

Body Mass Index reference curves for Iran

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Summary. Body Mass Index (BMI) charts for boys and girls aged 2–18 years in Iran are presented. The charts are based on a random cluster sample survey of 1702 boys and 1599 girls living in urban Tehran, whose height and weights were measured in the 1990–1992 National Health Survey of the whole country. Charts were constructed using Healy's method as modified by Pan, Goldstein and Yang (1990), and for boys at one point were smoothed manually. The resulting charts are shown to fit the data well and adequately describe raw BMI centiles of urban and rural children elsewhere in Iran. Comparison of these BMI charts with corresponding UK charts showed substantial differences at every age and emphasizes the necessity for the use of locally based BMI norms for assessing body mass of Iranian children.

1. Introduction

Reference growth curves for Iranian children and adolescents have been recently published allowing heights and weights of Iranian children to be assessed relative to centiles based on recently collected and nationally representative data (Hosseini, Carpenter and Mohammed 1998a). A general deficiency of such curves has been their inability to assess child fatness. Weight and height are highly correlated during childhood and adolescence so that a child's weight centile tends to be strongly influenced by his or her height centile. Both are a reflection of the child's size, large versus small, rather than their shape, fat versus thin (Cole, Freeman and Preece 1995).

BMI has been used widely in adults for the last 25 years as a simple summary measure of overweight but its use in childhood has developed relatively recently. Adult BMI increases fairly slowly with age, so that age independent cut-offs can be used to grade obesity. In children, however, BMI changes substantially with age, rising steeply in infancy, falling during their pre-school years, and then rising again into adulthood. For this reason, child BMI needs to be assessed using age related reference curves (Cole *et al.* 1995).

In this paper we present BMI age related reference curves based on measurements of children in Tehran which were used to construct the growth charts, and examine how far the results generalize to the rest of Iran. We also compare our BMI charts with charts based on UK data. It is shown (Hosseini, Carpenter and Mohammed 1999) that BMI is a satisfactory alternative to weight-for-height for age tables, except for short children under the age of six.

2. Material and methods

2.1. Subjects

Data were obtained from the National Health Survey 1990–1992, a random cluster sample survey of 1 in 1000 families throughout Iran. In total 10 660 house-

holds were surveyed in random clusters of households in all provinces of Iran. Clusters were formed by systematically selecting 1 in 7000 families with their six nearest neighbours from the registers of families that were available in each health department of every province, except for Tehran and a few other large cities. There the required number of households was obtained by the random selection of families from lists of all mothers having their first or second child in one of the city's hospitals over a 48-hour period. Trained health staff collected extensive data, including height to the nearest centimetre and weight to the nearest kilogram of boys and girls between the ages of 2 and 18. Ages were recorded in completed years.

Outliers in the data on weight and height measurements were identified and removed as described by Hosseini, Carpenter and Mohammed (1998b). Because of the differences between the growth data from the different provinces, data for children in urban Tehran were used as a representative subset of the total data (Hosseini, Carpenter and Mohammed 1998c) to construct the growth charts for Iranian children. The data comprised the weights and heights of 3301 children (1702 boys (51.6%) and 1599 girls (48.4%)) aged 2–18 years old living in urban Tehran.

2.2. Methods

The BMI charts for boys and girls were constructed using Healy's method (Healy, Rasbash and Yang 1988) as extended by Pan *et al.* (1990) and implemented in GROSTAT II (Rasbash, Pan and Goldstein 1993). Our data are in 1 year age groups. For such data, for each age group, 7 centiles (3, 10, 25, 50, 75, 90, 97) were computed in SPSS. These 'raw' centiles were read into GROSTAT II for smoothing. The program constructs the required smooth centile curves in terms of polynomials in both age, and Normal scores, z . Pan *et al.* (1990) showed that by splining the curves at selected ages, c , polynomials can be used to model a wide span of ages. It is a powerful method and produces centiles, which are smooth, close to the data, and constrained to accord with neighbouring centiles; observations can be converted to Z -scores. The GROSTAT method and its appropriateness to our data was recently described by Hosseini *et al.* (1998a).

Although the method makes no assumption about the distribution of the measurements across the ages, curves were fitted after taking log of BMI because the method works best when the data are approximately Normally distributed (Healy, personal communication, Ayatollahi, Cole and Matthews 1993), BMI charts presented here were derived by transforming the fitted curves back into the original scale and were drawn in STATA (1997). Goodness of fit of the centiles charts to the data was assessed by comparing observed and expected numbers of observations in regions defined by the centiles, the grid test, and Q statistics as described by Hosseini, Carpenter and Mohammed (1998a).

3. Results

3.1. BMI centile curves

Separate BMI charts were constructed for boys and girls aged 2–18 years old.

3.1.1. Boys. The smoothing polynomial found to fit the raw centiles of $\log(\text{BMI})$ is of the GROSTAT form of 3 3 3 3 2 and was splined at age 15 years. The first number shows that the polynomial is a cubic in age. The constant term, the coefficient of age and the coefficient of age² are cubic polynomials in z ; and

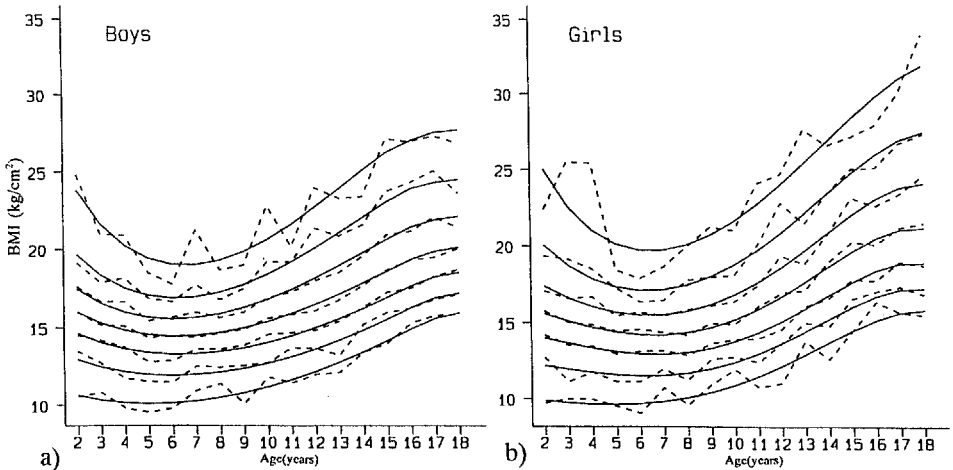


Figure 1. Smoothed centiles (solid line) for BMI of boys and girls in urban Tehran are compared with the corresponding raw centiles (broken lines). The standard 3rd, 10th, 25th, 50th, 75th, 90th, 97th centiles are shown.

the coefficient of age^3 is a quadratic polynomial in z . So the form of the overall polynomial for the i th smoothed centile (on log scale) in the above model when $age \leq 15$ is

$$Y = b_{00} + b_{01}z^2 + b_{03}z^3 + (b_{10} + b_{11}z + b_{12}z^2 + b_{13}z^3) age + (b_{20} + b_{21}z + b_{22}z^2 + b_{23}z^3) age^2 + (b_{31} + b_{31}z + b_{32}z^2) age^3$$

The splining introduces an additional term $(b_{40} + b_{41}z + b_{42}z^2)(age - 13)^3$ when $age \geq 15$. Parameter values are presented in the Appendix.

Figure 1a shows the smooth centiles for this model and that they correspond closely to the raw centiles from which they were derived. However, the 50th and higher centiles of the model tended to follow the raw centiles in a downward direction after age of 17 years which is not correct. So for the last age group the preceding upward trend of these centiles has been extended by hand. Smooth centile values by age are given in table 1. A grid test comparing with the expectation the total number of observations in eight regions defined by the seven centiles was not significant, $\chi^2 = 6.3$, with 7 df, $p = 0.51$. Similar grid tests for the four age groups 2–5, 6–10, 11–15 and 16–18 give p values ranging from 0.04 to 0.79 with a combined $\chi^2 = 32.37$, with 28 df, $p = 0.26$. The single significant χ^2 appears to be mainly due to a fortuitous difference between the raw and smoothed 50th centiles in the 11–15 age group. The three Q statistics testing bias, variance and Normality of the Z-scores of the data gave p values of 0.75, 0.45 and 0.96.

3.1.2. *Girls.* Figure 1b compares the raw and the smooth centiles for girls BMI, and smoothed centiles values by age are presented in table 1. The model for the fitted centiles is quartic in age with parameter values which are cubic and quadratic in z . Although different models with splining curves at age 13 years

Table 1. Smoothed percentiles of boys and girls BMI (kg/m²) in urban Tehran by age.

Sex and age group	Smoothed percentile						
	3rd	10th	25th	50th	75th	90th	97th
Boys							
2+	10.6	12.9	14.6	16.0	17.4	19.6	23.8
3+	10.3	12.5	14.0	15.3	16.5	18.3	21.6
4+	10.2	12.2	13.6	14.8	16.0	17.5	20.2
5+	10.1	12.0	13.4	14.6	15.6	17.0	19.4
6+	10.1	11.9	13.3	14.5	15.5	16.9	19.0
7+	10.3	12.0	13.3	14.5	15.6	17.0	19.0
8+	10.5	12.1	13.5	14.7	15.9	17.3	19.3
9+	10.8	12.4	13.7	15.0	16.3	17.7	19.8
10+	11.2	12.7	14.1	15.4	16.8	18.4	20.6
11+	11.7	13.1	14.5	15.9	17.4	19.2	21.6
12+	12.2	13.6	15.0	16.5	18.2	20.1	22.7
13+	12.8	14.2	15.6	17.1	18.9	21.0	23.9
14+	13.5	14.8	16.2	17.8	19.8	22.1	25.1
15+	14.2	15.5	16.9	18.6	20.6	23.0	26.3
16+	14.9	16.3	17.7	19.3	21.4	23.9	27.0
17+	15.6	16.9	18.2	19.9	21.9	24.3	27.5
18–19	15.9	17.2	18.5	20.1	22.1	24.5	27.7
Girls							
2+	9.9	12.2	14.0	15.6	17.4	20.0	25.0
3+	9.7	12.0	13.7	15.1	16.6	18.7	22.6
4+	9.6	11.7	13.3	14.7	16.0	17.9	21.0
5+	9.6	11.6	13.1	14.4	15.7	17.3	20.1
6+	9.7	11.5	13.0	14.2	15.5	17.1	19.7
7+	9.8	11.5	12.9	14.2	15.5	17.1	19.7
8+	10.1	11.7	13.1	14.3	15.7	17.4	20.1
9+	10.4	12.0	13.3	14.7	16.2	18.0	20.7
10+	10.9	12.4	13.8	15.2	16.8	18.7	21.6
11+	11.5	13.0	14.3	15.8	17.6	19.7	22.7
12+	12.2	13.6	15.0	16.7	18.6	20.9	24.0
13+	12.9	14.4	15.9	17.6	19.7	22.1	25.5
14+	13.7	15.2	16.8	18.6	20.9	23.5	27.0
15+	14.5	16.0	17.6	19.6	22.1	24.8	28.5
16+	15.1	16.7	18.4	20.5	23.1	26.1	29.9
17+	15.6	17.1	18.9	21.1	23.9	27.0	31.0
18–19	15.8	17.2	18.9	21.2	24.1	27.5	31.9

were tried, the quartic model covering the entire age range appeared to be the most appropriate one. The overall polynomial for the *i*th smoothed centile (Y_i) on log scale was

$$\begin{aligned}
 Y_i = & g_{00} + g_{01}z^2 + g_{03}z^3 + (g_{10} + g_{11}z + g_{12}z^2 + g_{13}z^3)age \\
 & + (g_{20} + g_{21}z + g_{22}z^2 + g_{23}z^3)age^2 + (g_{31} + g_{31}z + g_{32}z^2)age^3 \\
 & + (g_{40} + g_{41}z + g_{42}z^2)age^4
 \end{aligned}$$

Which is a GROSTAT model of the form 4 3 3 3 2 2. The model parameter values are shown in the Appendix.

The overall grid test gives $\chi^2_7 = 4.981$, $p = 0.66$. Grid tests for the four age groups 2–5, 6–10, 11–15 and 16–18 give p values ranging from 0.08 to 0.95, and a combined $\chi^2 = 28.32$, with 28 df, $p = 0.45$. Overall Q tests for the girls data gave p values of 0.9 for the means, 0.02 for the variances and 0.07 for Normality of the Z-scores. The Q

test for variance is small because the SD's of Z-scores in the three age groups, 5, 6, and 16 were appreciably less than 1 as would be expected from the pattern of the raw centiles for girls in figure 1. The Z-scores for age groups 6 and 13 are also appreciably non-Normal, the former appearing negatively skewed and the latter positively skewed. Inspection of figure 1 suggests that these statistically significant discrepancies are due to irregularities in the data. Overall the charts appear to fit the data well.

In general, the change in median BMI by age are on the whole very similar in the two sexes. Figures 1a and b show that for boys and girls at age 2 years, median BMI declines from 16.0 and 15.6 kg/m² and then flattens out at age 6–7 years when BMI are about 14.5 and 14.2 kg/m² respectively. This dip in the BMI is called the adiposity rebound (Rolland-Cachera, Deheeger, Bellisle *et al.* 1984). The age at adiposity rebound appears to occur slightly earlier on the lower than higher centiles (figures 1a and b). After the rebound median BMI increases more rapidly in girls than in boys and the curves cross at about 12 years. At 18, median BMI are 20.1 and 21.2 kg/m² for boys and girls respectively.

3.2. Body Mass Index (BMI) outside Tehran

The comparisons of BMI centiles for the rest of the urban areas of Iran and also all rural areas with the BMI charts for children in urban Tehran are presented in figure 2a–d. Figures 2a and b show that in all other urban districts of Iran taken together, from the age of 5 all lower chart centiles correspond closely to the raw centiles up to 75th, and that the higher chart centiles 90th and 97th are somewhat

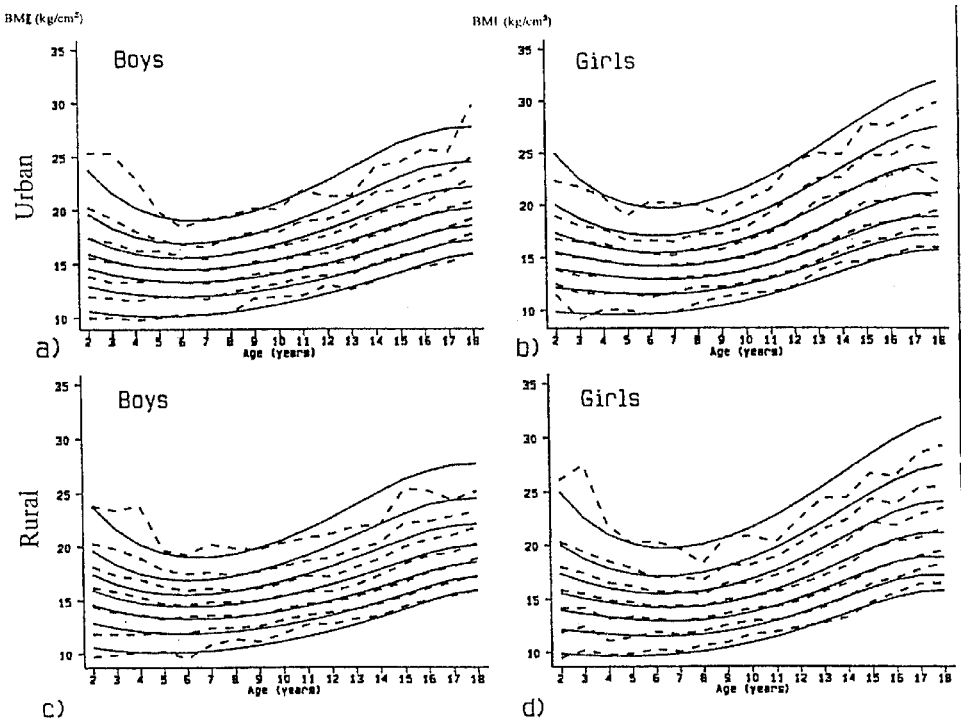


Figure 2. Raw centiles (broken line) for BMI of (a) boys and (b) girls in urban Iran (excluding Tehran), and rural areas (c and d) compared with the centiles of charts based on children in Tehran (solid line). The 3rd, 10th, 25th, 50th, 75th, 90th, 97th centiles are shown.

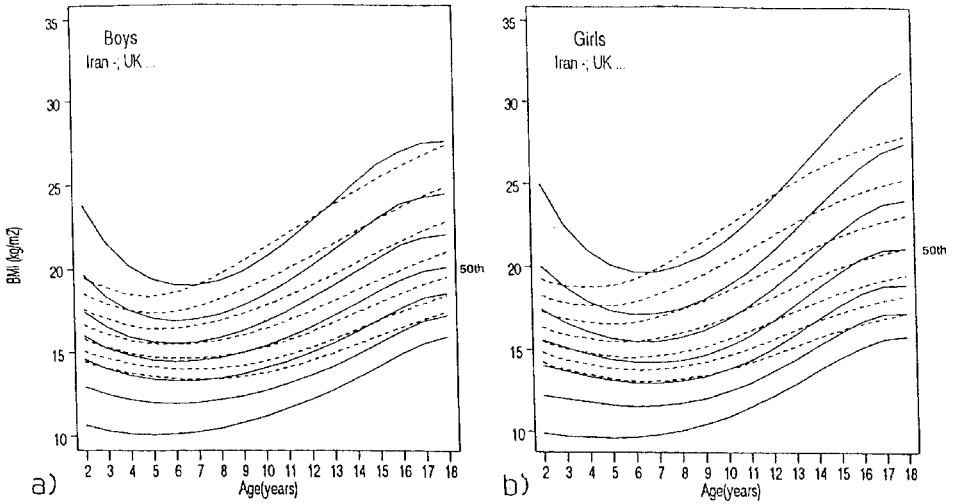


Figure 3. Comparison of UK and Iranian BMI charts for boys and girls; 3rd, 10th, 25th, 50th, 75th, 90th, 97th centiles are shown.

high in the age groups 11 and onwards, probably because of a greater tendency to obesity among children in better off homes in the capital city. Below the age of 5 the raw centiles for the urban girls are close to the chart, except for the 90th and 97th, which are a little lower. For boys in this age range, the 50th raw centile is very close to the chart centile, but at ages 2, 3 and 4 years the other raw centiles are more spread than the chart although the differences are not large. Multilevel analysis (Goldstein 1995) shows that differences in the mean BMI between urban Tehran and other urban areas of Iran are not significant, $p = 0.75$.

For rural children, the raw 3rd, 10th, 25th, and 50th BMI centiles correspond closely to the chart centiles except that for boys aged 2 and 3 years the lower centiles are below the chart centiles. In the younger age groups the 75th, 90th and 97th raw centiles are above the chart centiles; however, around the ages of 7–8 years the centiles curves cross and subsequently from 11 years and onwards the 75th and higher raw centiles for rural children increase more slowly than the trend of BMI charts for urban Tehran. Multilevel analysis confirms that there is little differences between the mean BMI of urban and rural children at the age of 10 years, but the BMI curves for urban children are increasing significantly faster than the BMI curves for rural children, $p < 0.0001$.

3.3. Comparison of the BMI in Iran and UK

Figures 3a–b compare our BMI charts for Tehrani children with charts for UK (Cole *et al.* 1995). The outstanding differences are in the lower centiles. Up to the age of 8 years for boys and 10 years for girls, the 25th Iranian BMI centiles are close to the 3rd UK centiles. After these ages the BMI in Tehran increases faster than in UK so that by 18 years, the Iranian 10th centile corresponds to the 3rd UK centile, the 50th centiles are close, and the 97th centiles for Tehrani girls is substantially higher than that of UK girls at 18 years. The 97th centiles for boys are similar in the two populations after the age of 7 years. Figures 3a and b also show that in some younger children, BMI may be much greater than in UK.

4. Discussion

Differences between provinces in the heights and weights of children of comparable age led us to use data on children living in Tehran as a baseline for growth charts (Hosseini *et al.* 1998a). We have used the same data for the BMI charts so that they complement the height and weight charts. The GROSTAT method used to model the raw centiles generated curves that were generally an excellent fit. One problem was at age 18 years on the boys, some fitted centiles tended to curve downwards. This trend was due to the raw centiles of the cross-sectional data. Analytical solutions might avoid this problem, e.g. adding further splines, but the simplest solution was adopted of manually modifying the relevant curves. The grid test of fit of the resulting curves was insignificant ($p = 0.63$) for the 16–18 year age group.

Differences between the charts based on the Tehrani children and other urban and rural children have been noted in relation to figures 2a to 2d. Overall, the lower centiles are remarkably similar, especially for girls. It is clear that if these charts are used throughout Iran, BMI will seldom be regarded as too low but after 9 years in girls and 11 years in boys the 97th BMI centile should be reckoned to lie between the top two centiles on the charts.

The BMI charts for Iran are of similar general shape to those for UK (Cole *et al.* 1995) and American children (Hamill, Drizd, Johnson *et al.* 1979, Hammer, Kraemer, Wilson *et al.* 1991). However, as shown in figure 3, the range of BMI found in normal Iranian children at any age is substantially different and the use in Iran of reference curves published for the developed world would be seriously misleading. Iranian children develop differently due to differences in genetic, cultural and environmental factors acting singly or in combination.

We conclude that the BMI charts developed from measurements on children in Tehran are generally applicable for the whole country. Comparison with UK BMI charts shows that, as with other growth charts, population specific BMI charts are essential to assess body mass relative to population norms as advocated by Goldstein and Tanner (1980).

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Appendix. Model parameter estimates for log(BMI) of boys and girls in urban Tehran

Boys		Girls	
Parameter	Estimate	Parameter	Estimate
b ₀₀	2.9060	g ₀₀	2.7970
b ₀₁	1.4508E-01	g ₀₁	2.0388E-01
b ₀₂	1.4050E-02	g ₀₂	3.4868E-02
b ₀₃	3.3625E-02	g ₀₃	3.3583E-02
b ₁₀	– 8.3976E-02	g ₁₀	– 1.8195E-02
b ₁₁	– 1.8331E-02	g ₁₁	– 3.8873E-02
b ₁₂	– 9.9279E-03	g ₁₂	– 2.3174E-02
b ₁₃	– 3.3844E-03	g ₁₃	– 2.8593E-03
b ₂₀	8.6732E-03	g ₂₀	– 5.8993E-03
b ₂₁	2.5324E-03	g ₂₁	6.1614E-03
b ₂₂	1.1557E-03	g ₂₂	4.0291E-03
b ₂₃	1.0052E-04	g ₂₃	6.1094E-05
b ₃₀	– 1.9983E-04	g ₃₀	1.0264E-03
b ₃₁	– 8.7515E-05	g ₃₁	– 3.6675E-04
b ₃₂	– 3.4000E-05	g ₃₂	– 2.6184E-04
b ₄₀	– 1.7752E-03*	g ₄₀	– 3.3248E-05
b ₄₁	– 2.4595E-04*	g ₄₁	7.7983E-06
b ₄₂	– 5.7798E-05*	g ₄₂	5.9073E-06

* Splined at age 15. The last three parameters are modifications that apply when age > 15, see text.

Zusammenfassung. Es werden Body Mass Index (BMI)-Charts für 2 bis 18 jährige Jungen und Mädchen aus dem Iran vorgestellt. Die Charts basieren auf einer Clusterzufallsstichprobe von 1702 Jungen und 1599 Mädchen aus dem städtischen Teheran, deren Körperhöhe und Körpergewicht im Rahmen des 1990 bis 1992 landesweit durchgeführten National Health Survey erhoben worden waren. Zur Konstruktion der Charts wurde die von Pan, Goldstein und Yang (1990) modifizierte Methode von Healy herangezogen. Bei Jungen wurde die Kurve an einer Stelle per Hand geglättet. Die so erstellten Kurven passen die Daten gut an und liefern eine adäquate Beschreibung der rohen BMI-Perzentile für Kinder städtischer und ländlicher Herkunft aus dem übrigen Iran. Ein Vergleich dieser BMI-Charts mit entsprechenden Charts aus Großbritannien lassen in jedem Alter deutliche Unterschiede erkennen, was die Notwendigkeit der Verwendung lokaler BMI-Referenzwerte zur Bewertung der Körperfülle iranischer Kinder unterstreicht.

Résumé. On présente les graphiques de l'indice de masse corporelle (IMC) pour les garçons et les filles iraniens âgés de 2 à 18 ans. Les graphiques sont établis à partir d'un échantillonnage aléatoire de 1702 garçons et 1599 filles vivant dans la ville de Téhéran, dont les poids et statures ont été mesurés lors de l'Enquête Nationale de Santé de 1990-1992. Les graphiques ont été construits suivant la méthode de Healy modifiée par Pan, Goldstein et Yang (1990) et ont été lissés manuellement à un point pour les garçons. Les graphiques résultant correspondent bien aux données et décrivent de façon appropriée les centiles bruts d'IMC pour les enfants ruraux ou urbains d'autre lieux en Iran. La comparaison de ces graphiques d'IMC avec leurs homologues britanniques montre de fortes différences à tout âge et indique la nécessité d'utiliser des normes locales d'IMC pour rendre compte de la masse corporelle des enfants iraniens.