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ESTIMATION OF CHRONOLOGICAL AGE, DENTAL AGE AND SKELETAL MATURITY USING ORTHOPANTOMOGRAPHY AND LATERAL CEPHALOGRAMS

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Apstract: The patient's age is one of the most important factors influencing the planning of orthodontic therapy. In some patients, there is a discrepancy between chronological age, dental age and skeletal maturity, which can affect the outcome of orthodontic therapy.
The aim of this work was to determine the correlation between chronological age, dental age and skeletal maturity in subjects of both sexes using orthopantomographic and lateral cephalometric images.
For the purpose of this study, orthopantomographic and lateral cephalometric images of 315 orthodontic patients aged 8 to 18 years were used. Dental age was determined on orthopantomographic images using the Demirjian method, while skeletal maturity was determined on lateral cephalometric images by observing the second, third and fourth cervical vertebrae.
The results of the study showed an extremely strong, positive and statistically significant correlation between dental and chronological age in both sexes ($rs = 0.870$, $N = 315$, $p < 0.05$), with the correlation being stronger in females ($rs = 0.869$). A positive, extremely strong and statistically significant correlation was also found between dental age and the CVM stage of the subjects ($rs = 0.684$, $N = 315$, $p < 0.05$). A statistically significant difference was found in the average dental age between the most of the CVM stages of the subjects ($p < 0.05$). Statistically significant differences in dental maturity were not recorded only between the 1st and 2nd CVM stages, as well as between the 3rd and 4th CVM stages.
Based on the results obtained, it was concluded that there is a strong positive correlation between chronological age, dental maturity and skeletal maturity in subjects of both sexes. The correlation between dental maturity and chronological age was slightly stronger in females than in males.

Keywords: chronological age, dental age, skeletal maturity, orthodontic therapy.

1. INTRODUCTION

The age of the patient is one of the most important factors that influence the planning of orthodontic therapy. Indicators of individual maturity of bone structures are important for defining the start of orthodontic treatment. The application of orthodontic therapy during favorable growth processes can significantly contribute to the efficient and effective improvement of skeletal problems in individual patients [1].

Mobile orthodontic appliances are most often used in children with mixed dentition who are indicated for orthodontic treatment. The transition from deciduous to mixed dentition takes place in three stages. The first stage is known as the stage of early mixed dentition, which is characterized by the presence of the first permanent molars and permanent incisors. The presence of these permanent teeth in the patient's mouth is a necessary condition for ensuring adequate retention of the mobile orthodontic appliance in the patient's mouth.

The second stage, known as the intertransitional phase, includes remodeling of the alveolar extensions of the upper and lower jaw, resorption of the roots of primary molars and primary canines, and further development of permanent teeth. The third stage represents the late mixed dentition, in which the deciduous molars and deciduous canines are replaced [2].

Some studies have shown that there are variations in tooth eruption and the presence of the appropriate stage of primary dentition in relation to the chronological age of the patient. A discrepancy between the chronological age and the dental age of the patient of ± 2 years compared to the average indicates premature or delayed dentition. Since the chronological age and dental age do not match in some patients, it is necessary to determine the individual dental age of the patient. For this purpose, the method of estimating dental age according to the stage of tooth mineralization is most often used. The most commonly used method for assessing dental age and its correlation with bone maturation and the chronological age of the patient is the Demirjian method, which was established on a sample of the French-Canadian population [3-5]. To perform this method, it is necessary to obtain an orthopantomographic image (OPT), and assign an appropriate score to each tooth in the mandibular left quadrant. However, studies by Reddy et al. and Altunsoy et al. have shown that there are deviations from the Demirjian method depending on the ethnicity of the subjects, which is why it is of great importance for planning the start of orthodontic therapy to determine the dental age and bone maturity of the patient [6,7].

Functional orthodontic appliances are used during the period of growth and development because they function on the principle of modifying the growth of skeletal structures. It is very important that their application begins during the period of the pre-pubertal growth spurt so that their effect has the maximum impact on the growth spurt in patients. However, it has been noted that this period can vary among patients and is highly individual. For these reasons, it is important to know the stage of patient's skeletal maturity [8, 9]. The application of the skeletal maturity assessment method in the patient is also of great importance in combined orthodontic-surgical therapy. Starting the therapy before the completion of growth in these patients can lead to subsequent relapses, which lead not only to relapse but also have a negative impact on the patient's mental health [10].

However, the pubertal growth spurt is influenced not only by the patient's age and ethnicity but also by gender, genetics, nutrition, and socioeconomic status. There are three reliable indicators of skeletal maturity: increase in physical height, maturation of the hand joint skeleton, and changes in the morphology of the cervical vertebrae. Since every patient requiring orthodontic treatment needs to obtain an orthopantomographic and lateral cephalometric image for the purpose of determining an accurate diagnosis and treatment plan for a specific abnormality, assessing skeletal maturity by observing the shape of the cervical vertebrae on a lateral cephalometric image is considered the most cost-effective and simplest method [11-13].

Modifications in the size and shape of the cervical vertebrae in growing subjects have gained increasing interest in recent years as a biological indicator of skeletal maturity [14]. The cervical vertebrae maturation (CVM) method has gained importance because the analysis of the cervical vertebrae is performed on a lateral cephalometric image, a type of radiograph routinely available for orthodontic diagnosis. In 1995, Hassel and Farman were the first to propose the use of this method based on the analysis of three vertebral bodies, namely the second (C2), third (C3), and fourth (C4) cervical vertebrae [15].

Baccetti et al. modified the method of determining skeletal maturity into five stages, due to the inability to accurately distinguish the first and second cervical stages [16-18]. Manabe et al. conducted a study on the lateral cephalometric images of 400 patients undergoing orthodontic treatment at the University Hospital of Tokyo. By applying the CVM method to the images, they indicated its importance as a significant indicator of the growth of the upper and lower jaws [19].

The aim of the study was to determine the correlation between chronological age, dental age and skeletal maturity in subjects of both sexes using orthopantomographic and lateral cephalometric images.

2. MATERIAL AND METHOD

The research was approved by the Ethics Committee for Research on Humans and Biological Material of the Faculty of Medicine, University of Banja Luka, Republic of Srpska, Bosnia and Herzegovina (No. 18/4.23/25.). For the purpose of this research, 315 orthopantomographic and lateral cephalometric

images of healthy orthodontic patients aged 8 to 18 years, undergoing orthodontic treatment at the Department of Orthodontics, Faculty of Medicine, University of Banja Luka were used. All subjects signed informed consent for obtaining an orthopantomographic and lateral cephalometric images and their use for scientific research purposes.

2.1. Dental age determination

Dental age was determined on 315 orthopantomographic images using the Demirjian method. The criteria for including images in the study were: good image quality, absence of pathological processes in the lower jaw, absence of irregularities in the teeth shape, position, size, and number of permanent teeth in the lower jaw. Each tooth in the lower left quadrant was assigned one of eight calcification stages (A to H) using the Demirjian method. Based on the sum of the scores obtained for all teeth in the lower left quadrant, the patient's dental age was determined. The OPT image was also used to obtain data on the patient's chronological age.

2.2. Skeletal maturity determination

Determination of skeletal maturity was performed on 315 lateral cephalometric images. The study included images of subjects without congenital malformations in the head and cervical spine, without trauma and surgery in the same region, without systemic diseases or growth and development disorders, without disorders affecting bone development, and where the second (C2), third (C3) and fourth cervical vertebra (C4) could be analysed clearly. The CVM (Cervical vertebrae maturation) method was used to determine skeletal maturity. Using this method, each subject was assigned a stage of bone maturity (Cervical vertebrae maturation stage-CVMS). The first step in applying this analysis was to assess the lower edge of the bodies of these three vertebrae. In CVMS 1, the lower edge of the bodies of all three vertebrae is flat. In CVMS 2, a concavity is observed on the lower edge of the C2 body (notched or recessed), with the concavity of the lower edge of the vertebral body becoming more obvious with maturity. In CVMS 3, similar concavities can also be observed at the lower edges of the C2 and C3 bodies. The second step in the analysis was to assess the shape of the C3 and C4 bodies. The bodies of the second, third, and fourth cervical vertebrae change shape in a typical sequence, progressing from trapezoidal and rectangular horizontal shapes through square shapes to rectangular vertical shapes. In stages CVMS 1 to CVMS 3, most of the bodies of the third and fourth vertebrae have a trapezoidal shape, but in CVMS 3, one of the vertebral bodies may have a rectangular horizontal shape in a limited number of subjects. The bodies of C3 and C4 are rectangular horizontal, then square in CVMS 5, and rectangular vertical in CVMS 6. Determination of dental age and skeletal maturity was performed by a single experienced researcher.

2.3. Statistical analysis

The statistical package IBM SPSS Statistics 20 and Microsoft Excel 2016 were used for data analysis. Descriptive statistics indicators (arithmetic mean, standard deviation, extreme values, confidence interval) were used to express the values of chronological, dental and skeletal age. The significance of the differences in mean values between the tested methods was determined by parametric analysis of variance (ANOVA) and post hoc analysis (Tukey post hoc test). The correlation of the tested parameters was determined by Spearman's correlation analysis.

3. RESULTS

The total number of subjects included in this study was 315, of which 141 (44.8%) were male and 174 (55.2%) were female. The minimum chronological age of the subjects was 8.0 years, while the maximum was 18.0 years. The average chronological age of the subjects was 12.113 years, with a standard deviation of ± 2.40 years and a variance of 5.76 years (Table 1).

Table 1. *Descriptive statistics indicators for chronological age*

	N	Range	Min.	Max	Mean	SE	SD	Variance
Total	315	10.0	8.0	18.0	12.113	.1352	2.4002	5.761
Male	141	9.5	8.0	17.5	11.772	.1978	2.3492	5.519
Female	174	10.0	8.0	18.0	12.390	.1829	2.4122	5.819

The minimum dental age of all subjects was 6.2 years, and the maximum was 16.7 years. The average dental age of all subjects was 12.078 years, with a standard deviation of ± 2.43 years and a variance of 5.91 years (Table 2).

Analysis of the results of Spearman's correlation between dental and chronological age indicated an extremely strong, positive and statistically significant correlation in both sexes (rs = 0.870, N = 315, $p < 0.05$). However, in females, the correlation between dental and chronological age was slightly stronger (rs = 0.869) (Table 3).

Table 4 shows the distribution of the subjects by gender and CVM stages. It was observed that the largest number of female orthodontic patients (41) was in CVMS 5. This is 13.0% of the total number of subjects, 58.6% of the total number of subjects with CVM stage 5 and 23.6% of the total number of female subjects. The largest number of orthodontic patients included in this study, 70 (22.2%) of the total number, belongs to CVMS 5.

Based on the results of Spearman's correlation analysis, it was determined that there is a positive, extremely strong and statistically significant correlation between dental age and CVMS of the subjects (rs = 0.684, N = 315, $p < 0.05$) (Chart 1).

Table 2. *Descriptive statistics indicators for dental age*

	N	Range	Min.	Max	Mean	SE	SD	Variance
Total	315	10.5	6.2	16.7	12.078	.1370	2.4311	5.910
Male	141	9.7	6.2	15.9	11.618	.2106	2.5010	6.255
Female	174	8.9	7.8	16.7	12.450	.1754	2.3139	5.354

Table 3. *Results of the correlation between dental and chronological age by gender*

Gender	Number	*rs* coefficient	*p* value
Male	141	0.850	< 0.05*
Female	174	**0.869**	< 0.05*
Total	315	0.870	< 0.05*

Table 4. *Distribution of subjects by gender and CVM stage*

Gender	Indicator	CVMS						Total
		1	2	3	4	5	6	
Male	Number	22	35	29	22	29	4	141
	% within gender	15.6%	24.8%	20.6%	15.6%	20.6%	2.8%	100.0%
	% within CMVS	56.4%	63.6%	42.0%	40.7%	41.4%	14.3%	44.8%
	% of total	7.0%	11.1%	9.2%	7.0%	9.2%	1.3%	44.8%
Female	Number	17	20	40	32	41	24	174
	% within gender	9.8%	11.5%	23.0%	18.4%	23.6%	13.8%	100.0%
	% within CMVS	43.6%	36.4%	58.0%	59.3%	58.6%	85.7%	55.2%
	% of total	5.4%	6.3%	12.7%	10.2%	13.0%	7.6%	55.2%
Total	Number	39	55	69	54	70	28	315
	% within gender	12.4%	17.5%	21.9%	17.1%	22.2%	8.9%	100.0%
	% within CMVS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	% of total	12.4%	17.5%	21.9%	17.1%	22.2%	8.9%	100.0%

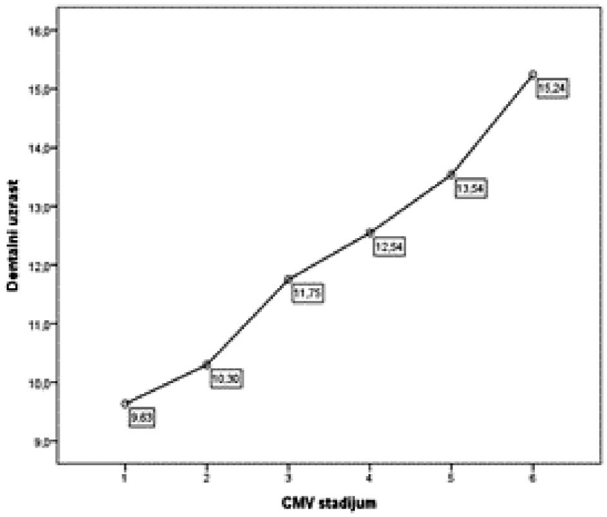

Chart 1. *Average dental age values by individual CVM stage*

Table 5 shows the results of the ANOVA analysis ($p < 0.05$) and indicates that there was a statistically significant difference in dental age among patients at different CVM stages.

Table 5*. ANOVA test results*

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	855.713	5	171.143	**52.878**	**.000**
Within groups	1000.092	309	3.237		
Total	1855.804	314			

Based on the previous results, it was determined that there were statistically significant differences between the CVMS in average dental age. However, Table 6 present the results of multiple comparisons, showing which CVMS groups differed significantly in dental maturity. By applying the Tukey post hoc test from the table below, it was observed that there was a statistically significant difference in average dental age between most of the CVMS of the subjects ($p < 0.05$). Statistically significant differences in dental age were not recorded only between CVMS 1 and 2, as well as between CVMS 3 and 4.

Table 6*. Tukey post hoc test results*

(I) CVMS	(J) CVMS	Mean Difference (IJ)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.6648	.3766	.490	-1.745	,415
	3	-2.1159*	.3604	**.000**	-3.149	-1.082
	4	-2.9111*	.3781	**.000**	-3.995	-1,827
	5	-3.9024*	.3595	**.000**	-4.933	-2,872
	6	-5.6095*	.4456	**.000**	-6.887	-4.332
2	1	.6648	.3766	.490	-.415	1.745
	3	-1.4511*	.3252	**.000**	-2.384	-.519
	4	-2.2463*	.3446	**.000**	-3.235	-1.258
	5	-3.2375*	.3242	**.000**	-4.167	-2.308
	6	-4.9447*	.4177	**.000**	-6.142	-3.747
3	1	2.1159*	.3604	**.000**	1.082	3.149
	2	1.4511*	.3252	**.000**	.519	2.384
	4	-.7952	.3269	.148	-1.733	.142
	5	-1.7864*	.3052	**.000**	-2.662	-.911
	6	-3.4936*	.4031	**.000**	-4.650	-2.338
4	1	2.9111*	.3781	**.000**	1.827	3.995
	2	2.2463*	.3446	**.000**	1.258	3.235
	3	.7952	.3269	.148	-.142	1.733
	5	-.9913*	.3258	**.030**	-1.926	-.057
	6	-2.6984*	.4190	**.000**	-3.900	-1.497
5	1	3.9024*	.3595	**.000**	2.872	4.933
	2	3.2375*	.3242	**.000**	2.308	4.167
	3	1.7864*	.3052	**.000**	.911	2.662
	4	.9913*	.3258	**.030**	.057	1.926
	6	-1.7071*	.4023	**.000**	-2.861	-.554
6	1	5.6095*	.4456	**.000**	4.332	6.887
	2	4.9447*	.4177	**.000**	3.747	6.142
	3	3.4936*	.4031	**.000**	2.338	4.650
	4	2.6984*	.4190	**.000**	1.497	3.900
	5	1.7071*	.4023	**.000**	.554	2.861

*. The mean difference is significant at the 0.05 level.

4. DISCUSSION

For adequate planning of orthodontic therapy, it is necessary to determine both the dental maturity and skeletal maturity of the patient. Determining the aforementioned parameters is of great importance, especially in younger patients who are still in the period of growth and development. In addition to dentistry and orthodontics, determining dental age is important in forensic medicine [20].

Although numerous studies have questioned the applicability of the Demirjian method for determining dental age in different populations, there is still no standardized method that would be used in our population. For these reasons, the Demirjian method was chosen for determining dental age in this study [21-23].

The aim of this research was to determine the correlation between chronological, dental and skeletal age of male and female subjects based on orthopantomographic and lateral cephalometric images. The results showed an extremely strong correlation between dental and chronological age, which was stronger in female subjects. A study by Cruz-Landeira et al., conducted on Spanish and Venezuelan subjects, also indicated a strong correlation between the dental and chronological age of subjects, which is consistent with the results of this study. However, the authors concluded that the Demirjian method applied to the studied populations is not sufficiently precise in determining dental age [24].

The CVM method was used to determine skeletal maturity, which is not only applied in clinical practice but is also frequently used for scientific purposes. In this study, a strong correlation was found between the dental and skeletal maturity of the subjects, which is in accordance with the results of the studies by Hashim et al. and Macha et al., who also found a strong correlation between dental age and skeletal age in their subjects [25,26]. Also, some studies have indicated a strong association between dental age and skeletal age determined using the CVM method [27-29].

Ojha et al. found a strong correlation between the maturation phase of the cervical vertebrae and the calcification phases of the canine, first premolar, second premolar and second molar using Demirjian's method [30]. On the other hand, some authors pointed to a very strong correlation between dental age and skeletal maturity determined by using a hand scan. Thus, Jouerih et al. went a step further and recommended the use of certain developmental grades of canines and second molars using the Demirjian method as indicators of skeletal maturity and emphasized their great diagnostic value in everyday practice [31].

Chen et al., in their study, which was conducted on orthopantomographic images and lateral cephalometric images of 302 patients, found a significant correlation between the stages of dental calcification and the stage of cervical vertebrae maturation. The development of the second mandibular molar in female subjects and the mandibular canine in male subjects had the strongest correlation with cervical vertebrae maturity. The authors point out the practicality of using the images in planning orthodontic treatment and determining dental and skeletal maturity [32].

Cummaudo et al. point out that despite the large number of studies based on determining dental and skeletal maturity using radiographs, there is no consensus on the acceptability of using the same methods for different populations. The authors highlighted the influence of genetic but also socio-economic factors on the growth and development of individuals [33]. However, the results of this study also indicated the existence of statistically significant differences between the dental ages of the subjects within the corresponding stages of skeletal maturity. Statistically significant differences in dental maturity were not recorded only between CVM stages 1 and 2 as well as between CVM stages 3 and 4. Such deviations could be attributed to the applicability of the Demirjian method to our population, which is why further studies should include a larger sample size and assess the applicability of this method to it. In this way, the correlation between chronological, dental and skeletal age in our population could be determined more precisely.

5. CONCLUSION

Based on the results obtained, we can conclude that there is a strong positive correlation between chronological age, dental age and skeletal maturity in both sexes. The correlation between dental and chronological age was slightly stronger in females than in males.

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ПРОЦЈЕНА ХРОНОЛОШКЕ СТАРОСТИ, ДЕНТАЛНЕ СТАРОСТИ И СКЕЛЕТНЕ ЗРЕЛОСТИ ПРИМЈЕНОМ ОРТОПАНТОМОГРАФСКОГ И ПРОФИЛНОГ КЕФАЛОМЕТРИЈСКОГ СНИМКА

Сажетак: Старост пацијента представља један од најважнијих фактора који утичу на планирање ортодонтске терапије. Код неких пацијената постоји неусклађеност између хронолошке старости, денталне старости и зрелости скелета што може утицати на крајњи исход ортодонтске терапије.
Циљ овог рада био је да се утврди корелација између хронолошке старости и денталне старости и зрелости скелета код испитаника оба пола коришћењем ортопантомографских и профилних кефалометријских снимака.
За потребе ове студије коришћени су ортопантомографски и профилни кефалометријски снимци 315 ортодонтских пацијената узраста од 8 до 18 година. Дентална старост одређена је на ортопантомографским снимцима методом по Demirjian-у, док је на профилним кефалометријским снимцима одређена скелетна зрелост посматрањем другог, трећег и четвртог вратног пршљена.
Резултати истраживања су показали постојање изразито снажне, позитивне и статистички значајне корелације између денталне и хронолошке старости код оба пола ($rs = 0,870$, $N = 315$, $p < 0,05$) иако је код женског пола повезаност била снажнија ($rs = 0,869$). Између денталне старости и стадијума коштане зрелости испитаника је такође утврђена позитивна, изразито снажна и статистички значајна корелациона веза ($rs = 0,684$, $N = 315$, $p < 0,05$). Статистички значајна разлика утврђена је у просјечној денталној старости између већине стадијума коштане зрелости испитаника ($p < 0,05$). Статистички значајне разлике у денталној старости нису евидентиране једино између првог и другог стадијума коштане зрелости, као и између трећег и четвртог стадијума коштане зрелости.
На основу добијених резултата закључено је да постоји снажна позитивна корелација између хронолошке старости, денталне старости и скелетне зрелости код испитаника оба пола. Корелација између денталне старости и хронолошке старости је код женског пола била мало јача у односу на мушки пол.

Кључне ријечи: хронолошка старост, дентална старост, скелетна зрелост, ортодонтска терапија

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