

Chronologic age and skeletal maturation of the cervical vertebrae and hand-wrist: Is there a relationship?

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Introduction: The aims of this study were (1) to investigate the relationship between chronologic age and maturation of cervical vertebrae, (2) to identify the relationship between chronologic age and maturation stage evaluated by hand-wrist radiographs, and (3) to determine whether the maturation of cervical vertebrae correlates with maturation indicated by hand-wrist radiographs in a Turkish population. **Methods:** The samples were derived from lateral cephalometric and hand-wrist radiographs of 503 subjects (213 male, 290 female; ages, 5.3-24.1 years). Cervical vertebral development was evaluated by the method of Hassel and Farman. Skeletal maturation of each hand-wrist radiograph was determined according to the method described by Björk and Grave, and Brown's system. The Spearman rank-order correlation coefficients were estimated separately for males and females to measure the relationships among chronologic age, cervical vertebral maturation, and the skeletal maturation measured at the hand-wrist. **Results:** The Spearman correlation coefficients were 0.72 ($P < .001$) between chronologic age and cervical vertebrae skeletal maturation, and 0.79 ($P < .001$) between chronologic age and maturation via hand-wrist radiographs. The correlation coefficient between hand-wrist and cervical-vertebrae maturation was 0.86 ($P < .001$). **Conclusions:** The cervical-vertebrae maturation stages are clinically useful maturity indicators of the pubertal growth period Turkish subjects. (Am J Orthod Dentofacial Orthop 2006;130:622-8)

The issue of optimal timing for dentofacial orthopedics is linked to the identification of periods of accelerated or intense growth that can contribute significantly to the correction of skeletal imbalances in a patient.¹

Sexual maturation characteristics, chronologic age, dental development, height, weight, and skeletal development are common maturational indexes that have been used to identify stages of growth.²

Skeletal maturation staging from radiographic analysis is a widely used approach to predict timing of pubertal growth, to estimate growth velocity, and to estimate the amount of growth remaining. The standard method of evaluating skeletal maturity has been a hand-wrist x-ray to compare the patient's hand-wrist bones with those in published atlases.³⁻⁶ To avoid taking an additional

x-ray, some researchers sought to relate maturation with dental and skeletal features other than the bones in the hand and wrist.^{4,7-9}

According to many authors,⁸⁻¹³ dental development indicators are not reliable predictors of a patient's stage of skeletal development. Because of wide variation among patients in the chronologic timing of the pubertal growth spurt, chronologic age is also unreliable in the prediction of the pubertal spurt.

Among maturational indexes, the cervical vertebral maturation method has proved effective in assessing the adolescent growth peak both in body height and mandibular size.^{14,15} Hellsing⁹ demonstrated that, during adulthood, there is significant correlation between height and length of the cervical vertebral bodies and statural height. Mitani and Sato¹⁶ also reported that changes in the cervical vertebrae correlated significantly with increases in mandibular size. The effectiveness of the cervical vertebrae as maturational indicators was corroborated by Hassel and Farman² and Garcia-Fernandez et al,¹⁷ who found high correlations between cervical vertebral maturation and the skeletal maturation of the hand-wrist. These researchers, as well as Pancherz and Szyska,¹⁸ who further evaluated Hassel and Farman's method in relation to increases in body height, stated that the cervical vertebral analysis had

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comparable high reliability and validity as the hand-wrist bone analysis in the assessment of skeletal maturity.

Relationships between skeletal maturation determined by cervical vertebrae and hand-wrist radiographs have been previously reported in various populations. Racial variations in the relationships were also suggested. Mappes et al¹¹ indicated that predominant ethnic origin, climate, nutrition, socioeconomic level, and urbanization are causative factors of these racial variations.

No study has assessed the relationship of skeletal maturation determined either by cervical vertebrae or hand-wrist radiographs in Turkish subjects. The aims of this study were (1) to investigate the relationship between chronologic age and maturation of cervical vertebrae, (2) to identify the relationship between chronologic age and maturation stage evaluated by hand-wrist radiographs, and (3) to determine whether the maturation of cervical vertebrae correlates with the maturation indicated by hand-wrist radiographs in a sample of Turkish subjects.

MATERIAL AND METHODS

This descriptive study was designed as a cross-sectional research project. The samples were derived from lateral cephalometric and hand-wrist radiographs of 503 patients (213 male, 290 female) at the Orthodontic Department, Faculty of Dentistry, Selçuk University, Konya, Turkey. The subjects ranged in age from 5 years 3 months to 24 years 1 month with a mean age of 12.02 ± 3.00 years (12.00 ± 2.07 years for males, 12.03 ± 3.03 years for females). The distributions and mean chronologic ages of the evaluation of hand-wrist radiographs according to cervical vertebrae stages are shown in Table I.

The selection criteria included Turkish ethnicity, good nutrition without serious illness, normal growth and development, no previous trauma or injury to the face and hand-wrist region, no congenital or acquired malformations of the cervical vertebrae or hand-wrist area, and no developmental alterations due to medical syndromes or hormonal disorders.

Cephalometric and hand-wrist radiographs of each patient were taken on the same day. All radiographs were taken with the same x-ray equipment (Planmeca Cephalometer PM 2002 EC Proline; Helsinki, Finland) at the same distance (x-ray source-film and film-subject distances) and intensity.

All assessments were performed in a darkened room with a radiographic illuminator to ensure contrast enhancement of the bone images.

Cervical vertebrae stages were determined by the

Table I. Distributions and mean chronologic ages of evaluation of hand-wrist radiographs according to cervical-vertebrae stages

Cervical vertebrae stage	n	Hand-wrist stage	n	Chronologic age
Stage 1	99	Stage 1 PP2	67	9 y 8 m
		Stage 2 MP3	15	
		Stage 3 Pisi, H1, R	17	
Stage 2	107	Stage 1 PP2	29	10 y 5 mo
		Stage 2 MP3	37	
		Stage 3 Pisi, H1, R	35	
		Stage 4 S, H2	3	
		Stage 5 MP3cap, PP1cap, Rcap	3	
Stage 3	77	Stage 1 PP2	12	12 y 9 mo
		Stage 2 MP3	9	
		Stage 3 Pisi, H1, R	26	
		Stage 4 S, H2	15	
		Stage 5 MP3cap, PP1cap, Rcap	12	
		Stage 6 DP3U	3	
Stage 4	68	Stage 1 PP2	1	12 y 11 mo
		Stage 2 MP3	1	
		Stage 3 Pisi, H1, R	18	
		Stage 4 S, H2	22	
		Stage 5 MP3cap, PP1cap, Rcap	16	
		Stage 6 DP3U	1	
		Stage 7 PP3U	3	
		Stage 8 MP3U	5	
		Stage 9 RU	1	
Stage 5	76	Stage 3 Pisi, H1, R	4	13 y 9 mo
		Stage 4 S, H2	3	
		Stage 5 MP3cap, PP1cap, Rcap	21	
		Stage 6 DP3U	13	
		Stage 7 PP3U	5	
		Stage 8 MP3U	14	
Stage 6	76	Stage 9 RU	16	15 y 8 mo
		Stage 4 S, H2	2	
		Stage 5 MP3cap, PP1cap, Rcap	3	
		Stage 6 DP3U	2	
		Stage 7 PP3U	5	
		Stage 8 MP3U	14	
		Stage 9 RU	50	

Hassel and Farman² modification of the criteria of Lamparski,⁴ which assess maturational changes on the second, third, and fourth cervical vertebrae (Table II). The cervical vertebrae maturation stages were rated by 2 orthodontists (T.U. and S.I.R.) separately and without knowing chronologic ages. The average of these ratings was used as the vertebrae maturation stage.

Skeletal maturation stage of each hand-wrist radiograph was determined according to the method described by Björk,¹⁹ and Grave and Brown²⁰ (Table

Table II. Six stages in evaluation of cervical vertebrae maturation according to method of Hassel and Farman²

Stage 1 (initiation): 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 (acceleration): 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 (transition): 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 (deceleration): 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 (maturation): 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 of all cervical vertebrae; spaces between bodies are reduced
Stage 6 (completion): Deep concavities are seen on inferior borders of C2, C3, and C4, and vertebral bodies are more vertical than horizontal

TABLE III. Skeletal maturation of each hand-wrist radiograph according to method of Björk¹⁹ and Grave and Brown²⁰

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

III). The conventional roentgenogram of the left hand was rated for each subject by the same 2 orthodontists separately, and the average of the ratings was used as the hand-wrist maturation stage.

Statistical analysis

All statistical analyses were performed with a software package (SPSS for Windows 98, version 10.0, SPSS, Chicago, Ill).

Table IV. Sample distribution according to cervical vertebrae stages in males and females

Maturation stage	Males		Females		Total	
	n	%	n	%	n	%
Stage 1. Initiation	54	25.4	45	15.5	99	19.7
Stage 2. Acceleration	56	26.3	51	17.6	107	21.3
Stage 3. Transition	38	17.8	39	13.4	77	15.3
Stage 4. Deceleration	33	15.5	35	12.1	68	13.5
Stage 5. Maturation	16	7.5	60	20.7	76	15.1
Stage 6. Completion	16	7.5	60	20.7	76	15.1
Total	213	100	290	100	503	100

Table V. Sample distribution according to hand-wrist stages

Hand-wrist maturation stage	Males		Females		Total	
	n	%	n	%	n	%
Stage 1. PP2	63	29.5	46	15.9	109	21.7
Stage 2. MP3	34	16.0	28	9.7	62	12.3
Stage 3. Pisi-H1-R	49	23.0	51	17.6	100	19.9
Stage 4. S-H2	25	11.7	20	6.9	45	8.9
Stage 5. MP3cap-PP1cap-Rcap	14	6.6	41	14.1	55	10.9
Stage 6. DP3u	7	3.3	12	4.1	19	3.8
Stage 7. PP3u	1	0.5	12	4.1	13	2.6
Stage 8. MP3u	8	3.8	25	8.6	33	6.6
Stage 9. Ru	12	5.6	55	19	67	13.3
Total	213	100	290	100	503	100

To assess intraexaminer and interexaminer reproducibility of the ratings for both methods, the Spearman Brown formula was used. The hand-wrist and cervical vertebrae of 30 randomly selected subjects were rated by the same orthodontists 5 weeks after the initial ratings.

Descriptive statistics were obtained by calculating the means of the chronologic ages for the 6 stages of the cervical vertebrae and the 9 stages of hand-wrist skeletal maturity indicators.

The Spearman rank order correlation coefficient was used to assess the relationship between chronologic age and cervical vertebrae maturation stages, chronologic age and hand-wrist maturation stages, and cervical vertebrae and hand-wrist maturation stages.

RESULTS

The reproducibility of all assessments was good, with high coefficient values. The coefficient ranges of reliability were between 0.955 and 0.987 for cervical-vertebrae assessments and between 0.983 and 1.000 for hand-wrist skeletal maturity assessments, for both intraexaminer and interexaminer reliability.

Table VI. Correlation and statistical evaluation of chronologic age and cervical vertebrae skeletal maturation

Cervical vertebra stage		Chronologic age (y)					Correlation (chronologic age and cervical vertebrae stage)			
		5-9	9-12	12-15	15-18	>18	r	Significance	r	Significance
Stage 1. Initiation	F	18	27	0	0	0	0.82	*	0.72	*
Stage 2. Acceleration	F	19	28	4	0	0				
Stage 3. Transition	F	6	23	10	0	0				
Stage 4. Deceleration	F	0	15	16	2	2				
Stage 5. Maturation	F	0	10	36	10	4				
Stage 6. Completion	F	0	0	23	24	13				
Stage 1. Initiation	M	15	25	14	0	0	0.68	*		
Stage 2. Acceleration	M	4	33	19	0	0				
Stage 3. Transition	M	2	16	19	1	0				
Stage 4. Deceleration	M	0	6	24	2	1				
Stage 5. Maturation	M	0	0	0	10	6				
Stage 6. Completion	M	0	0	0	5	11				

* $P < .001$.

r, Correlation coefficient; F, female; M, male.

Table VII. Correlation and statistical evaluation of chronologic age and hand-wrist skeletal maturation

Hand-wrist stage		Chronologic age (y)					Correlation (chronologic age and hand-wrist stage)			
		5-9	9-12	12-15	15-18	>18	r	Significance	r	Significance
Stage 1. PP2	F	25	21	0	0	0	0.86	*	0.79	*
Stage 2. MP3	F	8	20	0	0	0				
Stage 3. Pisi-H1-R	F	10	32	9	0	0				
Stage 4. S-H2	F	0	11	9	0	0				
Stage 5. MP3cap-PP1cap-Rcap	F	0	21	20	0	0				
Stage 6. DP3u	F	0	0	12	0	0				
Stage 7. PP3u	F	0	0	10	2	0				
Stage 8. MP3u	F	0	0	23	2	0				
Stage 9. Ru	F	0	0	7	33	15				
Stage 1. PP2	M	18	40	5	0	0	0.82	*		
Stage 2. MP3	M	2	21	11	0	0				
Stage 3. Pisi-H1-R	M	1	15	33	0	0				
Stage 4. S-H2	M	0	0	24	1	0				
Stage 5. MP3cap-PP1cap-Rcap	M	0	0	12	2	0				
Stage 6. DP3u	M	0	0	5	2	0				
Stage 7. PP3u	M	0	0	0	1	0				
Stage 8. MP3u	M	0	0	3	5	0				
Stage 9. Ru	M	0	0	0	7	5				

* $P < .001$.

r, Correlation coefficient; F, female; M, male.

The most frequent cervical vertebrae stages in females were stages 5 and 6 (20.7%), followed by stages 2 (17.6%) and 1 (15.5%) (Table IV). Males were more frequently in stages 2 (26.3%) and 1 (25.4%), followed by stages 3 (17.8%) and 4 (15.5%).

For hand-wrist skeletal maturation (Table V), the most frequent stages were stages 1 (29.5%) and 3 (23.0%) in males and stages 9 and 3 (19% and 17.6%, respectively) in females.

The Spearman rank-order correlation coefficient between chronologic age and cervical vertebrae mat-

uration stages was 0.72 for the sexes combined; it was significant at $P < .001$. Statistically significant correlations ($P < .001$) were also found for the male and female subjects: 0.68 and 0.82, respectively (Table VI).

The Spearman rank-order correlation coefficient between chronologic age and hand-wrist maturation stages was 0.79, also statistically significant ($P < .001$). Statistically significant correlations ($P < .001$) were also found for the male and female subjects: 0.82 and 0.86, respectively (Table VII).

Table VIII. Correlation of hand-wrist and cervical vertebrae skeletal maturation

Cervical vertebra stage		Hand-wrist stage									Correlation (hand-wrist and cervical vertebrae)			
		1	2	3	4	5	6	7	8	9	r	Significance	r	Significance
1	F	28	8	9	0	0	0	0	0	0	0.88	*	0.86	*
2	F	13	17	19	0	2	0	0	0	0				
3	F	5	3	12	8	9	2	0	0	0				
4	F	0	0	9	9	11	0	3	2	1				
5	F	0	0	2	2	18	8	4	12	14				
6	F	0	0	0	1	1	2	5	11	40				
1	M	39	7	8	0	0	0	0	0	0	0.78	*		
2	M	16	20	16	3	1	0	0	0	0				
3	M	7	6	14	7	3	1	0	0	0				
4	M	1	1	9	13	5	1	0	3	0				
5	M	0	0	2	1	3	5	1	2	2				
6	M	0	0	0	1	2	0	0	3	10				

* $P < .001$.

r, Correlation coefficient; F, female; M, male.

The correlations between hand-wrist and cervical vertebrae maturation are shown in Table VIII. The Spearman rank-order correlation coefficient with the sexes combined was 0.86; the coefficients for the male and the female subjects were 0.78 and 0.88, respectively. All were statistically significant at $P < .001$.

DISCUSSION

Conventional prediction indicators of maturation overestimate a child's developmental stage and, consequently, underestimate growth potential.²¹ Conversely, comparisons of a child's status with published standards from other countries^{22,23} might overestimate the degree of developmental delay^{24,25} or precocity.^{26,27} Racial variations in the relationships between skeletal maturity established by hand-wrist radiographs and cervical vertebrae were previously reported.^{4,17,28} For that reason, this study was carried out to investigate the relationships among chronologic age, and cervical vertebrae and hand-wrist skeletal maturations of Turkish subjects.

Roman et al²⁸ indicated that the Hassel and Farman classification² can be used to estimate the maturation stage in both sexes, whereas the Lamparski classification⁴ is not sufficiently accurate in males and can be used only in females. The Hassel and Farman classification includes a more detailed description of every stage and uses a limited number of vertebral bodies to perform the staging. In our study, for these reasons, Hassel and Farman's method was used instead of the classification of Lamparski.⁴

Sierra²⁹ found that the relationships between chronologic age and each of the 2 skeletal age assessment methods (Todd Inspectional Method and Ossification

Centers Method) proved to have relatively high correlations, with correlation coefficients ranging from 0.58 to 0.71. In our study, the correlation between chronologic age and skeletal maturation assessed by the cervical-vertebrae and the hand-wrist methods were 0.72 and 0.79, respectively—higher than the those reported by Sierra.²⁹ However, Fishman³⁰ stated that identifiable maturational indicators provide more reliable means of evaluating individualized maturational levels in the wide chronologic age ranges of normally growing children. Thus, the use of skeletal age would be more accurate and thus more clinically beneficial than chronologic age.

The current interest in nonextraction treatment involving modification of skeletal growth seems to require as much information as possible about a patient's growth potential. Orthodontic appliances, ie, activator, Jasper jumper, Herbst, Fränkel, bionator, and Twin-block, as well as cervical and high-pull headgears and protraction facemasks, will have the desired effect only in patients with growth capability. The hand-wrist radiograph has been used classically to determine the level of a child's maturation. To avoid taking additional x-rays, the cervical vertebrae investigation method has been more popular in recent years. Almost all authors found statistically significant correlations between hand-wrist and skeletal maturation of the cervical vertebrae.^{2,4,8,17,28,31} Similarly with the previous reports, the hypothesis that there is no significant difference between the hand-wrist and cervical vertebrae techniques of assessing skeletal maturation in a Turkish population can be accepted as valid at the 95% level for both sexes. This agrees with findings in other popula-

tion groups, suggesting that the cervical vertebrae technique is race neutral.

Regarding sex, our findings agree with those of Lamparski,⁴ Roman et al,²⁸ and Caltabiano et al,³¹ who suggested that this method is more reliable in females than males. Caltabiano et al³¹ found a lower correlation between hand-wrist and vertebral maturation, probably related to a different method of evaluation of hand-wrist maturation, which included the assessment of the carpal bones. Roman et al²⁸ also found lower correlation values between cervical vertebrae and hand-wrist in males. Good correlation was found between hand-wrist skeletal maturation and vertebral maturation in Turkish subjects in both males and females ($r = 0.78$ and 0.88 , respectively), although it was better for females.

The ability to accurately appraise skeletal maturity from the cervical vertebrae, without the need for additional radiographs, could improve orthodontic diagnostic and therapeutic decisions. The technique's simplicity and ease of use should encourage more orthodontists to use this method to assess skeletal maturation.

CONCLUSIONS

In determining the relationships among chronologic age, cervical vertebrae and hand-wrist skeletal maturation of 503 Turkish subjects, the following general conclusions can be drawn.

1. The most frequent cervical vertebrae stages were 5 and 6 (20.7%) in females, and 2 (26.3%) and 1 (25.4%) in males. For hand-wrist skeletal maturation, the most frequent stages were 1 (29.5%) and 3 (23.0%) in males, and 9 and 3 (19% and 17.6%, respectively) in females.
2. A high correlation coefficient was found between chronologic age and cervical vertebrae skeletal maturation. A high correlation was also found in both sexes, although it was significantly better for females.
3. Skeletal maturation evaluated by the hand-wrist method was found to have a high correlation with chronologic age and in both sexes.
4. A high correlation was found between hand-wrist skeletal maturation and vertebral maturation in Turkish subjects according to statistical evaluation.

These findings indicate that, in subjects of Turkish origin, the cervical vertebrae stages method can be used as a maturity indicator of the pubertal growth spurt with a degree of confidence similar to some other indicators such as the hand-wrist radiograph. It is appropriate to use the cervical vertebrae skeletal maturation method in

daily orthodontic diagnostic practice when treating Turkish patients.

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1968 to 1978 B. F. Dewel

1978 to 1985 Wayne G. Watson

1985 to 2000 Thomas M. Graber

2000 to present David L. Turpin