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ORIGINAL RESEARCH

Use of the Tooth Coronal Pulp Index for Recognition of the Pubertal Growth Period

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ABSTRACT

Aim: The present study aimed to investigate the association between the tooth coronal index (TCI) and the pubertal growth stages (PGS) for children and adolescents.

Materials and methods: A cross-sectional study was performed using retrospectively collected panoramic and hand-wrist radiographs of 262 individuals (125 males, 137 females). The coronal height (CH) and the coronal pulp cavity height (CPCH) of the left mandibular teeth were measured. Then the TCI for which was calculated according to Ikeda et al (1985). The estimated TCI for individuals with the following PGS after Fishman (1987) are: SMI 4 (S), SMI 5 (DP3 cap), SMI 6 (MP3 cap) and SMI 7 (Mp5 cap). The associations between the TCI and the PGS were investigated by correlation coefficient of Spearman's rho, and the validity values for the PGS were computed.

Results: Significant correlations were noted between the simple TCI values for premolars and molars and the PGS, and the highest correlation was for the summed TCI for both first and second molars. Utilizing the validity values of the summed TCI for both first and second mandibular molars, the PGS can be predicted as follows: S stage when TCI is 49.17 or lesser, DP3cap stage when TCI is 43.52 or lesser, MP3cap stage when TCI is 36.73 or lesser, and Mp5cap stage when TCI is 26.84 or lesser.

Conclusion: The TCI values declined along with the maturational process in children and adolescents. The TCI for both first and second molars was the best predictor of the PGS.

Clinical significance: Panoramic photographs can be beneficial for prediction of the skeletal maturity and treatment planning without resorting to hand-wrist radiographs.

Keywords: Cross-sectional study, Pubertal growth stages, Tooth coronal index.

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INTRODUCTION

Age estimation is an important requisite in clinical practice, especially for growing patients. This estimation is essential to decide timing of the orthodontic treatment, which conducts to brief treatment period and more stable outcome.[1]

The chronological age is clarified by birth date,[2] but it is not considered as an acceptable predictor of skeletal maturation due to the developmental variations among individuals.[3] In spite of the fact that growth of body frequently deviates to the chronological age, it relates well to skeletal age.[4] The skeletal maturity state of a patient assists to know the amount of growth remaining or timing of the pubertal growth spurt.[3,5] The most popular skeletal age evaluation tool is the hand-wrist radiograph, which depends on the stages of bone maturation that can be determined by the visual inspection of developing bones at several ossification centers of the hand.[6-8] In spite of the high acceptable accuracy of this record, they were questionable because of the further radiation exposure.[3] Attempting to exempt this additional record, many investigators tried to use the lateral cephalographs, which is already obtained as a routine record for diagnosis, to detect the skeletal maturation using cervical vertebrae.[9,10]

Since the dental age is a possible indicator for skeletal maturation,[11,12] several techniques have been developed in order to estimate the dental age using panoramic radiographs. These radiographs have the advantage of showing all the maxillary and mandibular teeth on a single film.[13] Various features were studied, such as mineralization of developing permanent teeth by Moorrees et al[14] and

Demirjian et al[15]; third molar development by Harris and Nortje[16]; secondary dentin deposition by Kvaal et al[17] and Drusini[18]; pulp/tooth area ratio by Cameriere et al[19]; tooth-coronal index (TCI) by Ikeda et al[13] and Drusini et al[20]; open apices by Cameriere et al.[21]

Among the assessed features, the TCI developed by Ikeda et al[13] has been lesser but has not been estimated on different ethnical groups. In this technique, the coronal height (CH) and the coronal pulp cavity height (CPCH) of teeth are measured. Then, the TCI is calculated for each tooth using the following formula [TCI = CPCH/CH × 100] and regressed on the real age of the sample. Drusini et al[20] and Karkhanis et al[22] followed the established technique of Ikeda et al[13] and verified the negative correlation between the TCI and the chronological age.

No previous study tried to correlate between this index and the pubertal growth stage (PGS). Therefore, the current study attempts to recognize the PGS utilizing panoramic radiographs. The aim of this study was to assess the TCI in children and adolescents, and to define the relation between the TCI and the PGS.

MATERIALS AND METHODS

This analytical cross-sectional study comprised digital panoramic and left hand-wrist radiographs of 262 Syrian individuals (125 males, 137 females) collected between August 2013 and January 2016 from the archive of Orthodontic Department of Dental School in Damascus University, Syria. For the studied sample, the age for males ranged from 10.22 to 16.01 years (mean 14.61 ± SD 1.26), while for females it was between 9.03 and 14.39 years (mean 12.58 ± SD 1.68).

The inclusion criteria include good panoramic and hand-wrist radiographs taken simultaneously from the same individual who had normal growth. Exclusion criteria were abnormal dental conditions, such as transposition, impaction, missing, supernumerary teeth, or retained deciduous teeth. Also teeth with caries, fillings, root canal treatment, crowns, pathologies, or attrition were excluded. In addition, individuals with severe periodontitis, systemic illness, nutritional or endocrine problems, previous history of orthodontic treatment, or history of trauma were not included in the current study.

The panoramic and hand-wrist radiographs for each individual were coded, then they were evaluated by the two authors separately using image processing software (Millensys, MiViewer, version 10.4) to the nearest 0.01 mm. The measurements for the left mandibular incisors, canine, premolars, and first and second molars were evaluated on panoramic radiographs according to Ikeda et al.[13] For each tooth, a straight line was drawn between the mesial and distal cementoenamel junction points. Following that, CH was measured perpendicularly from the drawn cervical line to the tip of the highest cusp of tooth, and CPCH was measured perpendicularly from the drawn cervical line to the tip of the highest pulp horn of tooth (Fig. 1). After that, the TCI was computed as follows: TCI = CPCH/CH × 100. Since the TCI is the CPCH-to-CH ratio, which is founded on two linear measurements assessed on the same site on the radiograph, there is no need for standardization of tooth size.

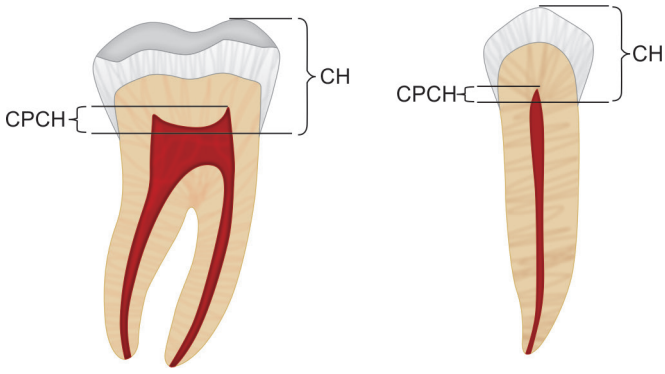

Fig. 1: The liner measurements demanded for calculation of the TCI

The left hand-wrist radiographs were assessed according to the system of skeletal maturation assessment presented by Fishman in a more accurate manner for rating the skeletal age in which 11 skeletal maturity indicators (SMI) had been included.[6] The current study was confined to the following maturational stages that cover the pubertal growth period[23]: SMI 4 is based on the ossification of the adductor sesamoid of the thumb (S) (31 males, 34 females), SMI 5 on the capping of the epiphysis of the distal phalanx of the third finger (DP3 cap) (30 males, 32 females), SMI 6 on the capping of the epiphysis of the middle phalanx of the third finger (MP3 cap) (31 males, 35 females), and SMI 7 on the capping of the epiphysis of the middle phalanx of the fifth finger (Mp5 cap) (33 males, 36 females).

Sample Size Estimation

The sample size was established using G* Power software, version 3.0.6 (Franz Faul, Universität Kiel, Germany) with one-way analysis of variance (ANOVA), a selected study power of 90%, a number of groups of 4, a significance level of 0.05, and an effect size of 0.25. The analysis revealed that 58 individuals were demanded in each group.

Statistical Analysis

Our data were analyzed using Statistical Package for the Social Sciences (SPSS) software version 20 (IBM SPSS Statistics, Armonk, NY: IBM Corp., USA). The reliability of the interexaminer measurements was calculated by the intraclass correlation coefficient.

The distribution of our data was studied using one-sample Kolmogorov-Smirnov test. The comparisons

Table 1: Descriptive statistics and normality distribution for the TCI values of teeth according to gender

Tooth	Males				Females				Total			
(FDI)	Mean	SD	†K-S	†p-value	Mean	SD	†K-S	†p-value	Mean	SD	†K-S	†p-value
31	20.49	3.38	0.718	0.681	20.18	3.46	0.677	0.748	20.33	3.38	0.885	0.414
32	22.35	5.40	0.710	0.695	22.00	4.59	0.465	0.982	22.17	4.95	0.674	0.755
33	23.30	4.12	0.775	0.585	26.36	7.54	0.867	0.440	24.83	6.19	0.924	0.360
34	25.94	6.67	0.471	0.980	26.67	7.56	0.369	0.999	26.31	7.05	0.436	0.991
35	24.85	6.23	0.694	0.722	25.89	6.44	0.552	0.921	25.37	6.28	0.558	0.915
36	25.28	5.06	0.464	0.983	24.80	7.23	0.585	0.883	25.04	6.17	0.591	0.877
37	21.40	5.63	0.520	0.950	21.17	4.91	0.543	0.930	21.28	5.22	0.493	0.968

TCI: Tooth coronal index; ; SD: Standard deviation; †Using Kolmogorov-Smirnov test

were made between the values for males and females with regard to measurements of each tooth individually using two-sample t-test. The means of the TCI for the left mandibular teeth in the four stages of the pubertal growth were compared by one-way ANOVA to investigate differences. Then, the *post hoc* Tukey's test was performed to investigate groups having differences. The Spearman's rho correlation coefficient was used to investigate the correlations between the TCI values and the PGS. To study the possibility of identifying each PGS depending on the TCI, the amounts of space under the curves of receiver operating characteristic were computed, and the validity values for the PGS according to the summed TCI for the mandibular molars were calculated. A p-value of 0.05 or less was accounted significant.

RESULTS

The interexaminer correlation coefficients in this study varied from 0.86 to 0.97, expressing good correlations of measurements. The TCI values of the left mandibular teeth were dispensed naturally (Table 1). It was observed that there were no differences between the TCI values for males and females (Table 2). Thus, these data were integrated in all subsequent comparisons.

Table 3 shows that there were no differences in the TCI values for incisors between the PGS groups, while it displays differences in the TCI values for the rest of

Table 2: Differences in the TCI values of the left mandibular teeth between the male and female

Tooth	Mean		Levene's test for equality of variances		Two samples t-test for equality of means	
(FDI)	difference	SD	F-value	p-value	t-value	p-value
31	0.31	1.08	0.021	0.886	0.283	0.778
32	0.35	1.58	0.920	0.344	0.222	0.825
33	–3.06	1.92	3.557	0.067	–1.594	0.119
34	–0.73	2.25	0.345	0.560	–0.323	0.748
35	–1.04	2.00	0.262	0.612	–0.521	0.605
36	0.48	1.97	2.307	0.137	0.245	0.808
37	0.23	1.67	0.000	0.982	0.135	0.893

TCI: Tooth coronal index; SD: Standard deviation

Table 3: Differences in the TCI values between the PGS

Tooth (FDI)	Stage	Mean	SD	∞F-value	∞p-value
31	S	20.00	3.35	3.139	0.057
	DP3cap	19.82	2.24		
	MP3cap	18.69	2.45		
	MP5cap	22.82	4.12		
32	S	21.22	2.60	2.498	0.075
	DP3cap	23.45	5.86		
	MP3cap	19.37	4.68		
	MP5cap	24.64	4.99		
33	S	30.53	8.59	7.081	<0.001***
	DP3cap	23.72	3.45		
	MP3cap	20.16	2.88		
	MP5cap	24.91	3.25		
34	S	31.35	4.09	3.378	0.029*
	DP3cap	26.51	10.41		
	MP3cap	22.41	4.15		
	MP5cap	24.96	5.06		
35	S	27.49	5.89	3.810	0.018*
	DP3cap	29.11	5.65		
	MP3cap	21.60	3.67		
	MP5cap	23.28	7.03		
36	S	30.14	4.51	5.267	0.004**
	DP3cap	25.62	4.32		
	MP3cap	21.05	7.73		
	MP5cap	23.34	3.98		
37	S	24.83	2.64	3.611	0.022*
	DP3cap	22.37	7.19		
	MP3cap	18.87	2.92		
	MP5cap	19.07	4.83		
(34, 35, 36, 37)	S	113.82	13.44	6.863	<0.001***
	DP3cap	103.62	19.75		
	MP3cap	83.92	12.98		
	MP5cap	90.65	17.27		
(36, 37)	S	54.98	5.44	7.096	<0.001***
	DP3cap	47.99	10.04		
	MP3cap	39.91	8.04		
	MP5cap	42.40	7.56		

TCI: Tooth coronal index; PGS Pubertal growth stages; ∞ Using the one-way ANOVA test; SD: standard deviation; S: The stage based on the ossification of the adductor sesamoid of the thumb; DP3cap: The stage based on the capping of the epiphysis of the distal phalanx of the third finger; MP3cap: The stage based on the capping of the epiphysis of the middle phalanx of the third finger; MP5cap: The stage based on the capping of the epiphysis of the middle phalanx of the fifth finger; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001

teeth and the dental groups between the PGS groups. These findings revealed that there were, at least, differences between two groups. To detect these groups, multiple comparisons were fulfilled (Table 4).

There was no significant correlation between the TCI values for incisors and canine and the PGS, while significant correlations were observed for premolars and molars. The correlation coefficients were the highest for first and second molars. Thus, the correlation between the summed TCI for premolars and molars and the summed TCI for both first and second molars with the PGS were assessed. It was found that the correlation coefficients rose when gathering the TCI values, and the highest correlation was between the summed TCI for both first and second molars and the PGS (Table 5).

Noticing the amounts of space under the receiver operating characteristic curves of the summed TCI for both first and second mandibular molars, it can be manifested that the degree of identification for the S stage was high, the MP3cap stage was medium, and the Mp5cap and DP3cap stages were low (Table 6). Observing the top values of validity, which are the sum of sensitivity and specificity, it can be seen that S stage is predictable when TCI is 49.17 or lesser, DP3cap stage is predictable when TCI is 43.52 or lesser, MP3cap stage is predictable when TCI is 36.73 or lesser, and Mp5cap stage is predictable when TCI is 26.84 or lesser.

DISCUSSION

The assessment of skeletal age provides insight for recognizing the stage of development progression during childhood and adolescence regardless of chronological age. Therefore, it can be used for comparing between children and planning for orthodontic treatment.[23] To the best of our knowledge, the current research is the first study investigating the relation between the PGS and the TCI in children and adolescents using panoramic radiographs, which are a common diagnostic records in dental practices. This might be useful for exempting hand-wrist radiographs.

The panoramic and left hand-wrist radiographs in the current study were coded to keep away from bias, then the two authors assessed them independently. The inter-examiner correlation coefficients ranged from 0.86 to 0.97; thus, our results are reliable. In this study, the TCI was calculated using the mandibular teeth because they are

Table 4: Multiple comparisons in the TCI values between the PGS

Tooth (FDI)	*Variables*		*Mean difference*	*Standard error*	*$^{\Omega}$p–value*
33	MP5cap	S	–5.62	2.29	0.084
		DP3cap	1.19	2.29	0.954
		MP3cap	4.75	2.29	0.180
	MP3cap	S	–10.37	2.29	<0.001***
		DP3cap	–3.56	2.29	0.416
	DP3cap	S	–6.81	2.29	0.025*
34	MP5cap	S	–6.39	2.90	0.141
		DP3cap	–1.55	2.90	0.950
		MP3cap	2.56	2.90	0.814
	MP3cap	S	–8.95	2.90	0.019*
		DP3cap	–4.11	2.90	0.498
	DP3cap	S	–4.85	2.90	0.353
35	MP5cap	S	–4.21	2.55	0.363
		DP3cap	–5.83	2.55	0.119
		MP3cap	1.68	2.55	0.912
	MP3cap	S	–5.88	2.55	0.115
		DP3cap	–7.51	2.55	0.027*
	DP3cap	S	1.63	2.55	0.918
36	MP5cap	S	–6.80	2.39	0.035*
		DP3cap	–2.28	2.39	0.776
		MP3cap	2.30	2.39	0.773
	MP3cap	S	–9.10	2.39	0.003**
		DP3cap	–4.58	2.39	0.241
	DP3cap	S	–4.52	2.39	0.251
37	MP5cap	S	–5.77	2.13	0.048*
		DP3cap	–3.30	2.13	0.418
		MP3cap	0.20	2.13	1.000
	MP3cap	S	–5.97	2.13	0.039*
		DP3cap	–3.50	2.13	0.366
	DP3cap	S	–2.46	2.13	0.657
(34, 35, 36, 37)	MP5cap	S	–23.17	7.20	0.014*
		DP3cap	–12.97	7.20	0.290
		MP3cap	6.72	7.20	0.787
	MP3cap	S	–29.90	7.20	<0.001***
		DP3cap	–19.69	7.20	0.045*
	DP3cap	S	–10.20	7.20	0.498
(36, 37)	MP5cap	S	–12.57	3.55	0.006**
		DP3cap	–5.59	3.55	0.406
		MP3cap	2.49	3.55	0.896
	MP3cap	S	–15.07	3.55	<0.001***
		DP3cap	–8.08	3.55	0.123
	DP3cap	S	–6.99	3.55	0.219

TCI: Tooth coronal index; PGS Pubertal growth stages; $^{\Omega}$ Using the Tukey HSD test; SD: standard deviation; S: The stage based on the ossification of the adductor sesamoid of the thumb; DP3cap: The stage based on the capping of the epiphysis of the distal phalanx of the third finger; MP3cap: The stage based on the capping of the epiphysis of the middle phalanx of the third finger; MP5cap: The stage based on the capping of the epiphysis of the middle phalanx of the fifth finger; * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001

Table 5: Correlation coefficient (Spearman's rho) between the TCI values and the PGS for the total sample

Tooth (FDI)		*31*	*32*	*33*	*34*	*35*	*36*	*37*	*(34, 35, 36, 37)*	*(36, 37)*
Stage	Correlation coefficient	–0.149	–0.130	0.253	0.426	0.355	0.488	0.469	0.521	0.599
	p-value	0.358	0.425	0.116	0.006**	0.025*	<0.001***	0.002**	<0.001***	<0.001***

TCI: Tooth coronal index; PGS: Pubertal growth stages; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001

Table 6: Areas under the receiver operating characteristic based on the TCI values of the left mandibular molars in different PGS

Stage	Area	Standard error	Asymptotic significance	Discrimination
S	0.900	0.049	0.000	high
DP3cap	0.653	0.108	0.048	low
MP3cap	0.223	0.081	0.010	medium
MP5cap	0.323	0.087	0.043	low

TCI: Tooth coronal index; PGS: Pubertal growth stages; S: The stage based on the ossification of the adductor sesamoid of the thumb; DP3cap: The stage based on the capping of the epiphysis of the distal phalanx of the third finger; MP3cap: The stage based on the capping of the epiphysis of the middle phalanx of the third finger; MP5cap: The stage based on the capping of the epiphysis of the middle phalanx of the fifth finger

easily visible, which could guarantee only sound teeth were measured. The left side of the mandible was considered because most previous studies reported that differences between tooth side is disregarded at radiographic age estimation.[22,24] Considering the clinical significance, the current study was restrained to the stages covering the pubertal growth period: S, DP3 cap, MP3 cap, and Mp5 cap. In these stages, children represented the very high growth speed.[23]

The current results showed that there were no differences in the TCI values between males and females. Therefore, the data were combined. These findings were in agreement with the data reported in Western Australia by Karkhanis et al.[22] In contrast to our findings, some studies in Japan[25] and Malawi[24] mentioned that gender had a significant influence on the TCI values. They attributed these differences to the effect of estrogen on formation of secondary dentin.

There were negative correlations between the simple TCI values for premolars and molars and the PGS in the present study. These results could be attributed to secondary dentin deposition which is a continuous process leading to reduction of the dental pulp chamber size with increasing age. These findings are in line with those of Drusini et al[20] in Italy; Igbigbi and Nyirenda[24] in Malawi; Karkhanis et al[22] in Western Australia, and Talabani et al[26] in Iraq, who mentioned that negative correlations between the TCI and the chronological age were recorded.

For the correlations between the simple TCI of each tooth and the PGS, the highest correlations were for first and second molars. In contrast to our finding, Igbigbi and Nyirenda[24] in Malawi declared that the correlation was greater for premolar than molar teeth. These differences could be explained by ethnic and genetic differences. It was also observed that the correlation coefficient between the TCI values and the PGS increased when the summed TCI values were used, and the highest correlation was with the summed TCI for both first and second molars. These findings are in line with those of Karkhanis et al[22] in Western Australia, who demonstrated that the accuracy of age estimation using the TCI rose when multiple linear regression models were used compared to simple regressions.

It is of interest to note that the summed TCI for mandibular molars can be used to assign the PGS of children, and the degree of identification for the S stage was high, the MP3cap stage was medium, and the Mp5cap and DP3cap stages were low. Considering the top values of the validity for the PGS according to the summed TCI for both first and second molars, it would be possible to classify individuals into maturational stages of S (TCI ≤ 49.17), DP3cap (TCI ≤ 43.52), MP3cap (TCI ≤ 36.73), and Mp5cap (TCI ≤ 26.84). Thus, the TCI is a feasible and simple method for the PGS recognition. However, it is important to note that these findings are only applicable to Syrian children and adolescents, and further studies with different populations are required in order to devise customized values for each one.

CONCLUSION

- The TCI values concurrently decreased with development progression in children and adolescents.
- Gender had no influence on the TCI values.
- The simple TCI for first and second mandibular molars were the most relevant with the PGS compared to those of the rest of teeth.
- Gathering the TCI values improved the PGS prediction, and the best indicator was with the summed TCI for both first and second mandibular molars. The PGS can be predicted according to this TCI as follows: S stage when the TCI is 49.17 or lesser, DP3cap stage when the TCI is 43.52 or lesser, MP3cap stage when the TCI is 36.73 or lesser, and Mp5cap stage when the TCI is 26.84 or lesser.

CLINICAL SIGNIFICANCE

Panoramic photographs provide an opportunity to identify the PGS using the TCI for predicting skeletal maturity. They help us make further therapeutic decisions without need to obtain hand-wrist radiographs; thus, exposure to radiation during treatment would be lesser. It is recommended that the assessment of skeletal maturity be based on the summed TCI values for both first and second mandibular molars.

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