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EVALUATION OF SKELETAL MATURATION BY COMPARING THE HAND-WRIST MATURATION AND CERVICAL VERTEBRAE MATURATION IN A PORTUGUESE POPULATION

Avaliação da maturação esquelética de uma população portuguesa através da comparação da análise da Radiografia da Mão e das Vértebras Cervicais

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Evaluation of Skeletal Maturation by Comparing The Hand-Wrist Maturation and Cervical Vertebrae Maturation in a Portuguese Population

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ABSTRACT

Objective: The objective of this study is to evaluate the correlation between chronological age, cervical vertebral maturation and hand-wrist skeletal maturity indicators in a Portuguese children sample.

Materials and Methods: Two hundred and eighty five contemporary hand-wrist and lateral cephalometric radiographs of Portuguese subjects were randomly selected and analyzed. The subjects' age ranged from 7 to 16 years old and all them were within the circumpubertal period. The cervical vertebral skeletal maturation was assessed using the method developed by Baccetti and co-workers. The hand-wrist skeletal maturation was assessed using the method developed by Grave and Brown. These two methods and the chronological age were correlated using the Spearman rank-order correlation coefficient analysis.

Results: The cervical vertebrae maturation was significantly correlated with the hand-wrist skeletal maturation (male r_s = 0.806, female r_s = 0.803). Strong correlations were found between the cervical vertebrae maturation and chronological age (male r_s = 0.778; female r_s = 0.788) and between the hand-wrist maturation and chronological age (male r_s = 0.820; female r_s = 0.847).

Conclusions: These results suggest that cervical vertebrae skeletal maturation method and hand-wrist skeletal maturation method have a strong statistical correlation in Portuguese subjects. Therefore is appropriate the use of the cervical vertebrae skeletal maturation method in daily orthodontic practice when treating Portuguese patients, thus avoiding additional radiation exposure. In the same way, the strong correlation between chronological age and hand-wrist skeletal maturation indicators suggest that within certain limits chronological age might be used to determine the skeletal stage of a given subject.

KEY WORDS: Cervical vertebral maturation; Hand-wrist maturation; Skeletal maturity; Chronological age

RESUMO

Objetivo: O objetivo deste estudo é estabelecer a correlação entre a idade cronológica, a maturação esquelética das vértebras cervicais e a maturação esquelética da mão e punho numa amostra de crianças portuguesas.

Materiais e Métodos: Foram selecionadas e analisadas de forma aleatória duzentos e oitenta e cinco radiografias da mão e punho e telerradiografias de perfil de crianças portuguesas. Os indivíduos do sexo feminino e masculino tinham entre 7 e 16 anos de idade e todos se encontravam no período circumpubertal. A maturação esquelética das vértebras cervicais foi avaliada através do método desenvolvido por Baccetti e colaboradores, enquanto que a maturação esquelética da mão e punho foi avaliada através do método desenvolvido por Grave e Brown. Ambos os métodos foram correlacionados com a idade cronológica através do coeficiente de correlação de postos de Spearman.

Resultados: A maturação esquelética das vértebras cervicais foi correlacionada significativamente com a idade óssea da mão e punho (r_s masculino = 0,806, r_s feminino = 0,803). Foi determinada uma forte correlação entre a maturação das vértebras cervicais e idade cronológica (r_s masculino = 0,778; r_s feminino = 0,788) e entre a maturação da mão e punho e idade cronológica (r_s masculino = 0,820; r_s feminino = 0,847).

Conclusões: Estes resultados demonstram que na amostra portuguesa existe uma forte correlação entre a maturação esquelética determinada a partir das vértebras cervicais e a maturação esquelética determinada a partir da mão e punho. Deste modo, é justificável a utilização do método de determinação da maturação esquelética através das vértebras cervicais na prática ortodôntica, no tratamento de crianças portuguesas, evitando assim exposição a radiação adicional. De igual modo, a forte correlação entre a idade cronológica e os estados de maturação esquelética da mão e punho e entre a idade cronológica e os estados de maturação esquelética das vértebras cervicais sugere que, dentro de certos limites, a idade cronológica pode ser utilizada para determinar o estado de maturação esquelética de um dado indivíduo.

PALAVRAS-CHAVE: Maturação das vértebras cervicais; Maturação da mão e punho; Maturação esquelética Idade cronológica

INTRODUCTION

The optimal timing for dentofacial orthopedics links up with the identification of periods of accelerated or intense growth that can contribute significantly to the skeletal imbalances correction in a patient face (1–3). Therefore the skeletal maturation status of a growing patient influences the selection and execution of treatment procedures (4). However, the orthodontist do not necessarily needs to know the exact patient's skeletal age, how much individual facial bones may grow during treatment, or even when that growth is likely to occur. He simply needs to know whether the patient will grow at all during the treatment period, usually one or two years, and what percentage of growth can reasonably be expected during that time (5).

A child's developmental status is usually assessed in relation to events that take place during the growth progress (6) but, due to individual variation, physiological and anatomical maturity cannot be accurately assessed by age alone itself (5). Chronological age; dental development; height and weight measurements; sexual maturation characteristics like menarche, increase in breast size, sexual hair or voice changes (7); and skeletal development are some biological indicators that have been used to identify growth stages (1,6,8-9). However, according to many authors, dental development indicators are not reliable predictors of a patient's skeletal development stage, and chronological age is also unreliable in the prediction of the pubertal spurt (1). Therefore, because of individual variations on timing, duration and velocity of growth, the determination of maturation and subsequent evaluation of growth potential during preadolescence or adolescence are extremely important and essential in formulating viable dentofacial orthopedic and orthodontic treatment plans (10).

The skeletal maturation staging, determined by radiographic analysis, is a widely used method for predicting the timing of pubertal growth and for estimating growth rate, as well as the remaining growth (1,2).

The hand-wrist is considered to be the most standardise method of assessing skeletal maturation (2,11–13). Its main drawback is that each patient, undergoing orthodontic treatment, besides a lateral cephalometric radiograph, which is routinely taken before any treatment, will have to do an additional hand-wrist radiograph. Although minimal radiation is associated with this type of radiograph, it would be ideal to assess the growth stage without submitting the patient to another radiation exposure (8). However there are some limitations to the interpretation of skeletal maturity assessed through this method: the ossification sequence and timing of skeletal maturity within the hand-wrist area reveal polymorphism and sexual dimorphism, which can limit the clinical predictive use of the method and although the events in the hand and wrist signal the maxim and the end of the pubertal growth spurt, they do not signal the onset of the pubertal growth spurt (2).

Skeletal maturation evaluation using cervical vertebrae has gained rising popularity due to the advantage of eliminating additional radiation exposure because the cervical vertebrae are visualized on the lateral cephalometric radiograph (1–23); and it is well known that as cervical vertebrae bodies changes with growth (2), maturation changes can be observed in a lateral view of cervical vertebrae from birth to full maturity (6).

However, this method is not sensitive in detecting the growth maturity in periods away from the growth spurt (9). In 1972, Lamparsky developed the first method to assess skeletal age through the cervical vertebrae, concluding that cervical vertebrae evaluation was statistically and clinically as reliable in assessing skeletal age as the hand-wrist technique (14). Since then the cervical vertebrae maturation (CVM) method have been consecutively modified by authors as Hassel and Farman (10), San Roman (8) or Baccetti (23). The relationships between skeletal maturation determined by cervical vertebrae and hand-wrist radiographs have been reported in various populations (1).

The present study objectives are: assess the correlation between chronologic age and maturation of cervical vertebrae; identify the relationship between chronologic age and maturation stage evaluated by hand-wrist radiographs; and determine whether the maturation of cervical vertebrae correlates with the maturation indicated by hand-wrist radiographs in a sample of Portuguese subjects.

MATERIALS AND METHODS

The study group consisted of 285 subjects (171 females and 114 males) that attended the Orthodontic Department consultation at Dental Medicine Area, Faculty of Medicine, University of Coimbra. The subjects' age ranged from 7 to 16 years old with a mean age of 14.45 ± 2.12 years for females and 11.99 ± 2.04 years for males. The subjects' distribution by chronological age and gender is shown in Table I.

Each subject had to fulfill the following criteria: Caucasian; no general developmental anomaly; and no abnormal cervical vertebral bodies or abnormal hand and wrist bones.

Table I. Frequency distribution of subjects by age groups and gender

		Gender		Total
		Female	**Male**	
	[7-9[	12	4	16
	[9-10[	23	9	32
	[10-11[	23	15	38
Choronological Age (*y*)	[11-12[	30	23	53
	[12-13[	32	17	49
	[13-14[	19	17	36
	[14-15[	16	14	30
	[15-16]	16	15	31
Total		171	114	285

The material used in the study comprised good-quality left hand-wrist radiograph and lateral cephalometric radiograph of each study subject taken on the same date. All radiographic analyses were performed with a light box in a darkened room to ensure contrast enhancement of the bone images. Each hand-wrist radiograph was evaluated and classified according to the Grave and Brown method (24), and all skeletal maturation indicators (SMI) of this method are illustrated in Table II and Figure 1. The cervical vertebrae maturation was evaluated using the method developed by Baccetti (15). This method depends on the anatomical changes of the three cervical vertebrae C2, C3, and C4, which were visually evaluated accordingly to two sets of variables: the presence or absence of a concavity at the inferior border of the C2, C3, and C4; and the shape of the body of C3 and C4 as age progresses (trapezoid, rectangular horizontal, square, and rectangular vertical). The six stages of this method are shown in Table III and Figure 2 (15).

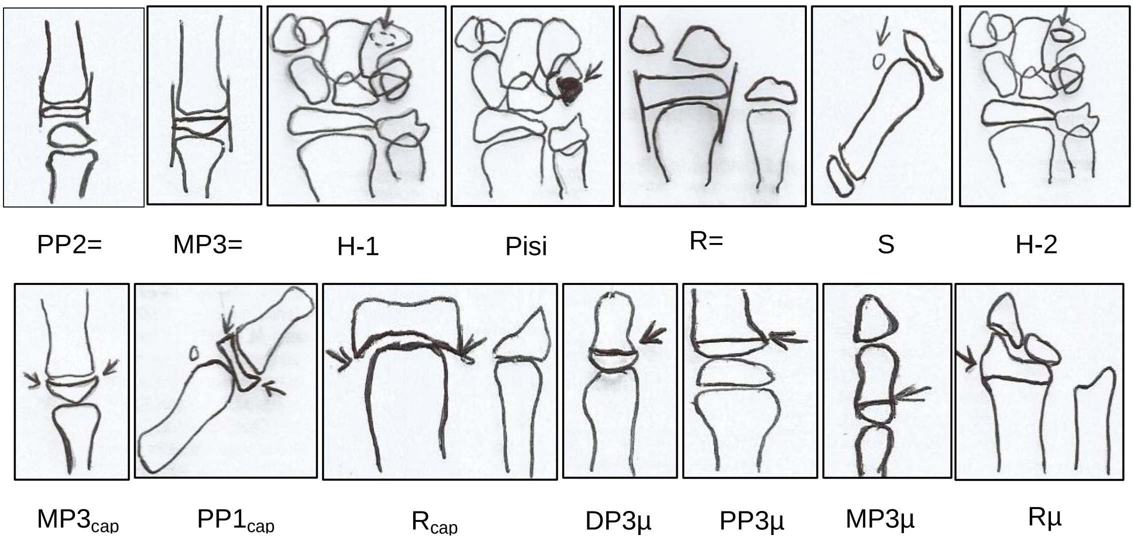

Figure 1: Schematic representation of the Hand-wrist SMI according to the Grave and Brown method

Table II. Hand-wrist SMI according to the Grave and Brown method

		Ossification event
1	*PP2=*	Epiphysis of proximal phalanx of second finger is as wide as its diaphysis
2	*MP3=*	Epiphysis of middle phalanx of third finger is as wide as its diaphysis
3	*H-1*	Hooking of hamate (stage 1)
4	*Pisi*	Appearance of pisiform
5	*R=*	Epiphysis of radius is as wide as its diaphysis
6	*S*	Appearance of ulnar sesamoid
7	*H-2*	Hooking of hamate (stage 2)
8	$MP3_{cap}$	Epiphysis of middle phalanx of third finger caps its diaphysis
9	$PP1_{cap}$	Epiphysis of proximal phalanx of first finger caps its diaphysis
10	R_{cap}	Epiphysis of radius caps its diaphysis
11	$DP3_{u}$	Complete epiphyseal union of distal phalanx of third finger
12	$PP3_{u}$	Complete epiphyseal union of proximal phalanx of third finger
13	$MP3_{u}$	Complete epiphyseal union of middle phalanx of third finger
14	R_{u}	Complete epiphyseal union of radius

Table III. The six CVM stages according to the Baccetti method

	Inferior vertebral body border	Shape of the body C3 and C4	Peak in mandibular growth
CVMS I	C2, C3, C4 flat	C3, C4 trapezoids	2 years after this stage
CVMS II	C2 concave; C3, C4 flat	C3, C4 trapezoids	1 year after this stage
CVMS III	C2, C3 concave; C4 flat	C3, C4 trapezoid or rectangular horizontal	During the year after this stage
CVMS IV	C2, C3, C4 concave	C3, C4 rectangular horizontal	1 or 2 years before this stage
CVMS V	C2, C3, C4 concave	C3 or C4 squared. If not squared, the body of the other still is rectangular horizontal	Ended at least 1 year before this stage
CVMS VI	C2, C3, C4 concave	C3 or C4 rectangular vertical. If not rectangular vertical, the body of the other is squared	Ended at least 2 years before this stage.

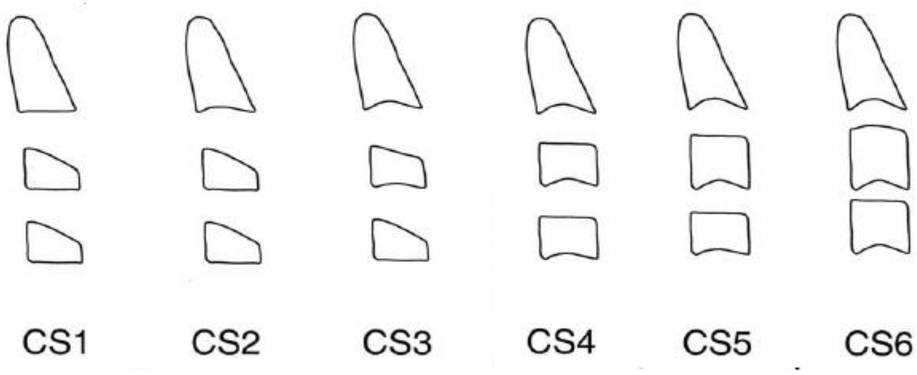

Figure 2. Schematic representation of the six CVM stages according to the Baccetti method (picture taken from the article (16))

The lateral cephalometric radiographs and hand-wrist radiographs of all the 285 subjects were evaluated by two examiners (examiner A and B) for skeletal maturation staging according to Baccetti and to Grave and Brown method, respectively. Efforts were made to make the research process as blind as possible: when rating hand-wrist SMI each examiner was blind to the cervical vertebrae maturation stages (CVMS) and vice-versa.

To assess intra and inter-examiner reliability, 15 hand-wrist radiographs and 15 lateral cephalometric radiographs were randomly selected and read by each examiner independently and accordingly to the evaluation criteria. The time interval between two independent assessments of the same image was one week. Therefore, a total of 60 measurements, 30 for each examiner, were performed.

A statistician completed the statistic analysis without specific knowledge of the coding for the maturation stages and all analyses were performed with a software package (IBM SPSS Statistics v. 21). To assess intra-examiner and inter-examiner reproducibility of the ratings for both methods, the kappa coefficient was used (25). Descriptive statistics were obtained by calculating the mean chronologic age for each of the 6 CVMS and each of the 14 hand-wrist SMI. The Spearman rank-order correlation coefficient (r_s) was used to assess the relationship between hand-wrist maturation and chronologic age and between cervical vertebrae and hand-wrist maturation.

RESULTS

The reproducibility of all assessments was almost perfect, with strong coefficient values. As to the hand-wrist SMI, the results obtained revealed an almost perfect inter-examiner agreement (k=0.918 for the first evaluation and k=0.836 for the second), as well as an almost perfect intra-examiner agreement (k=1 for examiner A and k=0.918 for examiner

B). As to the CVMS, also both inter-examiner agreement (*k*=0913 in both evaluations) and intra-examiner agreement were almost perfect (*k*=1 for both examiners) (25).

Table IV. Hand-wrist SMI inter-examiner agreement

			Confidence Interval (95%)		
	Kappa coefficient	**Standard error (SE of *K*)**	**Lower Limit**	**Upper limit**	**Weighted *K***
First evaluation	0.918	0.077	0.768	1.068	0.975
Second evaluation	0.836	0.101	0.638	1.034	0.951

Table V. Hand-wrist SMI intra-examiner agreement

			Confidence Interval (95%)		
	Kappa coefficient	**Standard error (SE of *K*)**	**Lower Limit**	**Upper limit**	**Weighted *K***
Examiner A	1				
Examiner B	0.918	0.078	0.766	1.069	0.975

Table VI. CVMS inter-examiner agreement

			Confidence Interval (95%)		
	Kappa coefficient	**Standard error (SE of *K*)**	**Lower Limit**	**Upper limit**	**Weighted *K***
First evaluation	0.913	0.083	0.75	1.077	0.955
Second evaluation	0.913	0.083	0.75	1.077	0.955

Table VII. CVMS intra-examiner agreement

			Confidence Interval (95%)		
	Kappa coefficient	**Standard error (SE of *K*)**	**Lower Limit**	**Upper limit**	**Weighted *K***
Examiner A	1				
Examiner B	1				

I. Analysis and correlation between hand-wrist maturation and chronologic age

According to table IV, hand-wrist maturation in both gender groups showed a statically significant difference, confirmed by the non-parametric Krustal-Wallis test (whole sample) and the non-parametric ANOVA (for independent gender). The most frequent hand-wrist SMI in females was R_{cap} (*n* = 38) with a mean chronological age of 11.63 ± 1.13, followed by indicators R_{μ} (*n* = 27) and PP2= (*n* = 20). For males the most frequent indicator was PP2= (*n* = 22) with a mean chronological age of 9.77 ± 1.07, followed by indicators R_{cap} (*n* = 19) and Pisi (*n* = 18). In the whole sample, the most frequent hand-wrist indicator was R_{cap} (*n* = 57), followed by indicators PP2= (*n* = 42) and Pisi (*n* = 31).

The non-parametric Mann-Whitney U test confirmed a statistically significant difference in mean chronological age between males and females for PP2= (p = 0,001), Pisi (p = 0,02), H-2 (p < 0,01), $PP1_{cap}$ (p =0,03), R_{cap} (p <0,001) and $MP3_{\mu}$ (p <0,001) indicators. A striking feature observed was that female maturation development occurred earlier than their male counterparts. (Figures 3 and 4)

The mean age for the onset of the pubertal growth spurt was 8.45±1.09 years for females and 9.77±1.07 years for males at PP2=. Females completed skeletal maturation at a mean age of 14.26±1.26 years while males completed their skeletal maturation at a mean age of 14.67±0.58 years at Rµ, indicating that growth spurt duration is longer in males as compared to their female counterparts.

The Spearman rank-order correlation coefficient revealed strong relationships between chronologic age and hand-wrist SMI for the whole group (r_s = 0.752); and for the male (r_s = 0.820) and female groups (r_s = 0.847); with p < 0.0001 considered statistically significant for all groups (Table VIII).

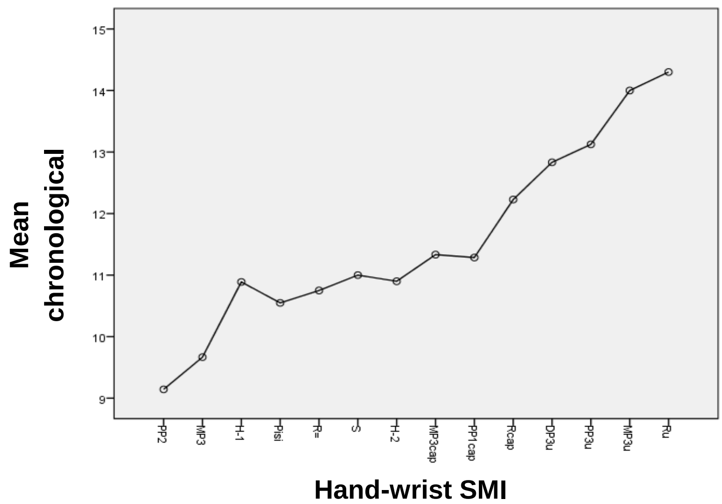

Figure 3. Mean chronological age versus hand-wrist maturation

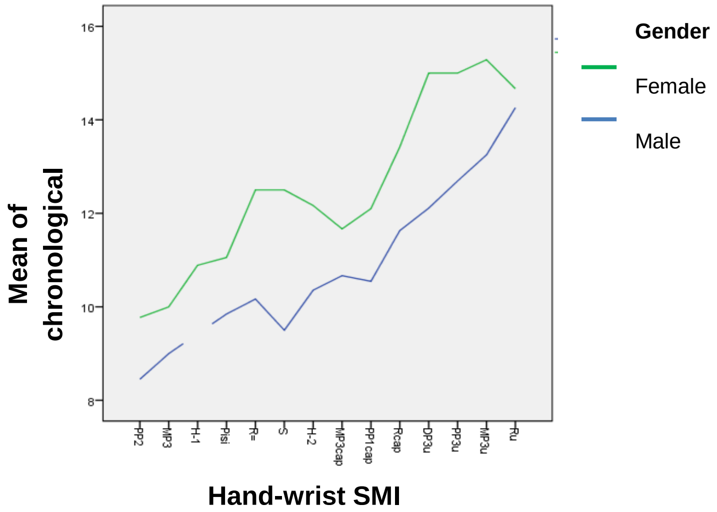

Figure 4. Gender differences in mean chronological age and hand-wrist maturation

Table VIII. Subjects classified according to the Grave and Brown method

Gender		**Female**			**Male**			**Total**		
		n	**Mean**	**SD**	***n***	**Mean**	**SD**	***n***	**Mean**	**SD**
Hand-wrist SMI	**PP2=**	20	8,45**	1,10	22	9,77**	1,07	42	9,14	1,26
	MP3=	1	9,00	.	2	10,00	1,41	3	9,67	1,16
	H-1				9	10,89	1,36	9	10,89	1,36
	Pisi	13	9,85*	1,21	18	11,06*	1,31	31	10,55	1,39
	R=	6	10,17	0,75	2	12,50	0,71	8	10,75	1,28
	S	4	9,50	1,00	4	12,50	1,29	8	11,00	1,93
	H-2	14	10,36**	1,08	6	12,17**	1,17	20	10,90	1,37
	$MP3_{cap}$	3	10,67	0,58	6	11,67	1,21	9	11,33	1,12
	$PP1_{cap}$	11	10,55*	1,37	10	12,10*	1,45	21	11,29	1,59
	R_{cap}	38	11,63**	1,13	19	13,42**	1,07	57	12,23	1,39
	$DP3_u$	9	12,11	1,27	3	15,00	1,00	12	12,83	1,75
	$PP3_u$	13	12,69	1,25	3	15,00	0,00	16	13,13	1,46
	$MP3_u$	12	13,25**	0,97	7	15,29**	0,76	19	14,00	1,33
	R_u	27	14,26	1,26	3	14,67	0,58	30	14,30	1,21
	Total	171	11,45	2,12	114	11,99	2,04	285	11,67	2,10
Correlation Coefficient (r_s)			,847***			,820***			,752***	

Notes: *p < 0,05; **p < 0,01. *** Correlation is significant at the 0,01 level (2-tailed). Cases of abnormal small samples were excluded

II. Analysis and correlation between cervical vertebrae maturation and chronologic age

According to table V, the mean chronological age for both genders increases steadily in relation to the progress in CVMS. As the hand-wrist SMI, the CVMS in both genders showed a statistical significant difference, confirmed by the non-parametric Krustal-Wallis test (whole sample) and the non-parametric ANOVA (for independent genders). The most frequent CVMS in females were CS1 (n = 51) and CS5 (n = 41), while in males the most frequent stage was CS1 (n = 28), followed by CS2 and CS3, both with 21 subjects. In the whole sample, the most frequent CVMS were CSI and CS5 with 79 and 59 subjects, respectively.

The non-parametric Mann-Whitney U test confirmed a significant difference in the chronological ages of the boys and girls in stages CS1 (p = 0.005), CS5 (p = 0.005) and CS6 (p = 0.026), which suggests that the maturational development of females occurs earlier than their male counterparts (Figures 3 and 4).

The mean age for the beginning of skeletal maturation associated with the pubertal growth spurt was 10.54±1.26 years for males and 9.57±1.38 years for females. The mean age for maximum growth was 10.89±1.29 years for females and 11.71±1.19 years for males. Females completed skeletal maturation at a mean age of 13.60±1.39 years while males completed skeletal maturation at a mean age of 14.78±0.83, also confirming the fact that females mature at an earlier age than males.

According to the Spearman rank-order correlation coefficient, strong correlation values were obtained when the association between chronologic age and CVMS was examined for the whole group (r_s = 0.768); and also for the male (r_s = 0.778) and female groups (r_s = 0.788); with p < 0.0001 considered statistically significant for all groups (Table IX).

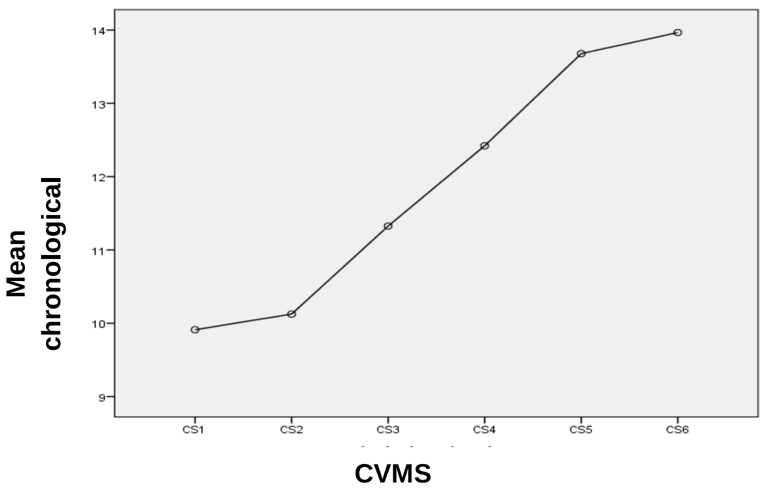

Figure 5. Mean chronological age versus cervical vertebrae maturation

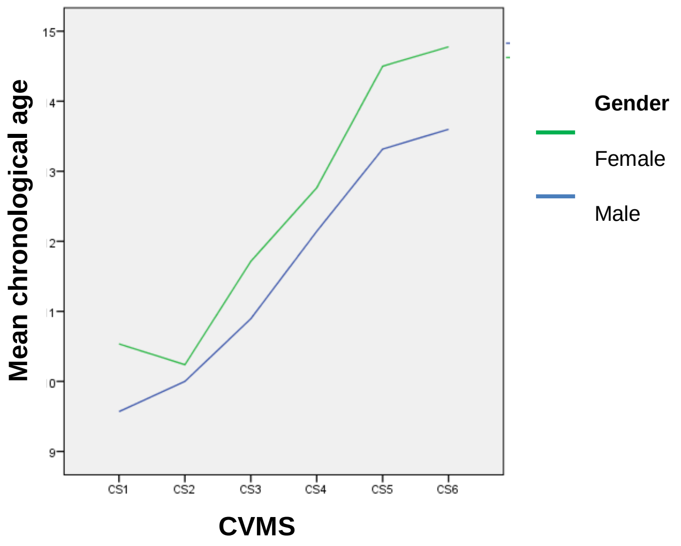

Figure 6. Gender differences in mean chronological age and in cervical vertebrae maturation

Table IX. Subjects classified according to the Baccetti method

Gender		**Female**			**Male**			**Total**		
		n	**Mean**	**SD**	***n***	**Mean**	**SD**	***n***	**Mean**	**SD**
CVM stages	CS1	51	9,57**	1,38	28	10,54**	1,26	79	9,91	1,41
	CS2	19	10,00	1,00	21	10,24	1,30	40	10,13	1,16
	CS3	19	10,89	1,29	21	11,71	1,19	40	11,33	1,29
	CS4	21	12,14	1,01	17	12,76	1,20	38	12,42	1,13
	CS5	41	13,32**	1,49	18	14,50**	1,04	59	13,68	1,47
	CS6	20	13,60*	1,39	9	14,78*	0,83	29	13,97	1,35
	Total	171	11,45	2,12	114	11,99	2,04	285	11,67	2,10
Correlation Coefficient			,788***			,778***			,768***	

Notes: *p < 0,05; **p < 0,01. *** Correlation is significant at the 0.01 level (2-tailed). Cases of abnormal small samples were excluded

III. Correlation between hand wrist and cervical vertebrae maturation

The correlations between hand-wrist and cervical vertebrae maturation are shown in Tables X and XI. A strong correlation between hand-wrist and cervical vertebrae maturation was observed at different age groups for both male and female (r_s = 0,789, p < 0.0001) (Table XI), especially between the age groups of 10-11, 12-13 and 13–14 years old (Table

X). Likewise, a strong, positive correlation was observed between the hand-wrist SMI and CVMS in both genders (Table XI), being the Spearman's rho for the male and the female subjects 0.806 and 0.803, respectively. All groups were considered statistically significant at $p < 0.0001$.

Table X. Spearman correlation coefficient of hand-wrist SMI and CVMS at different age groups of both males and females

Chronological Age (y)	*n*	Correlation coefficient	*p* value
[7-9[	16	-,124	,647
[9-10[	32	,031	,865
[10-11[	38	,485**	,002
[11-12[	53	,297*	,031
[12-13[	49	,742**	,000
[13-14[	36	,673**	,000
[14-15[	30	,446*	,013
[15-16]	31	,143	,444

Notes: ** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed).

Table XI. Spearman correlation coefficient of hand-wrist SMI and CVM grades for both males and females

Gender	*n*	Correlation coefficient	*p* value
Female	171	,803**	<0,0001
Male	114	,806**	<0,0001
Total	285	,789**	<0,0001

Notes: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

Adolescence is a period during which growth rate accelerates, reaches a peak velocity and then decelerates until adulthood is achieved. Although this a common pattern to all normal individuals, there may be a marked individual variation in the initiation, duration rates and growth levels during this period of life. In certain individuals, physiologic development proceeds rapidly and the entire pubertal growth period is short, in others it is slothful and much longer (6).

Growth prediction methods, involving the determination of skeletal age and pubertal facial growth spurt in individual patients, entails particular clinical significance in the treatment protocols for a wide variety of dentoskeletal disharmonies (16). The optimal time to start therapy is one of the crucial aspects of dentofacial orthopedics treatment planning (16) and can be determined by assessing skeletal maturation (15).

Chronological age is considered a poor indicator for estimating the degree of skeletal maturity due to significant individual growth variations among children of the same age (3), proposing that chronological age is not a reliable method of establishing a child's skeletal development stage (11). Even if, according to some authors, a relatively strong correlation between chronological and skeletal age can be found, either for the CVMS or for the hand-wrist SMI (1); to others there is a low correlation between chorological age and hand-wrist and cervical vertebrae maturation (9). Thought, in general, skeletal maturity indicators proved to be a more accurate and clinically beneficial parameter for the appraisal of the growth status of individuals than chronological age (11), Grave and Brown (24); Franchi et al. (7), particularly to predict the remaining growth (14). Therefore, analyses approaches based on relative growth velocity and percentage of remaining growth are more useful than analyses that only yield a skeletal age (14). Nevertheless, in this Portuguese sample, the Spearman rank-order correlation coefficient revealed strong relationships between chronologic age and hand-wrist SMI and between chronological age and CVMS for the whole group, and for the male and female groups, suggesting that chronological age can, within some limits, be used to determine the maturation status of a patient.

Skeletal maturation assessed on hand-wrist radiograph has been considered the best indicator to determine somatic maturity stages, but the routine use of this type of radiograph has lately been questioned from radiation hygiene and safety point of view (6). To avoid taking additional x-rays, the evaluation of cervical vertebrae has gained popularity in recent years (1) as maturation changes can be observed in them from birth to full maturity; and also because is an economical, reliable and simple method to perform (6).

Some authors referred a lower correlation between hand-wrist and vertebral maturation, probably related to different methods of evaluating hand-wrist maturation (8). In this study, the tested hypothesis, that there are no significant differences between the hand-wrist and cervical vertebrae maturation techniques for the assessment of skeletal maturation in a Portuguese population, has been validated for both genders. The Kappa analysis revealed an inter-examiner and an intra-examiner almost perfect agreement, both for the hand-wrist SMI and CVMS, implying that the criteria used for the evaluation of these two methods is valid and clear. A strong correlation was found between hand-wrist SMI and CVMS, in Portuguese subjects, for the whole sample and for both male and female groups, demonstrating that the 14 discrete hand-wrist indicators can be confidently correlated to the corresponding 6 CVMS in both genders. This correlation is stronger at 10-11, 12-13 and 13-14 years of age groups, time period associated with pubertal spurt. This concurs with the findings reported by Uysal *et al.* (1); Alkhal *et al.* (9); Mahajan (6); and Lai *et al.* (4) that suggest there is a high correlation between hand-wrist SMI and CVMS methods both for male and female. Therefore cervical vertebral analysis has comparable high reliability and validity to the hand-wrist bone analysis in the assessing skeletal maturity (1) and can be used with the same confidence as the hand and wrist to evaluate skeletal maturation of an individual (11). Although the reliability of CVMS method have been statistically proven, this method should be used in association with other growth indicators such as overall bodily growth or sexual maturation, when evaluation of skeletal maturation is needed (18).

Gender is an important factor influencing the pubertal growth spurt (3) and female skeletal maturation is, as a general rule, advanced in relation to male skeletal maturation (1, 11). In the present study, there are statistical significant differences between males and females both for CVMS and hand-wrist SMI methods, findings agreeing with those of Román *et al.* (8), Kamal *et al.* (11) and Caltabiano *et al*. (1) who suggested that this method is more reliable in females than males. As stated by both analyses not only female onset of puberty occurs earlier but they also mature at an early age, while male tend to lag behind all through puberty, having a longer growth spurt. However hand-wrist SMI and CVMS show some differences: for both genders the puberty starts at an early age according to the hand-wrist method (13 months for females and 9 months for males) and females also complete their maturation earlier according to the CVM method (8 months).

The findings of this cross-sectional study demonstrate the validity of using cervical vertebrae for evaluation of skeletal maturation in Portuguese children and adolescents. This CVM method may be an useful clinical tool used to identify the optimal treatment timing for dentoskeletal disharmonies. However, a further longitudinal study is needed to address the exact relationships between CVMS and the growth of craniofacial structures in the Portuguese population.

CONCLUSIONS

The results report that, in Portuguese subjects, a strong correlation coefficient is found between chronologic age and hand-wrist SMI and CVM methods in both genders, suggesting that, with a degree of confidence similar to other indicators and within some parameters, chronological age may be used to assess an individual maturation status.

The statistical results also showed a strong correlation between hand-wrist SMI and CVMS, therefore suggesting that the CVM method may be used in daily dentofacial orthopedic and orthodontic practice when treating Portuguese patients, using the routine lateral cephalometric radiograph, namely to avoid additional radiation exposure.

The study also confirmed that female begin puberty at an early age, completing their growth earlier than the male.

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