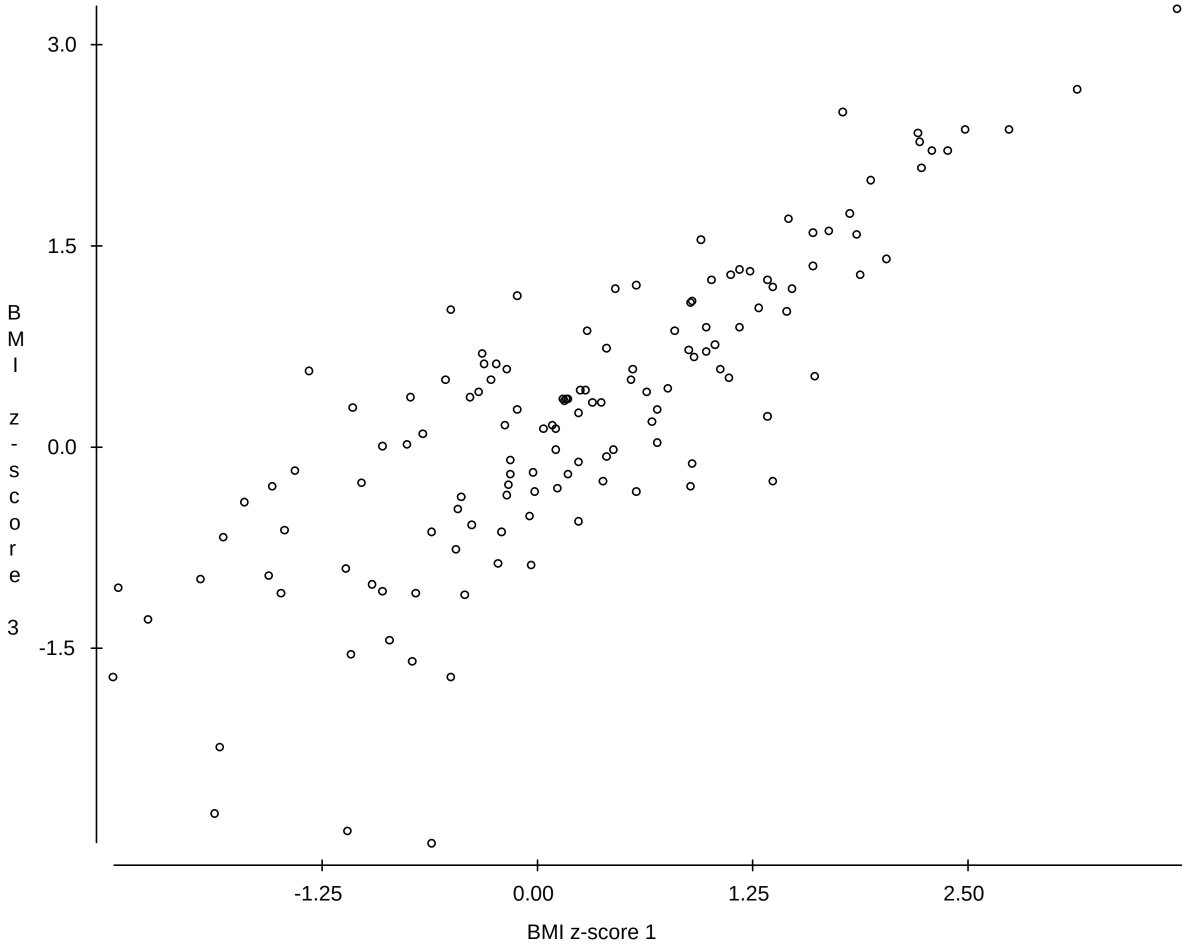


Figure 4. The within-child SD of BMI 3 plotted against baseline BMI z-score1 in 135 subjects,. The SD is square root transformed. both BMIs adjusted for age.


3.0
1.5
0.0
-1.5
BMI z-score 3
-1.25
0.00
1.25
2.50
BMI z-score 1

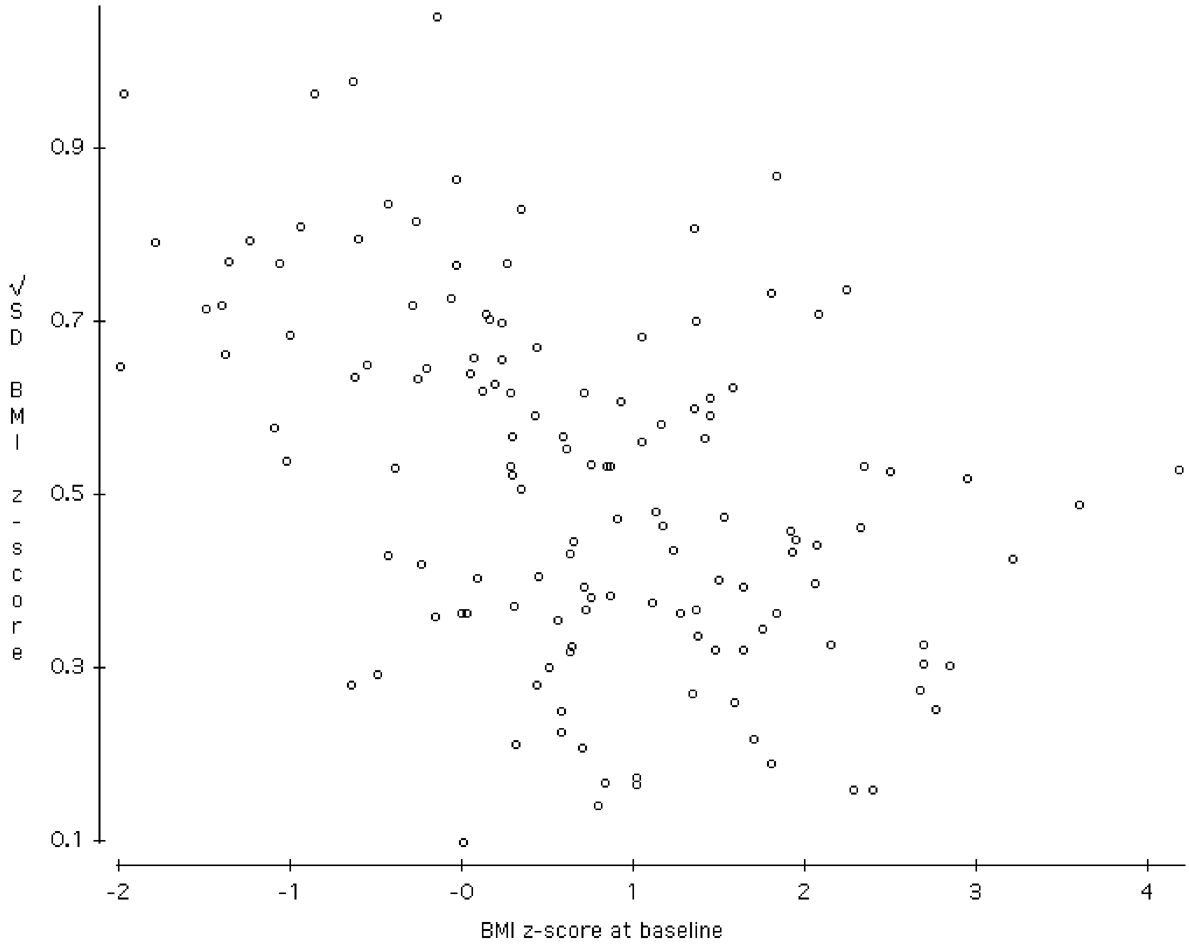


Figure 5. The within-child SD of BMI z-score 3 plotted against baseline BMI z-score 1 in 135 subjects. Note the pointed shape of the scatterplot.The SD is square root transformed.