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ORIGINAL ARTICLE

Effect of body mass index percentile on skeletal maturation of cervical vertebrae and hand-wrist and dental maturation

Turkan Sezen Erhamza, Yagmur Kilicaslan and Fatma Nazik Unver

Faculty of Dentistry, Department of Orthodontics, Kirikkale University, Kirikkale, Turkey

ABSTRACT

Objective: The aim of this study was to evaluate the relationship between age- and gender-specific body mass index (BMI) percentile and skeletal and dental maturation in Turkish adolescents.

Materials and methods: A sample of 429 patients (171 males, 258 females aged between 7 and 17 years) was selected. Skeletal maturation was identified in the hand-wrist radiography by Björk, Grave and Brown (BGB), and the cervical vertebrae maturation (CVM) method defined by Hassel and Farman in lateral cephalometric radiography. Dental maturation was determined by the Demirjian method. BMI was calculated by reference curves used for Turkish children. A regression model was used for the relationship between BMI percentile and skeletal and dental maturation.

Results: There was no significant correlation between BMI and skeletal maturation of cervical vertebrae and dental maturation. A one-percentile increase in BMI percentile accelerates the increase of period (likelihood of being post-pubertal period) to 1.016 times ($p < .05$). Skeletal maturation of hand-wrist and cervical vertebrae and dental maturation were more prominent in females compared to males ($p < .05$). Males and females were not statistically significantly different in BMI percentile ($p = .52$).

Conclusions: BMI may be considered before deciding to estimate the skeletal and dental maturation in an individual by the relevant methods.

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KEYWORDS
Body mass index; growth evaluation; maturation; skeletal age

Introduction

Obesity, a multifactorial problem, has become a worldwide health problem for all age groups as it affects various body systems. Environmental factors such as increased consumption of food with a high glycemic index and high sugar content, large portions of ready-to-eat foods, fast food, reduced number of meals with families, decreased physical activity, short sleep time, and the change in structural architecture of the surrounding area (i.e. availability of pavements and playgrounds) has contributed to the increased obesity incidence in children [1,2].

The term 'obesity' means excess fat and the methods used to measure body fat are not directly available in daily practice. Therefore, obesity is generally assessed by the relationship between weight and height, which provides body fat estimation and is considered sufficiently accurate for clinical purposes. Body mass index (BMI) is the standard measure accepted for overweight and obesity status for children ≥2-years-old [3]. BMI is calculated by dividing the body weight (in kilograms) by the height squared (in m^2). The normal ranges for BMI in children vary by age and gender. Although the National Centre for Health Care Statistics and the Centres for Disease Control (CDC) published BMI reference standards for children between 2 and 20-years-old in 2000, it is preferable to use national growth reference values in different countries as they provide a better reflection by considering genetic and ethnic characteristics of society [4,5].

Estimation and evaluation of growth during orthodontic treatments are of great importance. This is because children constitute the main patient group of orthodontics and dental, skeletal and soft tissues of children grow during the treatment period. Therefore, maximum success can be achieved by evaluating growth and development and applying appropriate treatment alternatives during the development period [6].

Growth and development are influenced by genetic and environmental factors [7]. Nutrition disorder which is one of the environmental factors might have negative effects on growth in childhood and may give rise to problems such as weakness, overweight or obesity in children [8,9].

Nutrition-related problems in children affect whole-body metabolism and also there are several effects on dentofacial structures, too. Obesity can lead to an average height increase in children and early craniofacial growth (increased mandibular length, prognathic maxilla and mandible and decreased anterior face height) [8,10].

The aim of this study was to evaluate the relationship between age- and gender-specific BMI percentile and skeletal maturation and dental maturation in Turkish adolescents. Our study has three null hypotheses. The first null hypothesis is 'the change in BMI percentile value does not affect dental

CONTACT Turkan Sezen Erhamza dt.turkansezen@gmail.com Faculty of Dentistry, Department of Orthodontics, Kirikkale University, Kirikkale 71100, Turkey

Table 1. Skeletal maturation in hand-wrist radiograph according to method of Björk [11] and Grave and Brown [12].

Stage 1 (PP2=): the width of the epiphysis of the proximal phalanx of the second finger is equal to the diaphysis width.
Stage 2 (MP3=): the epiphyseal width of the middle phalanx of the third finger is equal to the diaphysis width.
Stage 3 (Pisi=, R=, H1): Pisi=; the ossification of pisiform bone, R=; the epiphyseal width of the radius is equal to the diaphysis width, H1; the hamate hook becomes prominent.
Stage 4 (S, H2): S; sesamoid bone ossification occurs, H2; the hamate hooks become more prominent.
Stage 5 (MP3 cap, PP1cap, Rcap): MP3cap; epiphyseal capping on the middle phalanx of the third finger, PP1cap; capping on the proximal phalanx of the thumb, Rcap; capping on the radius are observed.
Stage 6 (DP3u): the epiphysis and diaphysis of the distal phalanx of the third finger fuse.
Stage 7 (PP3u): the epiphysis and diaphysis of the proximal phalanx of the third finger fuse.
Stage 8 (MP3u): the epiphysis and diaphysis of the middle phalanx of the third finger fuse.
Stage 9 (Ru): the epiphysis and diaphysis of the radius fuse.

Table 2. Skeletal maturation in lateral cephalometric radiograph according to Hassel and Farman [13].

Stage 1: vertebrae are wedge-shaped, with superior vertebral borders tapering from posterior to anterior; inferior borders of bodies of all cervical vertebrae are flat
Stage 2: concavities develop on inferior borders of C2 and C3; bodies of C3 and C4 are nearly rectangular, and inferior border of C4 is flat; anterior vertical height of bodies increases
Stage 3: distinct concavities develop on inferior borders of C2 and C3; concavity begins to develop on inferior border of C4, and bodies of C3 and C4 are rectangular
Stage 4: clear concavities are seen on inferior borders of C2, C3 and C4 with bodies of C3 and C4 nearly square; bodies of all cervical vertebrae are rectangular
Stage 5: accentuated cavities are seen on inferior borders of C2, C3 and C4, and bodies of C3 and C4 are nearly square; concavities are well defined in lower borders of bodies
Stage 6: deep concavities are seen on inferior borders of C2, C3 and C4, and vertebral bodies are more vertical than horizontal

C: cervical vertebrae.

maturation'. The second null hypothesis is 'the change in BMI percentile value does not affect the skeletal age (for the cervical vertebrae maturation [CVM] method)'. The third null hypothesis is 'the change in the BMI percentile value does not affect the skeletal age (for the Björk, Grave and Brown (BGB) method)'.

Materials and methods

Our study has a cross-sectional and retrospective design. Lateral cephalometric, hand-wrist and panoramic radiographs, present in the archives of the Department of Orthodontics of the Faculty of Dentistry of Kirikkale University between 2012 and 2017 were used for the study sample. The study was approved by the Kirikkale University Clinical Research Ethics Committee (Date:19 December 2018, Decision No: 2018.12.01).

Inclusion criteria were determined as follows: absence of any systemic, endocrine and nutrition disease that might affect growth and development, Turkish nationals, absence of impacted, transposed and congenital tooth deficiency, absence of permanent tooth extraction, absence of any syndrome, congenital or acquired malformation in the hand-wrist, craniofacial and cervical vertebra region, absence of artefact and distortion in the radiographs, and no history of previous orthodontic treatment.

A total of 429 individuals (171 male, 258 female, with a mean age of 13.51 ± 2.25 years, between ages 8 and 17 years) was included in the study. The height, weight, date of birth, gender and race of each patient were obtained from the patient's records. The height and weight of each patient applying to our clinic were measured via a fixed stadiometer with 0.001 cm sensitivity and a mechanical scale sensitive to standard 0.1 kg, respectively, and recorded in the patient's file at the first appointment before the treatment.

Hand-wrist and lateral cephalometric radiographs were used to evaluate skeletal maturation. The hand-wrist radiographs were evaluated by one researcher (FNU) according to the BGB method [11,12] to determine the growth and developmental stages of the subjects (Table 1). They were categorized into 2 groups:

Group 1: Prepubertal—Stage 1, Stage 2, Stage 3, Stage 4, Stage 5 ($n = 218$, 89 females, 129 males)
Group 2: Postpubertal—Stage 6, Stage 7, Stage 8, Stage 9 ($n = 211$, 169 females, 42 males) (according to Table 1).

FNU evaluated the cervical vertebral maturation using the method developed by Hassel and Farman [13]. Maturational changes on the second, third and fourth cervical vertebrae were evaluated (Table 2). The subjects were categorized into 2 groups:

Group 1: Prespurt: Stage 1, Stage 2, Stage 3 ($n = 147$, 52 females, 95 males)
Group 2: Postspurt: Stage 4, Stage 5, Stage 6 ($n = 282$, 206 females, 76 males) (according to Table 2).

FNU evaluated calcification stages of the teeth by the Demirjian method [14] on panoramic radiographs. Seven mandibular teeth (left central incisor to left second molar) were scored based on eight stages of tooth maturation and eruption (Table 3). Scoring was based on criteria of crown calcification, root development and apex characteristics.

BMI percentile value was calculated for each subject using the reference BMI index [5] for Turkish children. Children were classified as underweight (percentile of less than 5), normal weight (percentile of 5–84), overweight (percentile of 85–94) and obese (percentile of 95 or greater).

Table 3. Tooth calcification stages according to the method described by Demirjian et al. [14].

Stage A: cusp tips are calcified but have not yet fused
Stage B: calcified cusps are united, so an outlined occlusal surface is well defined.
Stage C: enamel formation is complete at the occlusal surface. Dentinal deposition has commenced. The outlines of the pulp chamber are curved.
Stage D: crown formation is complete to the cementoenamel junction. The pulp chamber in the uniradicular teeth is curved, being concave towards the cervical region. In the molars, the pulp chamber has a trapezoid form. The pulp horns are beginning to differentiate. Root formation is seen.
Stage E: the walls of pulp chamber are straight and the pulp horns are more differentiated. The root length is less than the crown height. In molars, the radicular bifurcation is visible.
Stage F: the apex ends in a funnel shape. The root length is equal to or greater than the crown height.
Stage G: the walls of the root canal are now parallel and its apical end is still partially open.
Stage H: the apical end of the root canal is completely closed. The periodontal membrane has a uniform width around the root and the apex.

Statistical analysis

Statistical analyses were performed with SPSS software (version 20; IBM, Armonk, NY). Mean, standard deviation, median, minimum and maximum values were presented in descriptive statistics for continuous data and percentage values in discrete data. The Shapiro–Wilk test was used to analyze the data for normal distribution.

t-Test was used to compare chronological age, dental maturation and BMI percentile values by gender. The chi-square test was used in the group comparisons of the nominal variables (cross-tabs) (gender vs. CVM and hand-wrist groups). The logistic regression model was used to examine the risk factors for CVM (prespurt vs. postspurt) and BGB (prepubertal vs. postpubertal) groups. A multivariate linear regression model was used to determine which variables were effective in explaining dental maturation.

Intraobserver reliability was evaluated by weighted kappa and intraclass correlation coefficient. To test the reproducibility of the assessments of skeletal and dental maturation, FNU re-evaluated blindly lateral cephalometric, hand-wrist and panoramic radiographs of 35 subjects 4 weeks after the first evaluation.

Results

In the multivariate linear regression analysis, in the presence of three independent variables, when the type-I error rate was taken as 0.05, the statistical power was found to be 0.84 ($R^2 = .662$) (G* Power 3.1 9.2, Kiel, Germany). The samples came from a normally distributed population.

The mean age was 13.51 ± 2.25 years (females 13.66 ± 2.36, males 13.27 ± 2.07), the mean dental maturation was 14.47 ± 1.69 years (females 14.70 ± 1.58, males 14.12 ± 1.79), and the mean BMI percentile was 54.76 ± 29.77 (females 54.38 ± 29.22, males 55.34 ± 30.67). The sample distribution included 10.7% ($n = 46$) underweight, 72.7% ($n = 312$) normal weight, 10.5% ($n = 45$) overweight, and 6.1% ($n = 26$) obese subjects. Chronological age and BMI percentile values did not differ significantly between males and females ($p = .073$ and $p = .521$, respectively). Dental maturation was higher in females than that in males ($p = .001$). Moreover, the obesity percentage was slightly higher (3.3% greater) for females.

There was a statistically significant difference in the prevalence of prespurt (CVM stages 1–3) vs. postspurt (CVM stages 4–6) stage and in the prevalence of prepubertal (hand-wrist stages 1–5) vs. postpubertal (hand-wrist stages 6–9) between males and females ($p < .001$) (Table 4). Gender and chronological age were statistically significant explanatory factors for CVM ($p < .001$) (Table 5). Females were more likely to be skeletally advanced (postspurt) than were males; that is, females were 20.630 times more likely to have postspurt growth than were males. A 1-year increase in chronological age accelerates the increase of stage (likelihood of being postspurt period) to 3.578 times. BMI percentile was not a statistically significant explanatory variable for CVM ($p = .204$). A one-percentile increase in the BMI percentile value accelerates the increase of period (likelihood of being postspurt period) to 0.204 times, but this was not statistically significant.

In the initial model for dental maturation, BMI percentile did not contribute significantly to the explanation beyond that of gender and chronological age ($p = .174$). Gender and chronological age were statistically significant explanatory variables for dental maturation (Table 6). The expected change in dental maturation for a year increase in chronological age was 0.598 years ($p < .001$). The mean dental maturation of females was found 0.35 years higher than that of males ($p < .001$).

Gender ($p < .001$), chronological age ($p < .001$) and BMI percentile ($p = .015$) were statistically significant explanatory variables for hand-wrist maturation differences (Table 7). Females were more likely to be skeletally advanced (hand-wrist maturation-postpubertal) than males; that is females were 121.776 times more likely to have postspurt growth than were males. A 1-year increase in chronological age accelerates the increase of stage (likelihood of being postpubertal period) to 7.336 times. A one-percentile increase in the BMI percentile accelerates the increase of period (likelihood of being postpubertal period) to 1.016 times ($p < .05$).

The reproducibility of all the evaluations was found great, with high coefficient values. The coefficients of reliability were found to be between 1.00–1.00 for the dental maturation assessments, between 0.847 and 0.999 for the CVM evaluations and between 1.00–1.00 for the hand-wrist assessments.

Discussion

The prevalence of overweight and obesity in children over recent years is steadily increasing worldwide. The rate of overweight among Turkish children is 4–13% and the rate for obese children is in the range of 9–27% [15]. It is clear that rates are quite high also in our country as in other countries [16–18]. Although there are studies about the effects of nutritional status on dental and skeletal ages in

Table 4. CVM, hand-wrist findings by gender.

	Chronological age						Dental age				BMI percentile			
	Male			Female			Male		Female		Male		Female	
	n	Mean	SD	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CVM stage														
CVM 1	18	10.38	1.04	4	10.35	1.63	11.87	1.27	11.90	1.72	47.61	32.62	57.00	35.43
CVM 2	32	11.68	1.15	14	10.35	1.24	12.86	1.46	12.61	1.79	62.50	30.07	48.50	32.02
CVM 3	45	12.82	1.01	34	11.19	1.47	13.82	1.46	13.07	1.64	56.46	32.53	52.55	33.04
CVM 4	37	13.82	1.25	60	12.41	1.38	14.86	1.37	14.06	1.26	56.43	32.96	51.20	29.93
CVM 5	23	15.28	0.81	74	14.12	1.43	15.71	0.59	15.30	0.87	50.26	23.94	57.52	27.84
CVM 6	16	16.78	0.70	16	16.21	13.64	15.95	0.13	15.92	0.29	51.37	28.05	55.65	27.79
CVM category														
Prespurt	95 (64.6%)	11.97	1.40	52 (35.4%)	10.90	1.45	13.13	1.60	12.86	1.69	56.82	31.83	51.80	32.36
Postspurt	76 (27%)	14.89	1.55	206 (73%)	14.35	2.01	15.35	1.12	15.16	1.15	53.50	29.25	55.02	28.42
p-Value		.000*												
Hand-wrist stage														
1	24	10.31	0.98	5	9.86	1.50	11.94	1.09	11.10	1.19	51.25	33.47	46.40	33.81
2	17	11.82	1.02	4	9.94	1.16	12.67	1.33	12.25	1.97	61.17	35.05	54.50	18.08
3	16	12.38	0.81	7	10.39	1.69	13.71	1.69	12.21	1.95	54.81	29.30	53.28	34.30
4	32	12.77	0.98	22	10.69	0.80	13.57	1.57	12.83	1.39	53.93	30.29	58.09	35.35
5	40	13.67	1.02	51	11.84	0.92	14.86	1.19	13.72	1.25	58.87	33.55	45.21	31.48
6	5	15.06	0.82	10	12.40	0.99	15.28	0.95	14.59	1.28	49.60	27.67	46.80	34.71
7	4	15.73	0.30	16	13.22	0.90	15.80	0.23	14.65	1.06	29.50	15.26	63.31	22.72
8	18	15.48	0.85	62	14.06	1.32	15.83	0.41	15.29	0.79	62.38	22.42	58.24	25.07
9	15	16.71	0.91	81	16.24	1.04	15.94	0.14	15.94	0.22	49.80	28.21	55.93	28.78
Hand-wrist category														
Prepubertal	129 (59.2%)	12.42	1.52	89 (40.8%)	11.25	1.23	13.56	1.71	13.17	1.54	56.03	32.13	49.51	27.28
Postpubertal	42 (19.9%)	15.89	1.03	169 (80.1%)	14.93	1.74	15.80	0.46	15.50	0.81	53.23	25.88	56.94	27.28
p-Value		.000*												

Significant at $^{*}p < .05$ (prevelance of genders in CVM and hand-wrist category).

Table 5. Results of logistic model for CVM (prespurt vs. postspurt).

Variable	df	OR	95%CI		*p*-Value
Gender (female)	1	20.630	9.580	44.424	.000
Chronological age	1	3.578	2.745	4.663	.000
BMI percentile	1	0.204	0.997	1.016	.204

OR: Odds ratio; CI: confidence interval.

Table 6. Results of logistic model for dental maturation with parameter estimates for explanatory variables.

Variable	df	Estimate	95%CI		*t*	*p*-Value
Intercept	1	6.055	5.446	6.663	19.557	.000
Gender (female)	1	0.349	0.158	0.514	3.589	.000
Chronological age	1	0.598	0.557	0.640	28.218	.000
BMI percentile	1	0.002	−0.001	0.005	1.362	.174

CI: Confidence interval.

Table 7. Results of logistic model for hand-wrist maturation (prepubertal vs. postpubertal).

Variable	df	OR	95%CI		*p*-Value
Gender (female)	1	121.776	36.497	406.318	.000
Chronological age	1	7.336	4.756	11.317	.000
BMI percentile	1	1.016	1.003	1.029	.015

OR: Odds ratio; CI: Confidence interval.

different countries, no similar study was found for Turkish children.

The use of age-specific percentile measures is reliable in children and adolescents as BMI changes with age [19,20]. There might be genetic, ethnicity and nutritional differences among nations, so it is preferable to use national growth reference values considering that they would reflect the genetic and ethnic characteristics of the population [4,5] We used BMI percentile values valid for Turkish children.

In our study sample, children were categorized as underweight, normal weight, overweight and obese using growth curves. When the distribution was examined, 10.7% of the children were underweight, 72.7% were normal weight, 10.5% were overweight and 6.1% were obese. Thus, due to the large range of BMI percentiles representing the normal weight category and the relatively few patients falling into the obese category, we preferred to use the continuous measure of BMI percentile rather than categorical classifications in the statistical model.

In the current studies, the Demirjian method was used for the evaluation of dental maturation [19–21]. Although it is frequently preferred for reasons including easy applicability and high reproducibility, different researchers indicate that it tends to give dental maturation higher than actual value [20,21]. However, it is still the most preferred method, as the maturation difference between the estimated maturation and the chronological age is low and it can be reliably applied by different observers [22,23]. We also used the Demirjian [14] method in our study.

Mack et al. [20] found that increased BMI percentile led to progress in dental maturation. According to the results of the regression analysis, they reported that one-unit increase in the BMI percentile resulted in an annual 0.005-fold increase in dental maturation. DuPlessis et al. [19] found the BMI percentile to be a statistically significant explanatory variable for dental maturation differences in their multiple regression models. Dental maturation difference indicated that as the BMI percentile decreases by 1, dental maturation difference decreases by 0.008 years. In contrast, Eid et al. [24] did not find a significant correlation between dental maturation and BMI percentile values in Brazilian children. Similarly, in our study, the change in the BMI percentile value did not significantly affect dental maturation. This difference might be attributed to ethnic and genetic background differences. Our first hypothesis has been accepted. In our study, dental maturation varied between males and females. Females were found to develop more than males in terms of dental maturation. This result is in line with several studies in the literature [19,25].

The relationship between obesity and skeletal maturation is a matter of debate in the literature. Some studies report a moderate positive correlation; [26,27] however, the increase in body weight can also be considered a result of puberty rather than a determinant factor [28]. In our study, we found the change in BMI percentile value not to be associated with CVM stages; however, BMI percentile was noticed to be effective in wrist maturation. As a consequence, our second hypothesis has been accepted and the third hypothesis has been rejected. A one-unit increase in the BMI percentile value means 1.016 times accelerated skeletal maturation. Consequently, not only skeletal maturation but also the weight of the individual should be considered in the evaluation of growth and development in orthodontics and determining the treatment time. It should be noted that especially when obese Class II children are treated with growth modification, it should be kept in mind they should be evaluated earlier for the treatment than those with normal weight.

In the literature, there are studies that report CVM and BGB methods to be compatible; however, Hoseini et al. found a low agreement between the two methods in their studies evaluating the skeletal age with the wrist and cervical vertebra methods [29]. In our study, the reason why the relationship between BMI and the two methods is not similar might be explained by the lack of compatibility between the methods or by the differences in genetics, ethnicity and nutrition among nations.

Conclusion

The increase in weight status accelerates the skeletal maturation of the hand-wrist. BMI should be taken into consideration in determining the plan and timing of orthodontic treatment such as especially growth modification.

Disclosure statement

No potential conflict of interest was reported by the authors.

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