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ORIGINAL ARTICLE

Evaluation of the Relationships between Chronological Age, Skeletal Maturation, Dental Maturation, and Sagittal Jaw Relationships

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ABSTRACT

Objective: The present study aimed to determine whether there is a correlation between chronological age, skeletal maturation, dental maturation, and ANB angle.

Methods: Lateral cephalometric, panoramic, and hand–wrist radiographs of 200 orthodontic patients were used (100 males and 100 females; mean age 13.00 and 13.70 years, respectively). Skeletal maturation was determined by two different methods: cervical vertebral maturation (CVM) and the hand–wrist radiography method of Grave–Brown. Dental maturation was defined by the Demirjian Index using the mandibular canine, premolars, and second molar on the left side. The ANB angle was measured on lateral cephalometric head films. The data were analyzed by Spearman's rank correlation analysis.

Results: Correlation coefficients of the male and female subjects were 0.825 and 0.802 between chronological age and hand–wrist evaluation; 0.744 and 0.778 between chronological age and CVM evaluation; 0.677 and 0.443 between chronological age and mandibular canine development; 0.722 and 0.458 between chronological age and mandibular first premolar development; 0.730 and 0.517 between chronological age and mandibular second premolar development; 0.701 and 0.531 between chronological age and mandibular second molar development; and −0.183 and −0.045 between chronological age and ANB, respectively. All the correlations mentioned above were statistically significant ($p<0.001$), except for the last one.

Conclusions: High correlations were found between the chronological age, hand–wrist, and cervical vertebral maturation evaluations. Chronological age was also correlated with dental maturation, particularly in mandibular second molars. There was no correlation between ANB and the other parameters.

Keywords: Skeletal maturation, cervical vertebral maturation, Demirjian index, dental maturation

INTRODUCTION

In dentofacial orthopedic treatments, treatment timing is a key factor for successful orthodontic therapy.[1] Determination of the maturation level and growth stage of a growing patient with skeletal imbalances or dentofacial disorders is highly important in orthodontic treatment planning.[1-3] This determination is generally performed by the evaluation of chronological age, skeletal maturation, dental maturation, height–weight, and prepubertal maturation characteristics.[4]

It has been reported[1,5] that chronological age has a minor or no effect on the determination of the maturation phases of a child. Instead, biological (physiological) age may be more reliable because it includes parameters such as somatic, sexual, skeletal, and dental maturity.[6-9] Skeletal maturation shows the degree of development of ossification in bone. The growth and maturation of a bone may be different; therefore, skeletal maturation is more closely related to sexual maturity than to stature.[4]

Greulich and Pyle determined the sequence of hand and wrist bone ossification in 1950s and published a radiographic atlas for the evaluation of skeletal maturity.[10] Their evaluation method is still in use. In 1976, Grave and Brown published a classification of skeletal maturation based on checking the maturity markers on hand–wrist radiographs.[11] Hand–wrist radiography is a widespread and classically used diagnostic tool in the evaluation of

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Table 1. Evaluation method of cervical vertebral maturation[2]

Cervical stage 1 (CS1)	The lower borders of the second, third, and fourth cervical vertebrae (C2, C3, and C4) are flat; C3 and C4 have trapezoid-shaped bodies, which means that the superior border of vertebral bodies is tapered from posterior to anterior.
Cervical stage 2 (CS2)	Second cervical vertebra (C2) has a concave lower border; C3 and C4 have trapezoid-shaped bodies.
Cervical stage 3 (CS3)	Lower borders of C2 and C3 have concavities. C3 and C4 have a trapezoid or rectangular horizontal shape.
Cervical stage 4 (CS4)	C2, C3, and C4 have concavities at their lower borders. C3 and C4 have rectangular horizontal-shaped bodies.
Cervical stage 5 (CS5)	C2, C3, and C4 have still concavities at their lower borders. At least one of the bodies of C3 and C4 is square and the other one has a rectangular horizontal-shaped body.
Cervical stage 6 (CS6)	C2, C3, and C4 still have the concavities at their lower borders. At least one of the bodies of C3 and C4 is rectangular vertical and the bodies of the other cervical vertebrae are square.

C: cervical; CS: cervical stage

skeletal maturation, and an alternative to this method is cervical vertebral evaluation on lateral cephalometric radiographs. Many researchers have investigated cervical vertebral maturation indicators and concluded that this evaluation is a reliable method for skeletal maturation.[12-18] Hassel and Farman[5] stated that by briefly looking at the cervical vertebrae on a lateral cephalometric radiograph, the orthodontist can evaluate the skeletal maturity of a patient at that point. Baccetti et al.[19] published an improved version of the CVM method for the assessment of mandibular growth.

High correlations have generally been reported between skeletal and dental maturity.[8] It has been suggested, however, that racial variations also have an effect on this relationship. Ethnicity, climate, nutrition, socioeconomic levels, and urbanization are indicated as causative factors of these racial variations.[20] The relationships between dental and skeletal maturations have been evaluated by many investigators, and it has been found that the use of tooth calcification is more reliable than that of tooth eruption.[8,9,19,21-26] Some authors[6,26-28] have claimed that the calcification stages of mandibular second molars have the highest correlation with the stages of skeletal maturity, while according to others,[8,9,19] mandibular canines have the highest correlation.

According to Choi et al.,[29] the rate of skeletal maturation may differ in different types of malocclusion. Johnston et al.[30] investigated the relationships between skeletal maturation and cephalofacial development and found a retardation in subjects with Class II. A similar study conducted by Kim et al.[31,32] revealed that skeletal maturation in patients with Class II malocclusion begins later than that in those with Class I or III malocclusion. Sasaki et al.[33] suggested that the skeletal disharmony can be associated with different timings of the formation and eruption of permanent teeth.

The ANB angle is recognized as a skeletal sagittal discrepancy indicator and has become most commonly used for measurement among orthodontists. This angle has a definite tendency to decrease with increasing age.[34] If a relationship can be defined between skeletal maturation and ANB, this knowledge will be useful to predict the extent of growth remaining in the jaws. Previous reports[1,7,12,13,28] have laid emphasis on the relationships between chronological age, cervical vertebral maturation, hand–wrist evaluation, and dental maturation, but no study has evaluated the relationships between these parameters and the sagittal relationships of the jaws to date.

METHODS

The present study sample was chosen from the files of the Orthodontics Department of the Dental School at Istanbul Medipol University. Lateral cephalometric, panoramic, and hand–wrist radiographs of 200 subjects (100 males, 100 females) were used in this study. The mean age of the male and female subjects were 13.00±2.12 and 13.70±2.02 years, respectively. All of the radiographs were taken by one operator using the Kodak 9000 C system (Kodak Dental Systems, Carestream Health, Rochester, NY, USA).

Inclusion criteria for this study were as follows: 1) Chronological age ranging from 7 to 18 years; 2) No serious illness and nutritional or hormonal problems; 3) Normal growth and development; 4) Absence of previous history of trauma or congenital/acquired disease to the face, neck, and hand–wrist; 5) Absence of abnormal dental conditions, such as impaction, transposition, and congenitally missing teeth; 6) No previous orthodontic treatment; 7) No permanent teeth extracted.

Skeletal maturation was evaluated by means of both the improved version of the CVM3 (Table 1) and from hand–wrist radiographs (Table 2), and the skeletal ages were rated without any knowledge about the children's chronological ages.[11,18,28] Dental maturation was evaluated by the Demirjian Index (DI)[24] on panoramic radiographs (Table 3). The mandibular left canine, premolars, and second molar were used for this purpose. Skeletal classification was made on the basis of ANB angle; in skeletal Class I, the ANB angle was from 1 to 5 degrees, for skeletal Class II more than 5 degrees, and for skeletal Class III less than 1 degree.

Statistical Analysis

Statistical analyses were performed by the Statistical Package for Social Science (SPSS for Windows, version 14.0, SPSS Inc; Chicago, USA). The Student's t and Mann-Whitney U tests were used to find out the gender differences between the investigated parameters. The Spearman's rank correlation coefficients were computed separately for the male and female subjects to find out the relationships among chronological age, CVM, skeletal maturation, dental maturation, and ANB angle.

Table 2. Evaluation method of hand–wrist radiographs[11,18,29]

Stage 1 (PP2)	The epiphysis of the proximal phalanx of the index finger (PP2) has equal width as the diaphysis.
Stage 2 (MP3)	The epiphysis of the middle phalanx of the middle finger (MP3) has the same width as the diaphysis.
Stage 3 (Pisi-H1-R)	Pisi: visible ossification of the pisiform, H1: ossification of the hamular process of the hamatum, R: the same width of epiphysis and diaphysis of the radius.
Stage 4 (S-H2)	S: first mineralization of the ulnar sesamoid, H2: progressive ossification of hamular process of the hamatum.
Stage 5 (MP3cap-PP1cap-Rcap)	During this stage, the diaphysis is covered by the cap-shaped epiphysis. In the MP3cap, the process begins at the middle phalanx of the third finger, in the PP1cap at the proximal phalanx of the thumb, and in the Rcap at the radius.
Stage 6 (DP3u)	Visible union of the epiphysis and diaphysis at the distal phalanx of the middle finger (DP3).
Stage 7 (PP3u)	Visible union of the epiphysis and diaphysis at the proximal phalanx of the little finger (PP3).
Stage 8 (MP3u)	Union of the epiphysis and diaphysis at the middle phalanx of the middle finger is clearly visible (MP3).
Stage 9 (Ru)	Complete union of epiphysis and diaphysis of the radius.

PP: proximal phalanx; MP: middle phalanx; Pisi: pisiform; H: hamular; R: radius; S: sesamoid; C: capping; DP: distal phalanx; U: union

Table 3. Evaluation of dental maturation according to Demirjian[24]

Stage A	Calcification of single occlusal points without fusion of different calcifications.
Stage B	Fusion of mineralization points; the contour of the occlusal surface is recognizable.
Stage C	Enamel formation has been completed at the occlusal surface, and dentine formation has commenced. The pulp chamber is curved, and no pulp horns are visible
Stage D	Crown formation has been completed to the level of the amelocemental junction. Root formation has commenced. The pulp horns are beginning to differentiate, but the walls of the pulp chamber remain curved.
Stage E	The root length remains shorter than the crown height. The walls of the pulp chamber are straight, and the pulp horns have become more differentiated than those in the previous stage. In molars, the radicular bifurcation has commenced to calcify.
Stage F	The walls of the pulp chamber now form an isosceles triangle, and the root length is equal to or greater than the crown height. In molars, the bifurcation has sufficiently developed to give the roots a distinct form.
Stage G	The walls of the root canal are now parallel, but the apical end is partially open. In molars, only the distal root is rated.
Stage H	The root apex is completely closed (distal root in molars). The periodontal membrane surrounding the root and apex is uni form in width throughout.

Assessing the reproducibility of the ratings was done by reevaluating the radiographs of 20 males and 20 females randomly selected 6 weeks after the first evaluation, and the Spearman Brown formula was used for this purpose.

RESULTS

Descriptive statistics of all the variables for the male and female subjects and their comparisons are presented in Table 4. As shown in this table, all the parameters, except for ANB and the second molar and premolar, were statistically significant, and they were higher in female subjects.

The results of correlation analysis regarding the chronological age, skeletal maturity, and dental maturity indicators and ANB angle are presented in Table 5 and 6 for the males and females, respectively. As shown in these tables, the correlation coefficients for the male and female subjects were 0.825 and 0.802 between the chronological age and hand–wrist evaluation; 0.744 and 0.778 between chronological age and CVM evaluation; 0.677 and 0.443 between chronological age and mandibular canine development; 0.722 and 0.458 between chronological age and mandibular first premolar development; 0.730 and 0.517 between chronological age and mandibular second premolar development; and 0.701 and 0.531 between chronological age and mandibular second molar development, respectively; all of these were statistically significant ($p<0.001$). There was no correlation between chronological age and ANB.

Correlation coefficients between all the parameters, except for the ANB angle, were also statistically significant (Table 5, 6).

DISCUSSION

Maturation is an important concept for orthodontists when it is time to evaluate a growing child, especially one with dentofacial problems. Many researchers have investigated the different maturation indicators, such as chronological age, hand–wrist ossification, cervical vertebral maturation, and dental maturation to find out if there was a relationship between skeletal maturation and these parameters.[1,7,12,13,28] In these articles, the sagittal jaw relationship determined by the ANB angle was not included in the study model.

According to the previous reports, chronological age was not found to be sufficiently reliable in the prediction of pubertal growth spurts because of the wide variation among patients in

Table 4. Descriptive statistics of all variables for male and female subjects and their comparisons

Parameters	Gender	Mean/Median	Standard deviation	Minimum	Maximum	p	
Chron. age (years)	Male	13.17	2.12	7	18	0.0090***	a
	Female	13.95	2.02	7	18		
Hand–wrist (stage)	Male	7	3.78	1	14	0.000***	b
	Female	13	2.88	4	14		
CVM (stage)	Male	3	1.33	1	6	0.000***	b
	Female	4	1.05	1	6		
Mand Canine (stage)	Male	7	0.79	4	8	0.000***	b
	Female	8	0.46	6	8		
Mand Pm 1 (stage)	Male	8	0.85	4	8	0.0035**	b
	Female	8	0.53	6	8		
Mand Pm 2 (stage)	Male	7	0.89	4	8	0.05744	b
	Female	8	0.67	5	8		
Mand M 2 (stage)	Male	7	0.86	5	8	0.09692	b
	Female	7	0.63	5	8		
ANB (angle)	Male	3.68	2.25	-2	9	0.97606	a
	Female	3.79	2.40	-3	10		

Chron: chronological; CVM: cervical vertebral maturation; Mand: mandibular; Pm: premolar, M: molar
Alphabetical order in Demirjian classification was converted to numerical order in statistical evaluation.
a: Student's t test, b: Mann-Whitney U test
*p<0.05, **p<0.01, ***p<0.001

Table 5. Correlation coefficients and their significance levels between chronological age and the skeletal maturity indicators, dental development, and ANB in male subjects

Males		Chronological age	Hand–wrist	CVM	Mand Canine	Mand Pm 1	Mand Pm 2	Mand M 2	ANB
Chronological age	Correlation Coefficient (r)		0.825	0.744	0.677	0.722	0.730	0.701	-0.183
	p level		*	*	*		*	*	NS
Hand–wrist	Correlation Coefficient (r)	0.825	-	0.769	0.648	0.678	0.662	0.611	-0.240
	p level		-	*	*	*	*	*	NS
CVM	Correlation Coefficient (r)	0.744	0.769		0.538	0.522	0.557	0.501	-0.237
	p level	*	*	*	*	*	*	*	NS
Mand Canine	Correlation Coefficient (r)	0.677	0.648	0.538	-	0.801	0.673	0.546	-0.146
	p level	*	*	*	-	*	*	*	NS
Mand Pm 1	Correlation Coefficient (r)	0.722	0.678	0.522	0.801	-	0.745	0.707	-0.153
	p level	*	*	*	*	-	*	*	NS
Mand Pm 2	Correlation Coefficient (r)	0.730	0.662	0.557	0.673	0.745	-	0.666	-0.176
	p level	*	*	*	*	*	-	*	NS
Mand M2	Correlation Coefficient (r)	0.701	0.611	0.501	0.546	0.707	0.666	-	-0.122
	p level	*	*	*	*	*	*	-	NS

CVM: cervical vertebral maturation; Mand: mandibular; Pm: premolar
*p<0.001

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Table 6. Correlation coefficients and their significance levels between chronological age and the skeletal maturity indicators, dental development, and ANB in female subjects

Females		Chronological age	Hand–wrist	CVM	Mand Canine	Mand Pm 1	Mand Pm 2	Mand M 2	ANB
Chronological age	Correlation Coefficient (r)	-	0.802	0.778	0.443	0.458	0.517	0.531	-0.045
	p level	-	*	*	*	*	*	*	NS
Hand-wrist	Correlation Coefficient (r)	0.802	-	0.738	0.648	0.480	0.580	0.511	-0.015
	p level	*	-	*	*	*	*	*	NS
CVM	Correlation Coefficient (r)	0.778	0.738	-	0.538	0.475	0.530	0.462	-0.052
	p level	*	*	-	*	*	*	*	NS
Mand Canine	Correlation Coefficient (r)	0.443	0.448	0.411	-	0.794	0.546	0.371	-0.042
	p level	*	*	*	-	*	*	*	NS
Mand Pm 1	Correlation Coefficient (r)	0.458	0.480	0.475	0.794	-	0.597	0.419	-0.015
	p level	*	*	*	*	-	*	*	NS
Mand Pm 2	Correlation Coefficient (r)	0.517	0.580	0.530	0.546	0.597	-	0.621	-0.073
	p level	*	*	*	*	*	-	*	NS
Mand M2	Correlation Coefficient (r)	0.531	0.511	0.462	0.371	0.419	0.621	-	-0.007
	p level	*	*	*	*	*	*	-	NS

CVM: cervical vertebral maturation; Mand: mandibular; Pm: premolar
*p<0.001.

terms of chronological timing. The maturity level has generally been assessed by the evaluation of hand–wrist radiographs.[4,10,15] High correlations were found between chronological age and skeletal maturation.[9,13] In this study, the chronological ages of the patients showed high correlations with both hand–wrist ossification and CVM in the male and female subjects. The correlation coefficients of the hand–wrist evaluation were found higher than that of CVM in both genders.

Some authors[11,28] have suggested carrying out the evaluation of skeletal maturity without taking any additional radiograph because of the possible danger of X-rays, and instead used cervical vertebrae and tooth images on cephalometric and panoramic films, respectively. CVM is an efficient method in assessing the skeletal maturation. It has been proven by numerous studies[4,10,13] that CVM shows a high correlation with skeletal maturity. Baccetti et al.[16] and Franchi et al.[17] showed that statural height was related with cervical vertebral maturation. In this study, the CVM method modified by Franchi et al.[2] was used. The results of the present study showed that CVM had high correlations with the hand–wrist method for both male and female subjects. This finding was confirmed by the previous reports, according to which the CVM method is sufficiently reliable for the evaluation of skeletal maturation.[4,15,17]

Some authors [6,8,9,21,23-26] showed a high correlation between dental and skeletal maturity, while others[22] have reported weak or insignificant relationships between these parameters. In order to investigate this relationship, the Demirjian index, which was accepted as a reliable assessment method, was used in this study. For this purpose, radiographic images of the mandibular canine, the first and second premolars, and the second molar teeth on the left side were used, since the maxillary teeth had a disadvantage of superimposition on panoramic radiographs.[6,13,27] Dental development instead of tooth eruption was used because the previous reports commented that eruption was an alterable situation being affected more than calcification.[24,25] Developments of the first molar and incisor teeth are completed at the early ages, and therefore they were not included in the study model, and also third molars were not included because of their potential for agenesis. In male subjects, the best correlation was found between chronological age and the second premolar, which could be accepted as a mild-level relationship. In females, the best correlation couple was the second premolar and the hand–wrist evaluation.

The results of the present study showed that the rate of skeletal maturation in female subjects was greater than in males. This was an expected finding for skeletal development. Dental developments, however, did not show the same results. Although the mean chronological age of females was greater than that of male subjects, the developments of the second premolar and molar teeth did not show any statistically significant difference between the genders.

The skeletal jaw relationships were assessed by the ANB angle. This angle showed no correlation with any other parameters as opposed to in previous reports.[35,36] This result showed that skeletal maturation was similar in all sagittal skeletal abnormalities.

CONCLUSION

- The highest correlations were found between chronological age and hand–wrist evaluation in all subjects.
- A high correlation was found between the hand–wrist and CVM methods in both genders.
- In male subjects, correlations between chronological age and hand–wrist evaluation and between chronological age and CVM methods were found to be higher than those of females.
- In male subjects, the second premolars showed the highest correlations with chronological age, while the highest correlations were seen between hand–wrist evaluation and dental parameters, except for second molar in females.
- Developments of the second premolar and molar teeth did not show any statistically significant difference between the genders.
- There were no correlations between ANB and the other parameters.

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