ASSOCIATION BETWEEN DENTAL AND SKELETAL MATURATION STAGES IN CROATIAN SUBJECTS

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SUMMARY – This study investigated the relationships between the stages of calcification of teeth and cervical vertebral maturation. The sample consisted of 295 subjects (129 male and 166 female), mean age 13.36±2.65 (range 7-18) years. Dental age was evaluated from panoramic radiographs according to the method of Demirjian. Cervical vertebral maturation was determined on lateral cephalometric radiographs using cervical vertebrae maturation stages (CVS). For assessing the relationship between cervical vertebral and dental maturation, percentage distributions of the stages of calcification for each studied tooth were calculated. Only in the first CVS stage, boys and girls were of the same age. In all other stages (CVS 2- CVS 6) girls were by 0.98 (range 0.23-1.86) younger than boys. Gender differences in the mineralization pattern were also observed. It was found that dental maturation was finished earlier in female subjects. The highest correlation coefficient between dental and skeletal maturity was found for second premolars. Mineralization pattern of second premolars could be considered as a guideline for prediction of the pubertal growth spurt. Dental maturation stages might be clinically useful as a reliable indicator of facial growth.

Key words: *Tooth – growth and development; Cervical vertebrae – growth and development; Head – radiography; Cephalometry; Croatia*

Introduction

Assessment of skeletal maturity is an important method in the evaluation, treatment planning and outcome of orthodontic treatment in children with growth disorders[1]. Optimal timing for dentofacial orthopedics is closely related to the identification of periods of accelerated growth that can contribute to the correction of skeletal deformities[2], while expecting residual growth after orthodontic treatment might be important in predicting post-treatment rebound[3]. When planning orthodontic or orthopedic treatment in the growing patients, maturational indices have been proposed to evaluate skeletal maturity[4,5]. The maturational changes both in size and shape of cervical vertebrae in growing subjects have gained increasing interest in the last decades as a biological indicator of individual skeletal maturity. Several authors measured dimensional growth modifications in cervical vertebrae on lateral radiographs[6,7], and one of the main reasons for rising the popularity of the method is that the analysis is performed on lateral cephalogram, used routinely in orthodontic diagnosis, with no need of resorting to hand-wrist radiographs.

The greatest response to functional jaw orthopedics tends to occur during the circumpubertal growth period[8,9]. The cervical vertebral maturation method has been proven to be effective to assess the adolescent growth peak (spurt), thus representing a crucial diagnostic tool for rational treatment planning[10-12].

The aim of the present study was to investigate the relationships between the stages of calcification of teeth and the cervical vertebral maturity stages in Croatian subjects. The results from this study will be helpful in determining a valid clinical tool for indica-

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tors of the pubertal growth period and pubertal spurt with no need of resorting (exposing) to hand-wrist radiographs.

Materials and Methods

This research was designed as a retrospective cross-sectional study. The sample was derived from archives of the Department of Orthodontics, University of Zagreb, Croatia, from the records of orthodontic patients. More than one thousand patient files were reviewed. The inclusion criteria were as follows: all patients were Croatians with normal growth and development and free from any systemic disease; no dental anomalies (missing teeth, impaction, transposition); no extractions of permanent teeth (third molars were not considered part of the dentition); no history of orthodontic treatment; no history of trauma of teeth and face; and panoramic and lateral cephalometric radiographs available with high clarity and good contrast. A total of 295 subjects (129 male and 166 female) met the inclusion criteria. The mean age of the sample was 13.36±2.65 (range 7-18) years.

All radiographs were analyzed in a darkened room with a conventional negatoscope by a single examiner (T.S.).

Assessment of dental age

Dental age was evaluated from panoramic radiographs of the mandibular teeth on the left side. Tooth calcification was rated from A to H according to the method of Demirjian *et al.*[13] for each tooth.

Assessment of cervical vertebral maturation index

Cervical vertebral maturation was determined on lateral cephalometric radiographs using cervical vertebrae maturation stages (CVS)[9,14]. The morphology of the bodies of the second (C2), third (C3) and fourth (C4) cervical vertebrae was analyzed. In the evaluation of CVS, the following findings were considered:

1. CVS I – initiation stage of cervical vertebrae
   C2, C3 and C4 inferior vertebral body borders are flat
   C3 and C4 vertebral bodies are trapezoid in shape
2. CVS II – acceleration stage of cervical vertebrae
   concavities at the lower borders of C2 and C3 are present
   lower border of C4 vertebral body is flat
   the bodies of C3 and C4 may be either trapezoid or rectangular in shape
3. CVS III – transition stage of cervical vertebrae
   distinct concavities at the lower borders of C2 and C3 are present
   concavity is developing in the lower border of C4
   the bodies of both C3 and C4 are rectangular in shape
4. CVS IV – deceleration stage of cervical vertebrae
   concavities at the lower borders of C2, C3 and C 4 are still present the bodies of C3 and C4 are nearly square in shape
5. CVS V – maturation stage of cervical vertebrae
   concavities at the lower borders of C2, C3 and C4 are present
   the bodies of C3 and C4 are square in shape
6. CVS VI – completion stage of cervical vertebrae
   deep concavities are present in C2, C3 and C4 lower vertebral body borders
   the bodies of C3 and C4 are greater in height than in width.

Statistical analysis

Statistical analysis was performed with the SPSS software package (SPSS for Windows 98, version 10.0, SPSS Inc., Chicago, IL, USA). Descriptive statistics was done by calculating the means and standard deviations of chronological ages, dental maturity, and cervical vertebral maturity index. The Spearman rank order correlation coefficients were used to assess the relationship between dental and skeletal maturation. For assessing the relationship between cervical vertebral and dental maturation, percentage distributions of the stages of calcification were calculated for each studied tooth.

To assess the reproducibility, 30 randomly selected radiographs, both panoramic and lateral cephalometric (15 male and 15 female), were reevaluated eight weeks later by the same investigator. The results were evaluated by the Spearman-Brown formula.

Table 1. Chronological age distribution of all subjects grouped according to cervical vertebrae maturation stages (CVS)

	Gender	n	Mean	SD
CVS 1	Male	6	9.00	1.26
	Female	2	9.00	1.41
CVS 2	Male	7	9.57	1.72
	Female	3	8.33	0.58
CVS 3	Male	7	11.29	1.60
	Female	14	9.43	1.22
CVS 4	Male	71	13.18	1.98
	Female	61	12.07	1.97
CVS 5	Male	18	15.28	1.49
	Female	43	15.05	1.90
CVS 6	Male	20	15.75	1.59
	Female	43	15.26	1.66
Total		295	13.36	2.65

Results

Distribution of the sample according to chronological ages and CVS for both genders is presented in Table 1. Only in the first CVS, boys and girls were of the same age. In all other stages (CVS 2- CVS 6) girls were by 0.98 (range 0.23-1.86) younger than boys. The greatest between-gender difference in chronological age was found for CVS 4 and the least for CVS 5.

Reliability and stability of all assessments was very good with high coefficient values. For skeletal maturity, coefficients were 0.99, and for dental maturity from 0.98 to 1.0, depending on the evaluated teeth.

Table 2. Correlation coefficients between cervical and dental maturation

	Male		Female	
Tooth	r	Significance	r	Significance
31	0.334	**	0.171	*
32	0.422	**	0.340	**
33	0.600	**	0.567	**
34	0.611	**	0.577	**
35	0.650	**	0.615	**
36	0.445	**	0.380	**
37	0.649	**	0.602	**

*$p<0.05$; **$p<0.01$

The Spearman rank order correlation coefficients between tooth mineralization and CVS was 0.69 for male and 0.71 for female subjects ($p<0.001$) (Table 2).

The percentage of distribution of calcification stages for each tooth, except for third molars, according to gender is presented in Table 3a-c. Gender differences in the mineralization pattern were also observed. It was found that dental maturation was finished earlier in female subjects. The results showed a statistically significant correlation between chronological ages and dental maturity (r=0.844 for female and r=0.826 for male subjects).

The percentage of distribution of calcification stages of each tooth studied and the stages of cervical maturity according to gender was calculated and is presented in Tables 4-10. At CVS 1 (Table 4), the incisor stage H showed the highest percentage distri-

Table 3a. Percent distribution of calcification stages for each studied tooth

	Central incisor				Lateral incisor				Canine			
	Male		Female		Male		Female		Male		Female	
	n	%	n	%	n	%	n	%	n	%	n	%
C												
D									1	0.8		
E					1	0.8			9	7.0	8	4.8
F					3	2.3	3	1.8	15	11.6	13	7.8
G	5	3.9	2	1.2	9	7.0	7	4.2	22	17.1	17	10.2
H	124	96.1	164	98.8	116	89.9	156	94.0	82	63.6	128	77.1
Total	129	100	166	100	129	100	166	100	129	100	166	100

Table 3b. Percent distribution of calcification stages for each studied tooth

	First premolar				Second premolar				First molar			
	Male		Female		Male		Female		Male		Female	
	n	%	n	%	n	%	n	%	n	%	n	%
C	1	0.8			2	1.6						
D	4	3.1	3	1.8	6	4.7	6	3.6				
E	5	3.9	15	9.0	8	6.2	19	11.4				
F	10	7.8	10	6.0	19	14.7	14	8.4				
G	19	14.7	16	9.6	27	20.9	35	21.1	14	10.9	15	9.0
H	90	69.8	122	73.5	67	51.9	92	55.4	115	89.1	151	91.0
Total	129	100	166	100	129	100	166	100	129	100	166	100

Table 3c. Percent distribution of calcification stages for each studied tooth

	Second molar			
	Male		Female	
	n	%	n	%
C	1	0.8		
D	4	3.1	3	1.8
E	5	3.9	15	9.0
F	10	7.8	10	6.0
G	19	14.7	16	9.6
H	90	69.8	122	73.5
Total	129	100	166	100

bution (100% for females and 83.8% for males). A high percentage distribution of the first molar stage G was observed in both genders (100% for females and 66.7% for males). The highest percentage distribution of the first premolar, second premolar, second molar stage E (100%) and canine (66.7%) for females was observed at CVS 2 (Table 5). In male subjects, the distribution was scattered. At CVS 3 (Table 6), the closing of the roots of all teeth was seen in both genders (male 85.7% and female 64.3%), except for central and lateral incisor and first molar. The highest percentage distribution was found for the canine stage F in male subjects. At CVS 4 (Table 7), no mineralization stage C was seen, while mineralization stage D showed exceptionally low percentage distribution. The roots of canines and first premolars were closed. The second molar was in calcification stage G in both genders (male 54.9% and female 50.8%). At CVS 5 (Table 8), no mineralization stages C, D and E were seen. The closing of the roots of all teeth was finished in both genders except for second molars. The percentage distribution was evenly divided for stages G and H in males (50%/50%) and females (46.5%/51.2%). At CVS 6 (Table 9), the second molar root closing was finished in 70% of male and 58.1% of female subjects.

Table 4. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 1

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %
C									16.7				16.7	
D							33.3		16.7	50.0			16.7	50.0
E			16.7		66.7	50.0	33.3	50.0	33.3				66.7	
F					33.3				33.3	50.0				50.0
G	16.7		50.0	50.0		50.0	33.3	50.0			66.7	100		
H	83.3	100	33.3	50.0							33.3			

Table 5. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 2

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %
C							14.3		14.3				28.6	
D					14.3		28.6		42.9				28.6	
E					42.9	33.3		100	14.3	100			14.3	100
F			42.9		28.6	66.7	42.9		14.3				28.6	
G	57.1		14.3	33.3	14.3		14.3		14.3		71.4	100		
H	42.9	100	42.9	66.7							28.6			

Table 6. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 3

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %
C														7.1
D								14.3		28.6				35.7
E						35.7		50.0	28.6	42.9			28.6	14.3
F				14.3	57.1	35.7	42.9	21.4	42.9	14.3			42.9	28.6
G		14.3	14.3	21.4	14.3	21.4	28.6	7.1	14.3	14.3	14.3	35.7	14.3	14.3
H	100	85.7	85.7	64.3	28.6	7.1	28.6	7.1	14.3		85.7	64.3	14.3	

Table 7. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 4

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %
D								1.6	2.8	1.6				4.9
E					2.8	1.6	4.2	6.6	4.2	16.4			8.5	8.2
F				1.6	9.9	9.8	5.6	9.8	18.3	11.5			15.5	21.3
G			5.6	3.3	25.4	16.4	19.7	18.0	31.0	36.1	5.6	6.6	54.9	50.8
H	100	100	94.4	95.1	62.0	72.1	70.4	63.9	43.7	34.4	94.4	93.4	21.1	14.8

Spearman rank order correlation coefficients between cervical vertebral and dental maturation were statistically significant ($p<0.001$) (Table 2). The associations ranged from 0.171 to 0.615 in girls and from 0.334 to 0.649 in boys. There was no gender difference in the sequence from the lowest to the highest association. The sequence was as follows: central incisor, lateral incisor, first molar, canine, first premolar, second molar and second premolar. All correlation coefficients were higher for male than for female subjects.

Discussion

Assessing maturation status, whether the pubertal growth spurt of the patient has been reached or completed, is an important factor in orthodontic diagnosis, treatment planning and predicting post-treatment stability. This study was carried out to determine the relationship between dental development and skeletal maturation stage. Dental eruption has often been considered as an indicator of growth and development. Ac-

Table 8. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 5

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %	m %	f %
F										2.3				2.3
G					5.6	2.3		2.3	11.1	14.0			50.0	46.5
H	100	100	100	1000	94.4	97.7	100	97.7	88.9	83.7	100	100	50.0	51.2

Table 9. Percent distribution of calcification stages of teeth at cervical vertebrae maturation stage 6

	Central incisor		Lateral incisor		Canine		First premolar		Second premolar		First molar		Second molar	
	m %	f%	m %	f%	m %	f%	m %	f%	m %	f%	m %	f%	m %	f%
E														2.3
F								2.3		7.0				2.3
G					5.0	4.7		4.7	5.0	11.6		2.3	25.0	37.2
H	100	100	100	100	95.0	95.3	100	93.0	95.0	81.4	1000	97.7	75.0	58.1

cording to Nolla[15], dental eruption has been reported as more variable than the mineralization sequence in the dentition because of great environmental influence[13]. Therefore, for dental maturity assessment, the method according to Demirjian *et al.*[13] was chosen because of the accuracy in comparison with other known methods. Particularly, this method is based on the shape criteria and the proportion of root length, using the relative value to crown height rather than absolute length. Foreshortened or elongated projections of developing teeth do not affect determinations.

The most commonly used method for assessment of skeletal maturity is hand-wrist radiograph. In the last decade, modifications in the size and shape of cervical vertebrae in growing subjects have gained increasing interest as a biological indicator of individual skeletal maturity[2]; therefore the CVS appears to be a reliable method in prediction of pubertal growth spurt and mandibular growth[16-21]. One of the main reasons for the rising popularity of this method is that it is determined on lateral cephalometric radiographs which are part of patient records, and there is no need for additional x-ray. According to the literature[10,11,22] regarding growth and development, it is well known that the period during CVS 1 and CVS 2 is a pre-peak period, during CVS 3 and CVS 4 is a peak period, and during CVS 5 and CVS 6 is a post-peak period.

The distribution of chronological ages for all subjects, grouped according to CVS showed that the appearance of each CVS occurred earlier in female than in male subjects. The finding from our study that the mean age in each CVS was by 0.98 years higher for girls than for boys is in agreement with the results reported from other studies[2,23-25].

According to the literature, the relationship between dental and skeletal maturity is rather controversial[26-30]. Some authors[26-28] have reported high, while the others[29,30] low or nonsignificant correlations between dental and skeletal maturation. The lack of compatibility could be caused by various sample size, different methods used on dental and skeletal maturity assessment, and different ethnic background. In an attempt to investigate the relationship between tooth mineralization and skeletal maturation, the percentage distribution of calcification stages for all teeth and the stages of cervical maturity was calculated.

In the present study, the maturation patterns of tooth development showed that male subjects tended to be more advanced as compared with females according to CVS. At the same skeletal maturity stage, male subjects had a higher distribution towards late dental stages, except for CVS 1 in which female subjects showed more advanced tooth mineralization. Several authors[1,26-28,31,32] have reported a high correlation be-

tween dental and skeletal maturity, while the others[33,34] report low or nonsignificant correlations. In the present study, the correlation coefficients between dental and skeletal maturity were 0.171-0.650 ($p<0.01$), while Basaran *et al.*[35] in their study found correlations from 0.601 to 0.911. Mineralization of the central and lateral incisor, as well as the first molar showed the weakest correlation with CVS. The correlation coefficient for canines was 0.600 for males and 0.567 for females. In the literature, the mineralization pattern of this tooth is rather controversial. Flores-Mir *et al.*[23] report on the highest degree of correlation between calcification of mandibular canine and skeletal maturation stage MP3 for both genders, while the others[1,28,35] found extremely weak correlation. Subsequently there are the coefficients for first premolar and second molar, which is in concordance with other studies[2,10]. In our study, the highest correlation coefficients, 0.065 for males and 0.615 for females, were found for second premolars. The same results have been reported by Krailassiri *et al.*[28]. On the contrary, in the study by Sierra[36], second premolars showed the lowest correlation, which was explained by the great variety in the morphology and mineralization time of these teeth.

Whereas the highest correlation coefficient between dental and skeletal maturity was found for second premolars, the mineralization pattern of these teeth could be considered as a guideline for prediction of the pubertal growth spurt. Particularly, the growth spurt appears between CVS 3 and CVS 4 and noted mineralization stages of second premolars could be used for its assessment. The mineralization stage E for boys and mineralization stage F for girls coincides with CVS 3. The mineralization stage G for both genders coincides with CVS 4 and announces the period of the growth peak. Therefore, time between mineralization stages F and G for boys and between E and G for girls could be considered as announcement of the pubertal growth spurt. The mineralization stage H, when the apical end of the root canal is completely closed, coincides with CVS 5 and CVS 6 in 80% of the subjects and represents slow or even finished growth.

Conclusion

The results of this study indicate that tooth calcification stages might be clinically used as a maturity indicator of the pubertal growth period. There was a high correlation between dental and skeletal maturity for second premolars in both genders and therefore the mineralization pattern of these teeth could be considered as a guideline in predicting the pubertal growth spurt. We also recommend additional studies in a larger sample size, which could possibly address development of canines and second molars. It could be clinically useful to include relationship between skeletal and dental maturity into orthodontic diagnosis on daily basis when treating patients.

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Sažetak

USPOREDBA DENTALNE I SKELETNE DOBI KOD HRVATSKIH ISPITANIKA

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Cilj ovoga istraživanja bio je odrediti odnos između stupnjeva mineralizacije zuba i stupnjeva skeletne zrelosti. Uzorak se sastojao od 295 ispitanika (129 muških i 166 ženskih). Srednja dob za uzorak je bila 13.36±2.65 (raspon 7-18) godina. Dentalna zrelost je određena metodom ortopantomograma prema Demirjianu. Skeletna zrelost vratne kralježnice određena je na laterolateralnim snimkama glave pomoću stupnjeva maturacije vratne kralježnice (*cervical vertebrae maturation stages*, CVS). Za određivanje odnosa između stupnjeva maturacije vratne kralježnice i zuba izračunata je postotna distribucija stupnjeva mineralizacije za svaki zub. Samo u prvom stupnju CVS dječaci i djevojčice su bili iste kronološke dobi. U svim ostalim stupnjevima (CVS 2-CVS 6) djevojčice su bile 0,98 (raspon 0,23-1,86) mlađe od dječaka. Pronađene su spolne razlike u dobu mineralizacije, naime, mineralizacija zuba završava ranije kod ženskih ispitanika. Najveći stupanj korelacije između dentalne i skeletne dobi pronađen je kod drugih premolara. Vrijeme mineralizacije drugih premolara moglo bi pomoći u predviđanju maksimalnog zamaha pubertalnog rasta. Stupnjevi dentalne zrelosti mogli bi biti pokazatelj kraniofacijalnog rasta.

Ključne riječi: *Zub – rast i razvoj; Kralježnica, cervikalna – rast i razvoj; Glava – radiografija; Kefalometrija; Hrvatska*