

## Head Circumference Charts for Turkish Children Aged Five to Eighteen Years Beş-On Sekiz Yaş Türk Çocuklarında Baş Çevresi Eğrileri

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### ABSTRACT

**Introduction:** Most head circumference growth references are useful during the first years of life, but they are also useful for older children when screening for developmental, neurological, and genetic disorders. We aimed to develop head circumference growth reference charts for age, height, and waist circumference for Turkish children aged 5–18 years.

**Methods:** Head circumference, height, and waist circumference measurements were obtained from 5079 students aged 5–18 years from İzmit, Kocaeli Province, Turkey. The LMS method was used to construct reference centile curves.

**Results:** Head circumference measurements were strongly correlated with height ( $r=0.74$ ), weight ( $r=0.76$ ), and waist circumference ( $r=0.68$ ). The mean head circumference values for boys were larger than those for girls at all ages. Compared with data from the United States, the World Health Organization, and other studies from Turkey, our data showed a decrease in head circumference at all ages for both sexes.

**Conclusion:** Local growth charts can be used to evaluate head circumference growth in older Turkish children and adolescents.

**Keywords:** Head circumference, waist circumference, height, growth curves, LMS method

### ÖZ

**Amaç:** Baş çevresi büyüme referans eğrileri genellikle yaşamın ilk yılları için hazırlanmakla birlikte, gelişimin izlenmesi, yanı sıra nörolojik ve genetik bozukluklarda daha büyük yaşlarda da kullanılmaları gerekmektedir. Bu çalışmada 5-18 yaş Türk çocuklarında yaş, boy ve bel çevresine göre baş çevresi büyüme referans eğrilerinin geliştirilmesi amaçlanmıştır.

**Yöntem:** Kocaeli ili İzmit merkez ilçesinde 5079 öğrencinin baş çevresi, boy ve bel çevresi ölçümleri yapıldı. Referans eğrileri LMS metodu kullanılarak oluşturuldu.

**Bulgular:** Baş çevresi ölçümleri boy ( $r=0,74$ ), tartı ( $r=0,76$ ) ve bel çevresi ( $r=0,68$ ) ölçümleriyle güçlü korelasyon göstermekteydi. Ortalama

baş çevresi değerleri tüm yaşlarda erkeklerde kızlara göre daha fazlaydı. Amerika Birleşik Devletleri, Dünya Sağlık Örgütü ve Türkiye'den yapılan diğer çalışmalarla karşılaştırıldığında, verilerimiz tüm yaşlarda baş çevresi ölçümlerinin daha düşük olduğunu gösterdi.

**Sonuç:** Çocukluk ve adolesan dönem Türk çocuklarında baş çevresi büyümesinin değerlendirilmesinde yerel büyüme eğrilerinin kullanımı daha güvenilir olacaktır.

**Anahtar kelimeler:** Baş çevresi, bel çevresi, boy, büyüme eğrileri, LMS metodu

### INTRODUCTION

Measuring head circumference is an easy, non-invasive, and inexpensive method to screen for normal growth and development (1). Head growth is more rapid in the first years of life; therefore, most head circumference growth charts have been produced for this time period. Head circumference reaches approximately 90% of the adult size at 3 years and 95% at 5 years of age (2).

Head size may be an important predictor of the severity of neurological insults or degeneration and a significant predictor of brain volume in children aged more than 3 years (3,4). Thus, measuring head circumference and monitoring head growth after the age of 3 years is helpful for diagnosing neurologic disorders and various genetic syndromes (5).

In Turkey, the current head circumference growth charts commonly used by Turkish clinicians are for children aged less than 36 months (6). Clinicians in Turkey who want to assess head circumference after the age of 36 months have to use growth charts produced in other countries, such as data from Nellhaus (7) or the United States head circumference reference data (5,8). Although some local studies have



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**Table 1.** Number of participants by sex and age as well as sex differences in mean head circumference

| Age (years) | F   | M   | Total | M>F (cm) | Age (years) | F   | M   | Total | M>F (cm) |
|-------------|-----|-----|-------|----------|-------------|-----|-----|-------|----------|
| 5.0–5.49    | 71  | 46  | 117   | 0.91     | 11.5–11.99  | 91  | 92  | 193   | 0.59     |
| 5.5–5.99    | 97  | 81  | 178   | 1.02     | 12.0–12.49  | 90  | 91  | 181   | 0.56     |
| 6.0–6.49    | 107 | 97  | 204   | 1.06     | 12.5–12.99  | 110 | 108 | 218   | 0.54     |
| 6.5–6.99    | 123 | 99  | 222   | 1.01     | 13.0–13.49  | 116 | 174 | 190   | 0.56     |
| 7.0–7.49    | 89  | 72  | 161   | 0.92     | 13.5–13.99  | 102 | 92  | 194   | 0.69     |
| 7.5–7.99    | 100 | 99  | 199   | 0.84     | 14.0–14.49  | 98  | 115 | 213   | 0.87     |
| 8.0–8.49    | 107 | 88  | 195   | 0.75     | 14.5–14.99  | 86  | 103 | 189   | 1.09     |
| 8.5–8.99    | 117 | 98  | 215   | 0.67     | 15.0–15.49  | 97  | 133 | 230   | 1.27     |
| 9.0–9.49    | 122 | 110 | 232   | 0.62     | 15.5–15.99  | 106 | 135 | 241   | 1.41     |
| 9.5–9.99    | 109 | 101 | 210   | 0.63     | 16.0–16.49  | 103 | 120 | 223   | 1.52     |
| 10.0–10.49  | 82  | 95  | 177   | 0.64     | 16.5–16.99  | 102 | 108 | 210   | 1.58     |
| 10.5–10.99  | 119 | 103 | 222   | 0.63     | 17.0–17.49  | 67  | 100 | 167   | 1.63     |
| 11.0–11.49  | 109 | 100 | 209   | 0.61     | 17.5–17.99  | 38  | 61  | 99    | 1.67     |

F: female; M: male

**Table 2.** The power of a Box-Cox transformation (L), the median (M), the coefficient of variation (S), and the percentiles of head circumference-for-age for girls

| Height (cm) | L    | M     | S    | Head circumference (cm) |       |       |       |       |       |       |       |       |
|-------------|------|-------|------|-------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|             |      |       |      | 3                       | 5     | 10    | 25    | 50    | 75    | 90    | 95    | 97    |
| 5           | 0.18 | 48.93 | 0.03 | 46.32                   | 46.64 | 47.14 | 47.98 | 48.93 | 49.90 | 50.78 | 51.31 | 51.66 |
| 5.5         | 0.37 | 49.19 | 0.03 | 46.55                   | 46.88 | 47.38 | 48.23 | 49.19 | 50.16 | 51.04 | 51.58 | 51.93 |
| 6           | 0.55 | 49.45 | 0.03 | 46.78                   | 47.11 | 47.62 | 48.48 | 49.45 | 50.42 | 51.31 | 51.84 | 52.19 |
| 6.5         | 0.73 | 49.70 | 0.03 | 47.00                   | 47.34 | 47.86 | 48.73 | 49.70 | 50.68 | 51.57 | 52.10 | 52.45 |
| 7           | 0.92 | 49.95 | 0.03 | 47.21                   | 47.56 | 48.09 | 48.97 | 49.95 | 50.94 | 51.83 | 52.36 | 52.70 |
| 7.5         | 1.10 | 50.20 | 0.03 | 47.43                   | 47.78 | 48.32 | 49.21 | 50.20 | 51.19 | 52.08 | 52.62 | 52.96 |
| 8           | 1.28 | 50.45 | 0.03 | 47.64                   | 48.00 | 48.54 | 49.45 | 50.45 | 51.45 | 52.34 | 52.87 | 53.22 |
| 8.5         | 1.46 | 50.69 | 0.03 | 47.85                   | 48.21 | 48.76 | 49.68 | 50.69 | 51.70 | 52.59 | 53.12 | 53.47 |
| 9           | 1.63 | 50.93 | 0.03 | 48.04                   | 48.41 | 48.97 | 49.91 | 50.93 | 51.94 | 52.84 | 53.37 | 53.71 |
| 9.5         | 1.77 | 51.15 | 0.03 | 48.23                   | 48.61 | 49.18 | 50.12 | 51.15 | 52.17 | 53.07 | 53.60 | 53.95 |
| 10          | 1.88 | 51.38 | 0.03 | 48.43                   | 48.80 | 49.38 | 50.34 | 51.38 | 52.40 | 53.30 | 53.84 | 54.18 |
| 10.5        | 1.95 | 51.60 | 0.03 | 48.62                   | 49.01 | 49.59 | 50.55 | 51.60 | 52.63 | 53.54 | 54.08 | 54.42 |
| 11          | 1.95 | 51.82 | 0.03 | 48.83                   | 49.21 | 49.80 | 50.77 | 51.82 | 52.86 | 53.77 | 54.31 | 54.66 |
| 11.5        | 1.90 | 52.04 | 0.03 | 49.04                   | 49.43 | 50.01 | 50.99 | 52.04 | 53.08 | 54.01 | 54.55 | 54.90 |
| 12          | 1.79 | 52.26 | 0.03 | 49.25                   | 49.64 | 50.23 | 51.20 | 52.26 | 53.30 | 54.23 | 54.78 | 55.13 |
| 12.5        | 1.66 | 52.46 | 0.03 | 49.46                   | 49.84 | 50.43 | 51.40 | 52.46 | 53.51 | 54.44 | 54.99 | 55.35 |
| 13          | 1.51 | 52.63 | 0.03 | 49.64                   | 50.02 | 50.61 | 51.57 | 52.63 | 53.69 | 54.62 | 55.18 | 55.54 |
| 13.5        | 1.37 | 52.78 | 0.03 | 49.80                   | 50.18 | 50.76 | 51.72 | 52.78 | 53.83 | 54.77 | 55.33 | 55.70 |
| 14          | 1.23 | 52.90 | 0.03 | 49.94                   | 50.32 | 50.89 | 51.85 | 52.90 | 53.95 | 54.89 | 55.46 | 55.82 |
| 14.5        | 1.10 | 53.00 | 0.03 | 50.07                   | 50.44 | 51.01 | 51.95 | 53.00 | 54.05 | 54.99 | 55.56 | 55.92 |
| 15          | 0.98 | 53.09 | 0.03 | 50.18                   | 50.55 | 51.11 | 52.05 | 53.09 | 54.14 | 55.08 | 55.64 | 56.01 |
| 15.5        | 0.86 | 53.18 | 0.03 | 50.29                   | 50.65 | 51.21 | 52.14 | 53.18 | 54.22 | 55.15 | 55.72 | 56.08 |
| 16          | 0.74 | 53.25 | 0.03 | 50.40                   | 50.76 | 51.31 | 52.23 | 53.25 | 54.29 | 55.22 | 55.78 | 56.15 |
| 16.5        | 0.63 | 53.32 | 0.03 | 50.50                   | 50.85 | 51.39 | 52.30 | 53.32 | 54.35 | 55.27 | 55.83 | 56.20 |
| 17          | 0.51 | 53.37 | 0.03 | 50.59                   | 50.93 | 51.47 | 52.37 | 53.37 | 54.39 | 55.31 | 55.87 | 56.23 |
| 17.5        | 0.41 | 53.42 | 0.03 | 50.66                   | 51.00 | 51.53 | 52.42 | 53.42 | 54.42 | 55.34 | 55.90 | 56.26 |

**Table 3.** The power of a Box-Cox transformation (L), the median (M), the coefficient of variation (S), and the percentiles of head circumference-for-age for boys

| Age (years) | L    | M     | S    | Head circumference (cm) |       |       |       |       |       |       |       |       |
|-------------|------|-------|------|-------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|             |      |       |      | 3                       | 5     | 10    | 25    | 50    | 75    | 90    | 95    | 97    |
| 5           | 2.95 | 49.93 | 0.03 | 47.05                   | 47.43 | 48.00 | 48.93 | 49.93 | 50.89 | 51.72 | 52.21 | 52.52 |
| 5.5         | 2.71 | 50.25 | 0.03 | 47.39                   | 47.76 | 48.33 | 49.26 | 50.25 | 51.22 | 52.06 | 52.55 | 52.86 |
| 6           | 2.48 | 50.53 | 0.03 | 47.68                   | 48.05 | 48.62 | 49.54 | 50.53 | 51.49 | 52.34 | 52.84 | 53.16 |
| 6.5         | 2.24 | 50.72 | 0.03 | 47.90                   | 48.26 | 48.82 | 49.73 | 50.72 | 51.68 | 52.53 | 53.03 | 53.35 |
| 7           | 1.98 | 50.87 | 0.03 | 48.08                   | 48.44 | 48.98 | 49.88 | 50.87 | 51.83 | 52.69 | 53.19 | 53.51 |
| 7.5         | 1.72 | 51.04 | 0.03 | 48.27                   | 48.62 | 49.16 | 50.06 | 51.04 | 52.00 | 52.86 | 53.37 | 53.70 |
| 8           | 1.46 | 51.21 | 0.03 | 48.46                   | 48.81 | 49.35 | 50.23 | 51.21 | 52.18 | 53.04 | 53.55 | 53.89 |
| 8.5         | 1.21 | 51.37 | 0.03 | 48.64                   | 48.99 | 49.52 | 50.40 | 51.37 | 52.35 | 53.22 | 53.74 | 54.08 |
| 9           | 0.96 | 51.55 | 0.03 | 48.82                   | 49.17 | 49.69 | 50.57 | 51.55 | 52.53 | 53.42 | 53.94 | 54.29 |
| 9.5         | 0.74 | 51.76 | 0.03 | 49.02                   | 49.37 | 49.89 | 50.78 | 51.76 | 52.76 | 53.65 | 54.19 | 54.54 |
| 10          | 0.54 | 51.99 | 0.03 | 49.23                   | 49.57 | 50.10 | 50.99 | 51.99 | 53.00 | 53.91 | 54.47 | 54.82 |
| 10.5        | 0.39 | 52.21 | 0.03 | 49.41                   | 49.76 | 50.30 | 51.20 | 52.21 | 53.24 | 54.18 | 54.74 | 55.11 |
| 11          | 0.29 | 52.43 | 0.03 | 49.59                   | 49.94 | 50.48 | 51.40 | 52.43 | 53.48 | 54.43 | 55.01 | 55.39 |
| 11.5        | 0.25 | 52.65 | 0.03 | 49.76                   | 50.12 | 50.67 | 51.60 | 52.65 | 53.72 | 54.69 | 55.28 | 55.67 |
| 12          | 0.27 | 52.87 | 0.03 | 49.92                   | 50.29 | 50.85 | 51.80 | 52.87 | 53.95 | 54.94 | 55.54 | 55.93 |
| 12.5        | 0.33 | 53.05 | 0.03 | 50.06                   | 50.43 | 51.00 | 51.97 | 53.05 | 54.16 | 55.16 | 55.77 | 56.17 |
| 13          | 0.43 | 53.25 | 0.03 | 50.21                   | 50.58 | 51.17 | 52.15 | 53.25 | 54.37 | 55.39 | 56.00 | 56.40 |
| 13.5        | 0.54 | 53.51 | 0.03 | 50.41                   | 50.80 | 51.39 | 52.39 | 53.51 | 54.64 | 55.67 | 56.29 | 56.69 |
| 14          | 0.66 | 53.79 | 0.03 | 50.65                   | 51.04 | 51.65 | 52.66 | 53.79 | 54.94 | 55.97 | 56.59 | 57.00 |
| 14.5        | 0.76 | 54.08 | 0.03 | 50.90                   | 51.30 | 51.91 | 52.93 | 54.08 | 55.22 | 56.26 | 56.89 | 57.29 |
| 15          | 0.84 | 54.34 | 0.03 | 51.16                   | 51.55 | 52.17 | 53.20 | 54.34 | 55.49 | 56.53 | 57.16 | 57.56 |
| 15.5        | 0.88 | 54.58 | 0.03 | 51.40                   | 51.80 | 52.41 | 53.44 | 54.58 | 55.73 | 56.76 | 57.38 | 57.78 |
| 16          | 0.90 | 54.78 | 0.03 | 51.63                   | 52.02 | 52.63 | 53.65 | 54.78 | 55.92 | 56.94 | 57.56 | 57.96 |
| 16.5        | 0.92 | 54.93 | 0.03 | 51.82                   | 52.21 | 52.81 | 53.81 | 54.93 | 56.05 | 57.06 | 57.66 | 58.05 |
| 17          | 0.93 | 55.03 | 0.03 | 51.97                   | 52.36 | 52.94 | 53.93 | 55.03 | 56.13 | 57.12 | 57.71 | 58.10 |
| 17.5        | 0.94 | 55.10 | 0.03 | 52.10                   | 52.48 | 53.06 | 54.02 | 55.10 | 56.18 | 57.15 | 57.73 | 58.11 |

provided head circumference reference values, the maximum age of the children in these studies is 12 years (9,10,11). There is a need to assess the head circumference of Turkish children aged more than 12 years; this data would be especially useful to child neurologists.

In this study, we aimed to develop head circumference growth references charts for age, height, and waist circumference in Turkish children aged 5–18 years.

## METHODS

We aimed to develop percentiles of head circumference for age, height, and waist circumference for children aged between 5 and 18 years. A cross-sectional study was performed between 2010 and 2013 in İzmit, the administrative center of Kocaeli Province, Turkey. Kocaeli, which is situated east of İstanbul, is the most industrialized district in Turkey. Because of the job opportunities related to industrialization, the residents of Kocaeli are mostly migrants from other regions in Turkey. Therefore, the population pattern in Kocaeli is considered to be representative of that in Turkey (12).

The study population comprised students in primary and middle level schools in İzmit wherein school attendance for those age groups is almost 100% (42,403 students in primary schools and 19,453 students in high schools). For the sample, 10 schools (seven primary schools and three high schools) were randomly selected using a random number table.

These schools had 5,788 registered students. All students were included in the study without any further sampling in the selected schools. Students and legal guardians were informed about the study protocol, and written informed consents were obtained. Excluding the students who were disabled, syndromic, or had spinal dystrophy, data were collected from 5,234 students (90.4% participation). Before the analyses, 66 students were excluded because they were less than 5 years old and 44 students were more than 18 years old. We also eliminated 21 students because of a lack of information and 24 students with extreme values. Thus, the analysis was conducted on 5,079 children aged between 5.0 and 17.9 years.

Ethics approval was obtained from the Ethical Committee of Kocaeli University, School of Medicine. Official approval was also obtained from the local government of Kocaeli.

The variables included in the study were age (calculated using birth date), sex (F/M), head circumference (cm), height (cm), and waist circumference (cm). The head circumference was measured with an inelastic tape from just above the eyebrows to the occipital prominence, with the child looking straight ahead; this gives the maximum measurement of head circumference (13). For the girls, hair braids were untied and hair barrettes were removed. The SECA stadiometer (Seca, 703, Hamburg, Germany) was used to measure both height and weight. Height was recorded to the

**Table 4.** The power of a Box-Cox transformation (L), the median (M), the coefficient of variation (S), and the percentiles of head circumference-for-height for girls and boys

| Height (cm)  | L    | M     | S    | Head circumference (cm) |       |       |       |       |       |       |       |       |
|--------------|------|-------|------|-------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|              |      |       |      | 3                       | 5     | 10    | 25    | 50    | 75    | 90    | 95    | 97    |
| <b>Girls</b> |      |       |      |                         |       |       |       |       |       |       |       |       |
| 105          | 0.42 | 48.43 | 0.03 | 45.95                   | 46.25 | 46.73 | 47.53 | 48.43 | 49.33 | 50.16 | 50.66 | 50.98 |
| 110          | 0.74 | 48.92 | 0.03 | 46.41                   | 46.73 | 47.21 | 48.02 | 48.92 | 49.82 | 50.64 | 51.13 | 51.46 |
| 115          | 1.05 | 49.39 | 0.03 | 46.87                   | 47.19 | 47.67 | 48.49 | 49.39 | 50.30 | 51.11 | 51.60 | 51.91 |
| 120          | 1.34 | 49.84 | 0.03 | 47.30                   | 47.62 | 48.12 | 48.94 | 49.84 | 50.75 | 51.55 | 52.03 | 52.34 |
| 125          | 1.57 | 50.27 | 0.03 | 47.71                   | 48.04 | 48.53 | 49.36 | 50.27 | 51.17 | 51.97 | 52.45 | 52.76 |
| 130          | 1.67 | 50.69 | 0.03 | 48.11                   | 48.44 | 48.94 | 49.77 | 50.69 | 51.59 | 52.39 | 52.87 | 53.18 |
| 135          | 1.62 | 51.11 | 0.03 | 48.53                   | 48.85 | 49.36 | 50.19 | 51.11 | 52.02 | 52.83 | 53.31 | 53.62 |
| 140          | 1.48 | 51.52 | 0.03 | 48.93                   | 49.26 | 49.76 | 50.60 | 51.52 | 52.44 | 53.25 | 53.74 | 54.05 |
| 145          | 1.28 | 51.93 | 0.03 | 49.32                   | 49.65 | 50.16 | 51.00 | 51.93 | 52.85 | 53.68 | 54.18 | 54.50 |
| 150          | 1.11 | 52.36 | 0.03 | 49.73                   | 50.06 | 50.57 | 51.42 | 52.36 | 53.29 | 54.14 | 54.64 | 54.97 |
| 155          | 0.96 | 52.81 | 0.03 | 50.16                   | 50.49 | 51.01 | 51.86 | 52.81 | 53.76 | 54.62 | 55.13 | 55.46 |
| 160          | 0.90 | 53.25 | 0.03 | 50.57                   | 50.90 | 51.42 | 52.28 | 53.25 | 54.21 | 55.08 | 55.60 | 55.94 |
| 165          | 0.92 | 53.65 | 0.03 | 50.94                   | 51.28 | 51.80 | 52.68 | 53.65 | 54.63 | 55.51 | 56.04 | 56.38 |
| 170          | 0.96 | 54.04 | 0.03 | 51.29                   | 51.63 | 52.16 | 53.05 | 54.04 | 55.03 | 55.92 | 56.45 | 56.80 |
| 175          | 1.00 | 54.41 | 0.03 | 51.62                   | 51.97 | 52.51 | 53.41 | 54.41 | 55.41 | 56.31 | 56.85 | 57.20 |
| 180          | 1.03 | 54.77 | 0.03 | 51.93                   | 52.29 | 52.84 | 53.75 | 54.77 | 55.78 | 56.69 | 57.24 | 57.59 |
| 185          | 1.06 | 55.11 | 0.03 | 52.24                   | 52.60 | 53.15 | 54.08 | 55.11 | 56.14 | 57.06 | 57.62 | 57.97 |
| 190          | 1.09 | 55.45 | 0.03 | 52.54                   | 52.90 | 53.47 | 54.41 | 55.45 | 56.49 | 57.42 | 57.98 | 58.35 |
| <b>Boys</b>  |      |       |      |                         |       |       |       |       |       |       |       |       |
| 105          | 0.65 | 49.40 | 0.03 | 46.96                   | 47.26 | 47.73 | 48.52 | 49.40 | 50.29 | 51.09 | 51.58 | 51.89 |
| 110          | 0.75 | 49.84 | 0.03 | 47.36                   | 47.67 | 48.15 | 48.95 | 49.84 | 50.74 | 51.55 | 52.03 | 52.35 |
| 115          | 0.84 | 50.26 | 0.03 | 47.75                   | 48.07 | 48.55 | 49.36 | 50.26 | 51.17 | 51.99 | 52.48 | 52.80 |
| 120          | 0.93 | 50.67 | 0.03 | 48.13                   | 48.45 | 48.94 | 49.76 | 50.67 | 51.58 | 52.41 | 52.90 | 53.22 |
| 125          | 1.03 | 51.06 | 0.03 | 48.49                   | 48.81 | 49.31 | 50.14 | 51.06 | 51.98 | 52.81 | 53.31 | 53.63 |
| 130          | 1.11 | 51.44 | 0.03 | 48.84                   | 49.17 | 49.67 | 50.51 | 51.44 | 52.37 | 53.21 | 53.71 | 54.03 |
| 135          | 1.11 | 51.82 | 0.03 | 49.19                   | 49.52 | 50.03 | 50.87 | 51.82 | 52.75 | 53.60 | 54.10 | 54.43 |
| 140          | 1.03 | 52.19 | 0.03 | 49.53                   | 49.87 | 50.38 | 51.24 | 52.19 | 53.14 | 53.99 | 54.50 | 54.83 |
| 145          | 0.95 | 52.56 | 0.03 | 49.89                   | 50.22 | 50.74 | 51.60 | 52.56 | 53.53 | 54.39 | 54.91 | 55.25 |
| 150          | 0.94 | 52.95 | 0.03 | 50.23                   | 50.57 | 51.10 | 51.97 | 52.95 | 53.92 | 54.80 | 55.33 | 55.67 |
| 155          | 0.99 | 53.35 | 0.03 | 50.59                   | 50.93 | 51.47 | 52.36 | 53.35 | 54.34 | 55.23 | 55.76 | 56.11 |
| 160          | 1.08 | 53.76 | 0.03 | 50.95                   | 51.30 | 51.85 | 52.76 | 53.76 | 54.77 | 55.68 | 56.22 | 56.57 |
| 165          | 1.20 | 54.19 | 0.03 | 51.31                   | 51.68 | 52.23 | 53.16 | 54.19 | 55.21 | 56.13 | 56.68 | 57.04 |
| 170          | 1.36 | 54.61 | 0.03 | 51.67                   | 52.04 | 52.61 | 53.56 | 54.61 | 55.65 | 56.58 | 57.13 | 57.49 |
| 175          | 1.50 | 55.02 | 0.03 | 52.02                   | 52.41 | 52.99 | 53.96 | 55.02 | 56.08 | 57.02 | 57.58 | 57.94 |
| 180          | 1.55 | 55.43 | 0.03 | 52.38                   | 52.77 | 53.36 | 54.34 | 55.43 | 56.49 | 57.45 | 58.01 | 58.38 |
| 185          | 1.59 | 55.82 | 0.03 | 52.73                   | 53.13 | 53.73 | 54.73 | 55.82 | 56.90 | 57.87 | 58.44 | 58.81 |
| 190          | 1.62 | 56.21 | 0.03 | 53.08                   | 53.48 | 54.09 | 55.10 | 56.21 | 57.31 | 58.28 | 58.86 | 59.24 |
| 195          | 1.65 | 56.60 | 0.03 | 53.43                   | 53.83 | 54.45 | 55.48 | 56.60 | 57.71 | 58.70 | 59.28 | 59.66 |

last whole unit rather than to the nearest unit. At the end of a normal respiration, waist circumference was measured with an inelastic tape at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest, nearly at the level of the umbilicus (14). At the time of waist circumference measurement, the participants stood with their arms at their sides and feet positioned close together in a relaxed posture as well as wore loose clothes. All head and waist circum-

ference measurements were performed by the same clinician who is a child neurologist. Height measurements were performed by three different medical doctors who had interobserver reliability. All measurements were performed twice for every participant, and the mean was used in the analyses. If there were differences of more than 0.5 cm for head circumference and height and 1.0 cm for waist circumference, an additional measurement was taken and used.

**Table 5.** The power of a Box-Cox transformation (L), the median (M), the coefficient of variation (S), and the percentiles of head circumference-for-waist circumference for girls and boys

| Waist circumference (cm) | L     | M     | S    | Head circumference (cm) |       |       |       |       |       |       |       |       |
|--------------------------|-------|-------|------|-------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|                          |       |       |      | 3                       | 5     | 10    | 25    | 50    | 75    | 90    | 95    | 97    |
| <b>Girls</b>             |       |       |      |                         |       |       |       |       |       |       |       |       |
| 40                       | 1.13  | 48.25 | 0.03 | 45.45                   | 45.80 | 46.34 | 47.25 | 48.25 | 49.25 | 50.15 | 50.68 | 51.03 |
| 45                       | 1.16  | 49.26 | 0.03 | 46.44                   | 46.80 | 47.35 | 48.25 | 49.26 | 50.27 | 51.17 | 51.71 | 52.05 |
| 50                       | 1.15  | 50.35 | 0.03 | 47.52                   | 47.87 | 48.42 | 49.34 | 50.35 | 51.36 | 52.26 | 52.80 | 53.16 |
| 55                       | 1.17  | 51.51 | 0.03 | 48.67                   | 49.03 | 49.58 | 50.50 | 51.51 | 52.53 | 53.43 | 53.98 | 54.33 |
| 60                       | 1.53  | 52.47 | 0.03 | 49.60                   | 49.97 | 50.53 | 51.45 | 52.47 | 53.47 | 54.37 | 54.90 | 55.25 |
| 65                       | 1.89  | 53.16 | 0.03 | 50.31                   | 50.67 | 51.23 | 52.16 | 53.16 | 54.16 | 55.04 | 55.56 | 55.89 |
| 70                       | 2.02  | 53.68 | 0.03 | 50.86                   | 51.22 | 51.78 | 52.69 | 53.68 | 54.66 | 55.52 | 56.03 | 56.36 |
| 75                       | 2.00  | 54.08 | 0.03 | 51.31                   | 51.66 | 52.21 | 53.10 | 54.08 | 55.04 | 55.89 | 56.39 | 56.72 |
| 80                       | 1.98  | 54.36 | 0.03 | 51.65                   | 52.00 | 52.53 | 53.41 | 54.36 | 55.31 | 56.14 | 56.64 | 56.95 |
| 85                       | 2.02  | 54.62 | 0.03 | 51.97                   | 52.31 | 52.83 | 53.68 | 54.62 | 55.54 | 56.35 | 56.84 | 57.15 |
| 90                       | 2.10  | 54.90 | 0.02 | 52.32                   | 52.65 | 53.16 | 53.99 | 54.90 | 55.80 | 56.59 | 57.06 | 57.36 |
| 95                       | 2.19  | 55.20 | 0.02 | 52.69                   | 53.02 | 53.51 | 54.32 | 55.20 | 56.07 | 56.84 | 57.29 | 57.58 |
| <b>Boys</b>              |       |       |      |                         |       |       |       |       |       |       |       |       |
| 45                       | -0.16 | 50.08 | 0.03 | 47.49                   | 47.80 | 48.30 | 49.13 | 50.08 | 51.04 | 51.93 | 52.47 | 52.83 |
| 50                       | 0.51  | 50.82 | 0.03 | 48.14                   | 48.48 | 48.99 | 49.85 | 50.82 | 51.80 | 52.69 | 53.22 | 53.57 |
| 55                       | 1.18  | 51.73 | 0.03 | 48.92                   | 49.27 | 49.81 | 50.72 | 51.73 | 52.73 | 53.63 | 54.16 | 54.51 |
| 60                       | 1.82  | 52.76 | 0.03 | 49.79                   | 50.17 | 50.75 | 51.71 | 52.76 | 53.79 | 54.70 | 55.24 | 55.59 |
| 65                       | 2.18  | 53.67 | 0.03 | 50.56                   | 50.96 | 51.57 | 52.58 | 53.67 | 54.74 | 55.68 | 56.23 | 56.59 |
| 70                       | 2.28  | 54.34 | 0.03 | 51.07                   | 51.50 | 52.14 | 53.20 | 54.34 | 55.45 | 56.43 | 57.00 | 57.37 |
| 75                       | 2.00  | 54.79 | 0.03 | 51.43                   | 51.86 | 52.52 | 53.61 | 54.79 | 55.95 | 56.97 | 57.57 | 57.96 |
| 80                       | 1.27  | 55.14 | 0.03 | 51.80                   | 52.23 | 52.87 | 53.95 | 55.14 | 56.33 | 57.39 | 58.02 | 58.43 |
| 85                       | 0.30  | 55.48 | 0.03 | 52.24                   | 52.63 | 53.25 | 54.30 | 55.48 | 56.67 | 57.76 | 58.42 | 58.85 |
| 90                       | -0.76 | 55.81 | 0.03 | 52.71                   | 53.08 | 53.67 | 54.67 | 55.81 | 57.01 | 58.12 | 58.80 | 59.25 |
| 95                       | -1.83 | 56.19 | 0.03 | 53.24                   | 53.58 | 54.13 | 55.08 | 56.19 | 57.37 | 58.49 | 59.20 | 59.66 |
| 100                      | -2.89 | 56.60 | 0.03 | 53.79                   | 54.11 | 54.63 | 55.53 | 56.60 | 57.76 | 58.89 | 59.61 | 60.09 |

### Statistical Analysis

Cross-sectional analysis of the data was performed. The LMS method was used to construct reference centile curves (15,16). The curves were fitted as cubic splines by non-linear regression using penalized likelihood; the extent of smoothing was controlled by equivalent degrees of freedom (17). Fitting and smoothing were performed with the program LMS v. 5.1. The required centiles (C) were calculated using the following equation:  $C=M(1+LSZ_{CX})^{1/L}$ , where L is the power of a Box-Cox transformation, M is the median, S is the coefficient of variation, and  $Z_{CX}$  is the normal equivalent deviate corresponding to the centile. The Z score of an individual measurement can be computed as  $Z=[(measurement/M)L-1]/(LS)$ . L values for length/height and head circumference were forced to 1 for a normal distribution because estimated L values offered only a slight improvement in the fit.

### RESULTS

There were 2,558 girls and 2,521 boys in the study group. The distribution of the students according to sex and age groups is shown in Table 1. The mean head circumference values for the boys were larger than those for the girls at all ages [minimum (0.54 cm) at 12.5–12.99 years and maximum (1.67 cm) at 17.5–17.99 years; Table 1].

Tables 2, 3, 4, and 5 show the LMS parameters for head circumference with regard to age, height, and waist circumference for both sexes. The

3<sup>rd</sup>, 10<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 90<sup>th</sup>, 97<sup>th</sup> smoothed centile curves for head circumference with regard to age, height, and waist circumference are presented in Figs. 1a, b; 2a, b; and 3a, b.

Head circumference measurements were significantly correlated with height ( $r=0.74$ ), weight ( $r=0.76$ ), and waist circumference ( $r=0.68$ ).

A comparison of our results with data from the United States (5), World Health Organization (WHO) (13), Gökçay et al. (10) (Istanbul, 2008), and Elmalı et al. (11) (Kayseri, 2012) is presented in Table 6 and Fig. 4.

### DISCUSSION

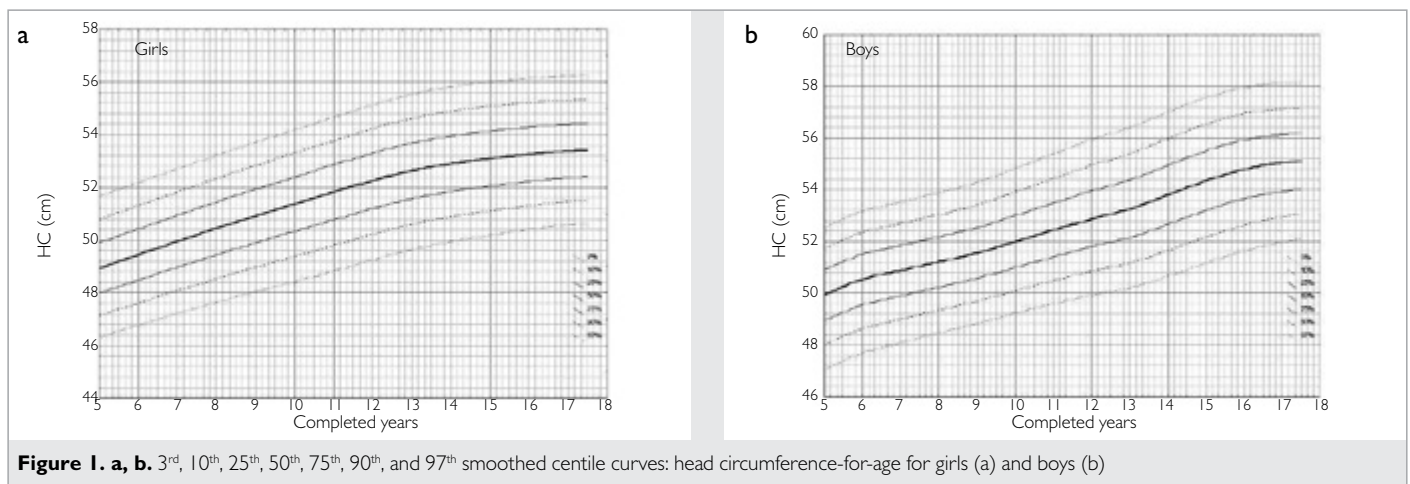
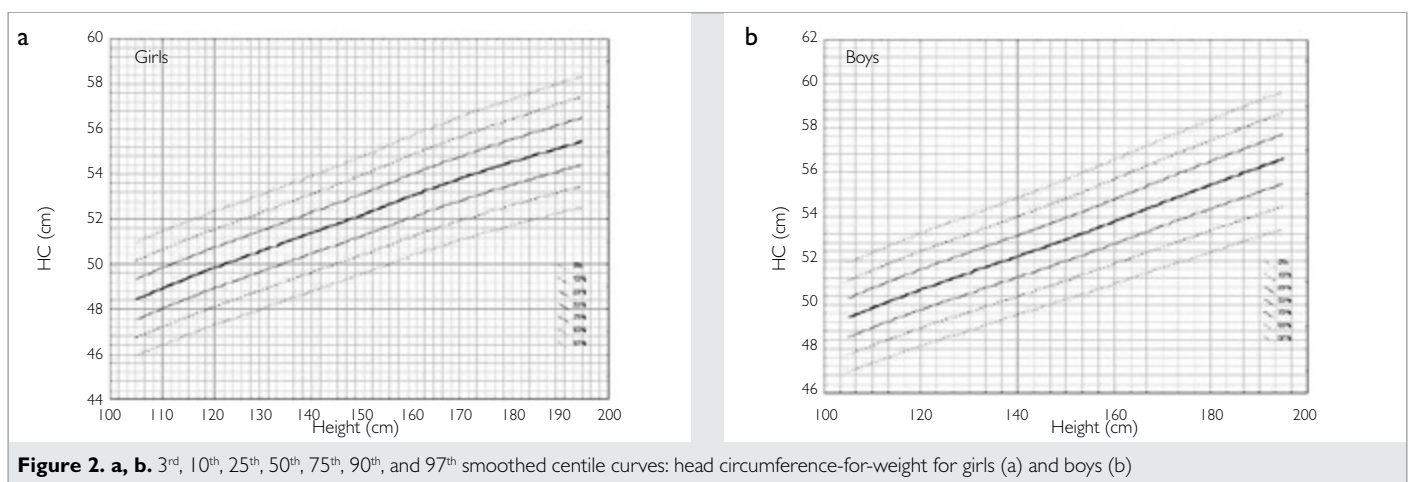
Head circumference is an important marker of normal growth and development and a powerful predictor of total brain volume in children (18). Head circumference reaches approximately 90% of the adult size at the age of 3 years; thus, for normally developing children, routine follow-up of head circumference growth is not recommended after 3 years of age (2). Many developmental disorders can influence head size, and some of these disorders appear after 3 years of age. Thus, for abnormally developing children, there is a need to monitor head growth after the age of 3 years. In Turkey, monitoring head circumference of older children is difficult because a locally developed head circumference growth chart is not available. This study provides an important tool to evaluate head circumference growth for Turkish children aged 5–18 years.

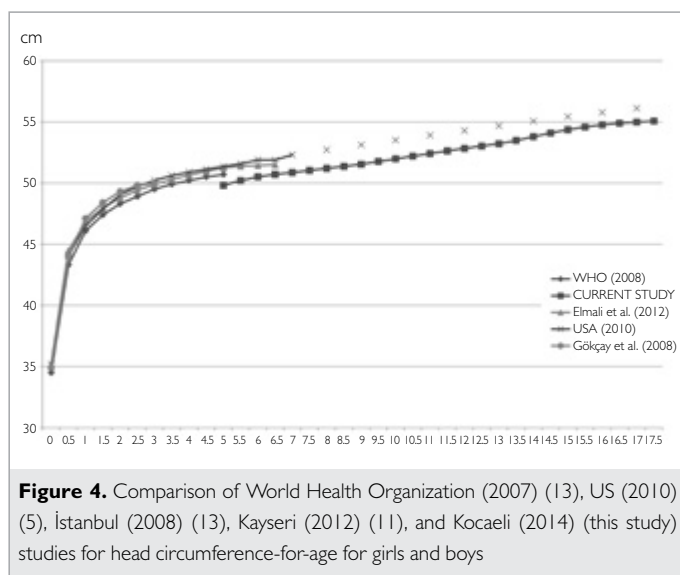
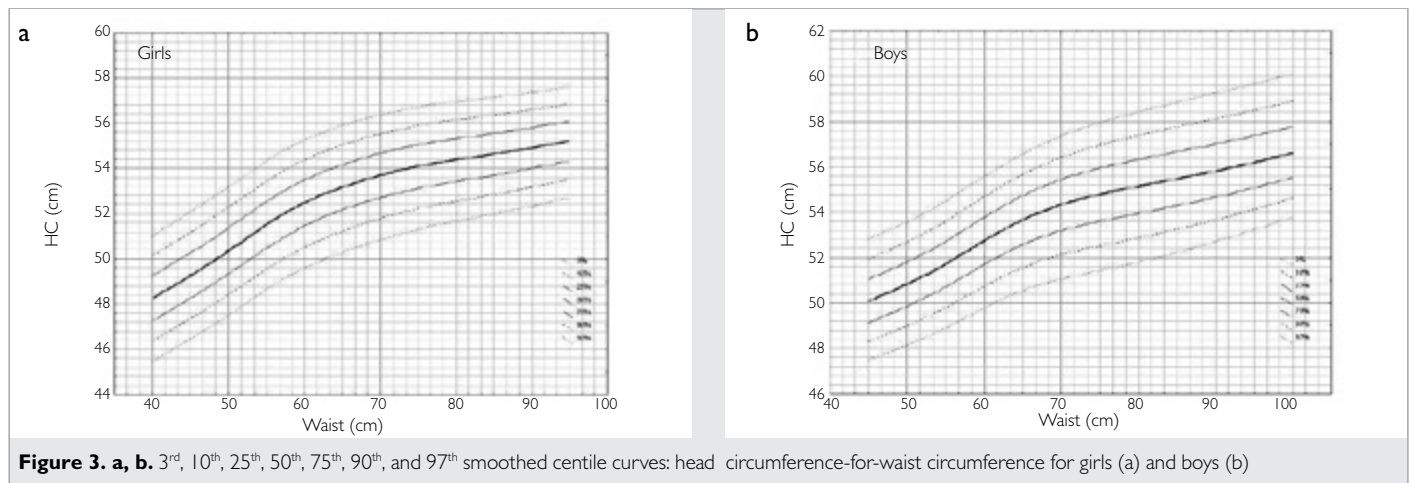
**Table 6.** Fiftieth percentile head circumference values according to sex and age groups in the US5, Kayseri (11), and Kocaeli studies

| Age group (years) | 50 <sup>th</sup> percentile values (cm) |       |                                   |       |                                  |       | $\Delta^1$ (US-Kocaeli) |       | $\Delta^2$ (Kayseri-Kocaeli) |       |
|-------------------|---|-------|-----------------------------------|-------|----------------------------------|-------|-------------------------|-------|------------------------------|-------|
|                   | US study (2010): 0-21 years             |       | Kayseri study (2012): 0-84 months |       | Kocaeli study (2014): 5-18 years |       |                         |       |                              |       |
|                   | Girl                                    | Boy   | Girl                              | Boy   | Girl                             | Boy   | Girl                    | Boy   | Girl                         | Boy   |
| 5.0-5.49          | 50.63                                   | 51.35 | 50.32                             | 51.23 | 48.93                            | 49.93 | +1.7                    | +1.42 | +1.39                        | +1.30 |
| 5.5-5.99          | 50.88                                   | 51.57 | 50.55                             | 51.38 | 49.19                            | 50.25 | +1.69                   | +1.32 | +1.36                        | +1.13 |
| 6.0-6.49          | -                                       | -     | 50.71                             | 51.43 | 49.45                            | 50.53 | -                       | -     | +1.26                        | +0.90 |
| 6.5-6.99          | 51.19                                   | 51.89 | 50.86                             | 51.48 | 49.70                            | 50.72 | +1.49                   | +1.17 | +1.16                        | +0.76 |
| 7.0-7.99          | 51.58                                   | 52.31 | -                                 | -     | 50.07                            | 50.95 | +1.51                   | +1.36 | -                            | -     |
| 8.0-8.99          | 51.95                                   | 52.72 | -                                 | -     | 50.57                            | 51.29 | +1.38                   | +1.43 | -                            | -     |
| 9.0-9.99          | 52.31                                   | 53.12 | -                                 | -     | 51.04                            | 51.65 | +1.27                   | +1.47 | -                            | -     |
| 10.0-10.99        | 52.66                                   | 53.51 | -                                 | -     | 51.49                            | 52.10 | +1.17                   | +1.41 | -                            | -     |
| 11.0-11.99        | 52.99                                   | 53.91 | -                                 | -     | 51.93                            | 52.54 | +1.06                   | +1.37 | -                            | -     |
| 12.0-12.99        | 53.31                                   | 54.29 | -                                 | -     | 52.36                            | 52.96 | +0.95                   | +1.33 | -                            | -     |
| 13.0-13.99        | 53.59                                   | 54.68 | -                                 | -     | 52.70                            | 53.38 | +0.89                   | +1.30 | -                            | -     |
| 14.0-14.99        | 53.86                                   | 55.06 | -                                 | -     | 52.95                            | 53.93 | +0.91                   | +1.13 | -                            | -     |
| 15.0-15.99        | 54.10                                   | 55.43 | -                                 | -     | 53.13                            | 54.46 | +0.97                   | +0.97 | -                            | -     |
| 16.0-16.99        | 54.31                                   | 55.77 | -                                 | -     | 53.28                            | 54.85 | +1.03                   | +0.92 | -                            | -     |
| 17.0-17.99        | 54.47                                   | 56.11 | -                                 | -     | 53.39                            | 55.06 | +1.08                   | +1.05 | -                            | -     |

$\Delta^1$ , differences in the head circumference measurements according to sex and age groups between the US study (5) and the Kocaeli study (this study).

$\Delta^2$ , differences in the head circumference measurements according to sex and age groups between the Kayseri study (11) and the Kocaeli study.

**Figure 1. a, b.** 3<sup>rd</sup>, 10<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 90<sup>th</sup>, and 97<sup>th</sup> smoothed centile curves: head circumference-for-age for girls (a) and boys (b)**Figure 2. a, b.** 3<sup>rd</sup>, 10<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 90<sup>th</sup>, and 97<sup>th</sup> smoothed centile curves: head circumference-for-weight for girls (a) and boys (b)



In our study, the mean head circumference values of boys were larger than those of girls at all ages, as in other studies. Before puberty, the head circumference of boys is approximately 1 cm larger than that of girls; at the age of 12.5–12.99 years, the difference is only 0.54 cm due to the earlier onset of puberty in girls; however, after puberty, the difference gradually increases and reaches 1.67 cm between 17.5 and 17.99 years of age. According to a US study, the differences in head circumference in boys and girls at the ages of 7.0–7.99 years, 12.5–12.99 years, and 17.5–17.99 years are 0.7 cm, 0.98 cm, and 1.64 cm, respectively (5). In our study, the difference in head circumference between the boys and girls was greater before puberty and smaller at the age of 12.5–12.99 years than that in the US study, but was approximately the same at the age of 17.5–17.99 years in both studies (5). The differences before and at puberty may be associated with racial characteristics, lifestyle factors among genders until puberty, and the timing of puberty. However, racial and environmental factors do not seem to influence the difference in the final head circumference values between boys and girls at the end of puberty.

A limited number of studies to construct head circumference growth curves have been conducted in Turkish children after 3 years of age. In 2001, Karabiber et al. (9) reported head circumference measurements of urban children in Malatya, including 1,826 healthy children (881 girls, 945 boys) aged between 6 and 12 years. The head circumference values for these Turkish children were similar to the values for Irish and Japanese children with regard to boys and Irish and English children with regard to 58 girls. In 2008, Gökçay et al. (10) reported updated growth curves for Turk-

ish children aged between 15 days and 60 months in Istanbul. In this study, height, weight, and head circumference measurements from a sample of 2,102 girls and 2,391 boys were obtained from Well Child Clinic Records, and the head circumference values for girls and boys were higher than those values reported by the studies conducted in the US and Sweden as well as the WHO growth standards. In 2012, Elmalı et al. (11) reported head circumference growth reference charts for Turkish children aged between 0 and 84 months in Kayseri. This was a population-based study and used family health center registers; it included 1,510 girls and 1,479 boys. The head circumference percentiles in this study group were similar to or not much lower than Belgian and US percentiles.

Nellhaus (7) noticed that race causes no appreciable difference in head circumference in either sex, at least in the first years of life, and head circumference is closely related to brain growth. The results of other studies support this hypothesis (6,10,13,15). The head circumference measurements of Turkish children before and after 5 years of age were evaluated only in the study by Elmalı et al. (11). They showed that these measurements were nearly the same as those for the Belgian and American percentiles before 5 years of age, but the curves declined after 5 years. In addition, Karabiber et al. (9) showed that the head circumference curves for Turkish children were lower than those for Japanese, English, and Irish children, especially in boys aged between 6 and 12 years (10). In the present study, the head circumference measurements were lower than those in a Malatya study in children aged 6 to 12 years and in a Kayseri study in children aged 5 and 7 years, but were much lower than those in the US study in children between 5 and 18 years old (5,9,11). According to these studies, we propose that there may be significant racial, national, and geographic differences in head circumference after 5 years of age, possibly due to factors affecting scalp and skull thickness. Differences in head circumference curves in the same country need to be clarified with further studies (5,9,11).

Age is the most effective factor related to head circumference, but evaluating head circumference only according to age may be misleading (e.g., in cases of constitutional growth failure). Increases in head circumference are influenced largely by skull and scalp thickness after 5 years of age (10). Waist circumference is a good predictive factor of abnormal fat deposition and may affect scalp thickness and, indirectly, head circumference. Thus, height and waist circumference should be taken into consideration when evaluating head circumference. In our study, we found significant correlations between height and head circumference and between waist circumference and head circumference. Similarly, Geraedts et al. (19) showed a strong correlation between head circumference and height, and reported that the charts of head circumference for height might be useful to interpret head circumference in short or tall children. We propose the use of growth curves for head circumference-for-height and head circum-

ference-for-waist circumference for children with growth disorders, obesity, and malnutrition, in addition to head circumference-for-age curves.

The growth of a child can be evaluated with a growth reference chart or a growth standard chart. Growth reference charts are usually based on cross-sectional data and they reflect growth according to the study sample. Growth standard charts are based on longitudinal data, and they reflect the potential growth of a sample as it ought to be (3). The age range of our study group (5–18 years) was too large to design a longitudinal study; in addition, it is not easy to define optimal growth criteria for children in this age group. Thus, we conducted our study in children with average socioeconomic and nutritional status using a cross-sectional design. There is no head circumference growth standard chart for children between 5 and 18 years of age. The WHO charts are the only head circumference growth standard charts, but they provide growth data only from 0 to 5 years. We believe that our head circumference growth reference charts are more reliable for local use than for use in other countries.

In conclusion, head circumference should be monitored in children after 3 years of age with developmental disorders. However, head circumference growth charts produced in other countries are not reliable for use in children after 5 years of age. The current instrument allows head circumference growth to be evaluated in older Turkish children and adolescents using a local growth chart.

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