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Diagnostic performance of dental maturity for identification of skeletal maturation phase

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SUMMARY The objective of this study is to analyse the diagnostic performance of the circumpubertal dental maturation phases for the identification of individual-specific skeletal maturation phases. A total of 354 healthy subjects, 208 females and 146 males (mean age, 11.1 ± 2.4 years; range, 6.8–17.1 years), were enrolled in the study. Dental maturity was assessed through the calcification stages from panoramic radiographs of the mandibular canine, the first and second premolars, and the second molar. Determination of skeletal maturity was according to the cervical vertebra maturation (CVM) method on lateral cephalograms. Diagnostic performances were evaluated according to the dental maturation stages for each tooth for the identification of the CVM stages and growth phases (as pre-pubertal, pubertal, and post-pubertal) using positive likelihood ratios (LHRs). A positive LHR threshold of 10 or more was considered for satisfactory reliability of any dental maturation stage for the identification of any of the CVM stages or growth phases. The positive LHRs were generally less than 2.0, with a few exceptions. These four teeth showed positive LHRs greater than 10 only for the identification of the pre-pubertal growth phase, with values from 10.8 for the second molar (stage E) to 39.3 for the first premolar (stage E). Dental maturation assessment is only useful for diagnosis of the pre-pubertal growth phase, and thus, precise information in relation to the timing of the onset of the growth spurt is not provided by these indices.

Introduction

It is well established that treatment timing has a significant role in the outcome of nearly all dentofacial orthopaedic treatments for dentoskeletal disharmonies in growing patients (Petrovic *et al.*, 1990; Baccetti *et al.*, 2005). Therefore, correct identification of the different phases of skeletal maturation represents a crucial issue in orthodontic diagnosis and treatment planning. Because chronological age is not a valid indicator of skeletal maturity (Bjork and Helm, 1967; Petrovic *et al.*, 1990; Baccetti *et al.*, 2006), several other clinical parameters have been proposed as diagnostic aids for the skeletal maturation phase, among which there are increase in stature height (Pancherz and Hagg, 1985) and radiographical methods based on analysis of bones of the hand and wrist (Greulich and Pyle, 1959; Bjork and Helm, 1967) and analysis of cervical vertebrae (Baccetti *et al.*, 2005).

Tooth emergence has also been investigated as a marker of skeletal maturity; however, this has been shown to be poorly correlated with individual skeletal maturity (Bjork and Helm, 1967; Hagg and Taranger, 1982; Franchi *et al.*, 2008). The only previous diagnostic performance study (Franchi *et al.*, 2008) showed that for early and intermediate mixed dentitions, satisfactory diagnostic accuracy is only seen for the identification of the pre-pubertal growth phase.

In addition to tooth emergence, dental maturity detected through radiographic methods appears to be highly related to skeletal maturity (Sierra, 1987; Coutinho *et al.*, 1993; Krailassiri *et al.*, 2002; Uysal *et al.*, 2004; Basaran *et al.*, 2007). In spite of some racial differences (Chertkow, 1980), high correlations have generally been reported between dental and skeletal maturity. The correlation coefficients between the mandibular canine and the skeletal maturity were reported to be from 0.53 to 0.85 (Coutinho *et al.*, 1993). Similarly, the maturity of several mandibular teeth, excluding the third molar, has been reported to be correlated with the skeletal maturation phases, with correlation coefficients of 0.63–0.81 (Sierra, 1987), 0.56–0.69 (Krailassiri *et al.*, 2002), 060–0.91 (Basaran *et al.*, 2007), and 0.63–0.84 (Uysal *et al.*, 2004). In contrast, one study failed to show significant correlations between dental maturation and other indices of skeletal maturation (Demirjian *et al.*, 1985). However, this last study recorded dental maturity as 90 per cent of development of the whole dentition rather than using individual tooth maturity.

On this basis, dental maturation has been proposed to be a clinically useful diagnostic aid for the identification of individual skeletal maturation stages (Chertkow, 1980; Sierra, 1987; Coutinho *et al.*, 1993; Krailassiri *et al.*, 2002; Uysal *et al.*, 2004; Basaran *et al.*, 2007). Moreover, dental

maturity assessment offers the advantage of being a simple procedure that can be carried out on panoramic radiographs that are routinely used for different purposes, and intraoral radiographs can be taken with minimal irradiation to the patient.

In spite of these previous investigations, no data on the clinical performance of the dental maturation stages for the identification of specific skeletal maturation stages on individual subjects have been reported. Indeed, even a high correlation coefficient does not provide information as to whether the dental maturation stage has a satisfactory performance for the diagnostic identification of the skeletal maturation stage on an individual basis. Therefore, the present study was aimed at analysing the diagnostic performance of the circumpubertal dental maturation phases for the identification of individual-specific skeletal maturation phases.

Materials and methods

Study population and design

This study enrolled subjects seeking orthodontic treatment who had never been treated before. Signed informed consent was obtained from the parents of the subjects prior to entry into the study, and the protocol was reviewed and approved by the Ethical Committee of the University of Trieste, Italy. The following enrolment criteria were observed: 1. age between 7 and 18 years, 2. intermediate or late mixed or early permanent phases of dentition, 3. good general health with absence of any hormonal, growth, nutritional, or dental development problems.

The subjects were scheduled for enrolment at their first clinical examination, when dental panoramic radiographs and lateral cephalograms were taken. A total of 354 subjects were enrolled in the study: 208 females and 146 males (mean age, 11.1 ± 2.4 years; range, 6.8–17.1 years).

Assessment of individual dental maturity

Assessment of dental maturity was carried out through the calcification stages according to the method of Demirjian *et al.* (1973; stages D–H) from the panoramic radiographs of the left-side mandibular teeth. Briefly, these stages are defined as follows:

- Stage D: When 1. the crown formation is complete down to the cementoenamel junction; 2. the superior border of the pulp chamber in the uniradicular teeth has a definite curved form, with it being concave towards the cervical region; the projection of the pulp horns, if present, gives an outline shaped like the top of an umbrella; and 3. the beginning of root formation is seen in the form of a spicule.
- Stage E: When 1. the walls of the pulp chamber form straight lines, the continuity of which is broken by the presence of the pulp horn, which is larger than in the previous stage and 2. the root length is less than the crown height.
- Stage F: When 1. the walls of the pulp chamber form a more or less isosceles triangle, with the apex ending in a funnel shape and 2. the root length is equal to or greater than the crown height.
- Stage G: When the walls of the root canal are parallel and its apical end is still partially open.
- Stage H: When 1. the apical end of the root canal is completely closed and 2. the periodontal membrane has a uniform width around the root and the apex.

An experienced orthodontist (PG), who was blinded to the skeletal maturation stages, assessed the dental maturity of the mandibular canine, the first and second premolars, and the second molars.

Assessment of individual skeletal maturity

Assessment of skeletal maturity was carried out through the cervical vertebra maturation (CVM) method on lateral cephalograms (Baccetti *et al.*, 2005). This method comprises six stages (CS1–CS6), which are defined as follows:

- CS1: When the lower borders of the second, third, and fourth cervical vertebrae (C2, C3, and C4) are flat and the bodies of C3 and C4 are trapezoid in shape. CS1 occurs at least 2 years before the pubertal growth spurt.
- CS2: When only the lower border of C2 is concave and the bodies of C3 and C4 are trapezoid. CS2 occurs 1 year before the pubertal growth spurt.
- CS3: When the lower borders of both C2 and C3 have concavities and the bodies of C3 and C4 are either trapezoid or rectangular horizontal in shape. CS3 marks the ascending portion of the pubertal growth spurt.
- CS4: When the lower borders of C2–C4 have concavities and the bodies of both C3 and C4 are rectangular horizontal. CS4 marks the descending portion of the pubertal growth spurt.
- CS5: When the lower borders of C2–C4 have concavities and at least one of the bodies of C3 or C4 is square. CS5 occurs 1 year after the pubertal growth spurt.
- CS6: When the lower borders of C2–C4 have concavities and at least one of the bodies of C3 or C4 is rectangular vertical. CS6 occurs at least 2 years after the pubertal growth spurt.

An experienced orthodontist (TB), who was blinded to the dental maturation stages, assessed the skeletal maturity of the subjects.

Statistical analysis

For each tooth under investigation and within each dental maturation stage, the prevalence of the CVM stages was calculated. To determine the degree of correlation between the two maturational indices, the Spearman rank correlation

coefficient was used. Moreover, to establish the clinical performance of each dental maturation stage for the diagnosis of each CVM stage, positive likelihood ratios (LHRs) were calculated (Greenhalgh, 1997). These positive LHRs provide estimates of how much a given dental maturation stage changes the odds of having a given CVM stage. The same analyses were repeated using the growth phases instead of the single CVM stages. The growth phases were defined as pre-pubertal (CS1 and CS2), pubertal (CS3 and CS4), or post-pubertal (CS4 and CS5). A threshold of a positive LHR of 10 or more (Deeks and Altman, 2004) was considered for assessment of satisfactory reliability of any dental maturation stage for the identification of any of the CVM stages or growth phases. Moreover, in these cases only (positive LHR of 10 more), comprehensive diagnostic performance analyses were performed (Greenhalgh, 1997), which included sensitivities, specificities, and positive predictive values. These analyses were performed for the whole sample as well as for each gender separately.

The per cent agreement and kappa statistics were calculated for evaluation of the intra-examiner agreement. For appraisal of the phases of dentition and the CVM stages, the kappa coefficients were greater than 0.94.

SPSS software 13.0 (SPSS® Inc., Chicago, Illinois, USA) and interactive Stats Calculator (http://ktclearinghouse.ca/cebm/practise/ca/calculators/statscalc) were used to perform the statistical analyses. A P value less than 0.05 was used for rejection of the null hypothesis.

Results

The analyses carried out within each gender yielded similar results, and the data are therefore presented here as a single whole sample ($N = 354$).

The distributions of the different dental maturation stages according to the skeletal maturation phases are shown in Table 1. The correlation coefficients for the dental maturation stages with the CVM stages ranged from 0.71 to 0.77 for the canine and second molar, respectively. Moreover, the correlation coefficients for the dental maturation stages with the three growth phases were also similar and ranged from 0.67 to 0.72 for the canine, first premolar, and the second molar, respectively. All the correlation coefficients were statistically significant, at $P < 0.01$.

The positive LHRs for the different dental maturation stages for the identification of each CVM stage are shown in Table 2. Most of these positive LHRs were less than 2, with values greater than 10 seen only for the identification of CS1 for the canine (stage E, positive LHR of 15.1) and second premolar (stage D, positive LHR of 52.3). The highest positive LHRs for the first premolar and second

Table 1 Relative distributions of the different dental maturation stages according to the skeletal maturation stages ($N = 354$). CVM, cervical vertebra maturation; *n*, number of cases in each dental maturation stage.

Tooth	Dental maturation stage	*n*	Skeletal maturation stage (%*n*)						Correlation coefficient	
			CS1	CS2	CS3	CS4	CS5	CS6	Across CVM stages	Across growth phases
Canine	D	4	100.0	—	—	—	—	—	0.71**	0.67**
	E	30	90.0	10.0	—	—	—	—		
	F	89	69.7	25.8	3.4	1.1	—	—		
	G	76	31.6	38.2	17.1	7.9	3.9	1.3		
	H	155	9.7	13.5	14.8	18.1	20.6	23.2		
First premolar	D	6	100.0	—	—	—	—	—	0.72**	0.67**
	E	57	78.9	19.3	1.8	—	—	—		
	F	75	62.7	26.7	8.0	1.3	1.3	—		
	G	73	35.6	32.9	15.1	8.2	5.5	2.7		
	H	143	5.6	14.7	14.7	19.6	21.0	24.5		
Second premolar	D	32	96.9	3.1	—	—	—	—	0.74**	0.68**
	E	76	69.7	25.0	5.3	—	—	—		
	F	68	50.0	32.4	8.8	4.4	2.9	1.5		
	G	88	9.1	29.5	18.2	18.2	15.9	9.1		
	H	88	5.7	8.0	14.8	18.2	21.6	31.8		
Second molar	D	67	85.1	11.9	1.5	1.5	—	—	0.77**	0.72**
	E	82	63.4	30.5	6.1	—	—	—		
	F	58	24.1	39.7	17.2	8.6	8.6	1.7		
	G	94	9.6	20.2	17.0	22.3	19.1	11.7		
	H	53	—	1.9	13.2	15.1	22.6	47.2		

Correlations between dental and skeletal maturation stages (as either CVM stage or growth phase) are quantified through Spearman's rho correlation coefficient. **$P < 0.01$.

Table 2 Positive LHRs for the dental maturation stages for diagnosis of the skeletal maturation stages (N = 354). LHR, likelihood ratio; —, null value or less than 0.1; bold value, positive LHR of 10 or more.

Tooth	Dental maturation stage	Skeletal maturation stage positive LHR					
		CS1	CS2	CS3	CS4	CS5	CS6
Canine	D	—	—	—	—	—	—
	E	**15.1**	0.4	—	—	—	—
	F	3.9	1.3	0.3	0.1	—	—
	G	0.8	2.3	1.7	0.8	0.4	0.1
	H	0.2	0.6	1.4	2.0	2.4	2.6
First premolar	D	—	—	—	—	—	—
	E	6.3	0.9	0.1	—	—	—
	F	2.8	1.3	0.7	0.1	0.1	—
	G	0.9	1.8	1.4	0.8	0.5	0.2
	H	0.1	0.6	1.4	2.2	2.4	2.8
Second premolar	D	**52.3**	0.1	—	—	—	—
	E	3.9	1.2	0.4	—	—	—
	F	1.7	1.8	0.8	0.4	0.3	0.1
	G	0.2	1.5	1.8	2.0	1.7	0.9
	H	0.1	0.3	1.4	2.0	2.5	4.0
Second molar	D	9.6	0.5	0.1	—	—	—
	E	2.9	1.6	0.5	—	—	—
	F	0.5	2.4	1.7	0.9	0.9	0.2
	G	0.2	0.9	1.7	2.6	2.2	1.1
	H	—	0.1	1.2	1.6	2.7	7.6

Table 3 Positive LHRs for the dental maturation stages for the diagnosis of the growth phases (N = 354). LHR, likelihood ratio; —, null value or less than 0.1; bold value, positive LHR of 10 or more.

Tooth	Dental maturation stage	Growth phase positive LHR		
		Pre-pubertal	Pubertal	Post-pubertal
Canine	D	—	—	—
	E	—	—	—
	F	**14.9**	0.2	0.0
	G	1.6	1.3	0.2
	H	0.2	1.9	3.1
First premolar	D	—	—	—
	E	**39.3**	0.1	—
	F	5.9	0.4	0.1
	G	1.5	1.1	0.4
	H	0.2	2.0	3.3
Second premolar	D	—	—	—
	E	**12.8**	0.2	—
	F	3.3	0.6	0.2
	G	0.4	2.1	1.3
	H	0.1	1.8	4.5
Second molar	D	**22.8**	0.1	0.0
	E	**10.8**	0.2	0.0
	F	1.2	1.3	0.5
	G	0.3	2.5	1.7
	H	0.0	1.5	9.1

molar were 6.3 (stage E) and 9.6 (stage D), respectively, again for the identification of CS1.

The positive LHRs for the different dental maturation stages for the identification of each growth phase are shown in Table 3. Most of these positive LHRs were less than 2, especially when the pubertal and post-pubertal growth phases were considered. However, each of the four teeth showed a positive LHR of 10 or more for identification of the pre-pubertal growth phase. In particular, these ranged from 10.8 for the second molar (stage E) to 39.3 for the first premolar (stage E), while the canine (stage F), second premolar (stage E), and second molar (stage D) gave intermediate positive LHRs of 14.9, 12.8, and 22.8, respectively.

The other diagnostic performance parameters of the selected teeth and the corresponding dental maturation stages that gave positive LHRs of 10 or more are shown in Table 4. According to the four parameters of sensitivity, specificity, positive predictive value, and positive LHR, the first premolar (stage E) showed the highest diagnostic performance for identification of the pre-pubertal growth phase, with specificity and positive predictive values of 99.3 per cent and 98.2 per cent. However, the 95 per cent confidence intervals for the positive LHRs of these selected stages for the identification of the pre-pubertal growth phase were wide for all the teeth investigated, with the widest range seen for the first premolar (5.5–280.7).

Discussion

The present study investigated the diagnostic performance of the circumpubertal maturation stages of four mandibular teeth for the identification of the skeletal maturation stages. The data show that in spite of the high correlation coefficients, the clinical usefulness of dental maturational stages for the identification of individual skeletal maturity is limited in both male and female subjects.

Due to the presence of calcified structures that superimpose on the maxillary teeth, the mandibular teeth have been reported as being the best for identification of the maturity stages based on panoramic radiographs (Krailassiri *et al.*, 2002; Uysal *et al.*, 2004; Basaran *et al.*, 2007). In the present study, only the canine, first and second premolars, and second molar were investigated, as their maturation occurs in the circumpubertal growth phases. Indeed, the incisors and first molars develop fully long before the onset of the pubertal growth spurt (Basaran *et al.*, 2007), while the third molars develop after this pubertal period (Engstrom *et al.*, 1983).

In the present study, the correlation coefficients between the dental and skeletal maturity phases were generally high for all the teeth investigated (Table 1) and are similar to those of previous investigations that reported significant and high correlation coefficients between dental and skeletal maturity for several mandibular teeth, including the canine (Chertkow, 1980; Sierra, 1987; Coutinho *et al.*, 1993), the

Table 4 Diagnostic performance parameters of selected tooth and maturation stage in diagnosis of the pre-pubertal growth phases ($N = 354$). CI, confidence interval; LHR, likelihood ratio.

Parameter	Tooth (stage)			
	Canine (stage F)	First premolar (stage E)	Second premolar (stage E)	Second molar (stage E)
Sensitivity, % (CI)	40.9 (34.1–47.7)	26.9 (21.3–33.3)	35.0 (28.7–41.7)	37.0 (30.8–43.8)
Specificity, % (CI)	97.3 (93.2–98.9)	99.3 (96.2–99.9)	97.3 (93.2–98.9)	96.6 (92.2–98.5)
Positive predictive value, % (CI)	95.5 (89.0–98.2)	98.2 (90.7–99.7)	94.7 (87.2–97.9)	93.9 (86.5–97.4)
Positive LHR (CI)	14.9 (5.6–39.7)	39.3 (5.5–280.7)	12.8 (4.8–34.1)	10.8 (4.5–26.0)

Data on the second molar (stage D) are not shown because of its redundancy.

second premolar (Krailassiri *et al.*, 2002), and the second molar (Sierra, 1987; Uysal *et al.*, 2004; Basaran *et al.*, 2007).

In the present study, only the dental stages D and E (and F for the canine) showed clear distributions that were limited to the pre-pubertal stages CS1 or CS2. In contrast, all the other dental maturation stages were widely distributed across the six CVM stages (Table 1). Previous studies have reported close relationships between mandibular canine calcification stages G (Chertkow, 1980) and F (Krailassiri *et al.*, 2002) and various skeletal indicators of the pubertal growth spurt. Similar results were reported in samples of Turkish subjects (Uysal *et al.*, 2004; Basaran *et al.*, 2007). The intermediate stage between stages F and G of the mandibular canine has been proposed as a reliable indicator to assess the early stages of the pubertal growth spurt (Coutinho *et al.*, 1993). However, none of these investigations (Chertkow, 1980; Sierra, 1987; Coutinho *et al.*, 1993; Krailassiri *et al.*, 2002; Uysal *et al.*, 2004; Basaran *et al.*, 2007) determined the true diagnostic performances of the dental maturity for the assessment of the skeletal maturation phases, as they were limited to analyses of the distributions of the dental maturation stages according to the skeletal maturation stages.

The present study shows that in spite of the entity of the correlations between the dental and skeletal maturation stages, the overall diagnostic performance of the former for the identification of the pubertal growth spurt is generally low according to the positive LHRs (Tables 2 and 3). Here, a positive LHR indicates that a subject who tests positive for any clinical parameter (i.e. any dental maturation stage) has a high probability of having the given condition that needs to be diagnosed (i.e. any skeletal maturation stage). The positive LHR incorporates both the sensitivity and the specificity of the test, and it provides a direct estimate of how much a test result changes the odds of having a condition (Greenhalgh, 1997). A positive LHR greater than 1 indicates that the test result is associated with the given condition; however, only when the positive LHR of 10 or more is the test considered to be a reliable diagnostic aid (Deeks and Altman, 2004). Therefore, a positive LHR of 10 or more was used herein for reliable assessment of the dental maturation stages for the identification of the individual skeletal maturity.

When considering each of the CVM stages, only a few of the maturation phases of the teeth investigated gave positive LHRs of 10 or more and only for CS1 (Table 2). This shows that these dental maturation stages are not sufficiently reliable for the assessment of all the six CVM stages. Similarly, when the CVM stages are clustered as the three growth phases of pre-pubertal, pubertal, and post-pubertal, only 5 of 46 positive (0.1 or more) LHRs were 10 or more (Table 3). In particular, stage F of the canines; stages E of the first premolars, second premolars, and second molars; and stage D of the second molars gave positive LHRs of 14.9, 39.3, 12.8, 10.8, and 22.8, respectively, for identification of the pre-pubertal growth phase (Table 3). However, the use of the second molar stage D in the identification of this growth phase would be redundant because of the satisfactory diagnostic performance of the subsequent stage E. Of note, the highest and lowest positive LHRs were seen for the first premolar and the second molar, respectively, while the corresponding correlation coefficients with growth phase showed an inverse behaviour (Table 1). The full diagnostic performance parameters (Table 4) included the sensitivities, specificities, and positive predictive values for the canines (stage F) and for the other teeth investigated (stage E), which show high specificities and positive predictive values that were again greatest for the first premolar and lowest for the second molar (excluding its stage D, which is redundant and less clinically useful than the subsequent stage E). Of interest, none of the previous investigations reported the first premolar as the tooth most correlated with skeletal maturity (Chertkow, 1980; Sierra, 1987; Coutinho *et al.*, 1993; Krailassiri *et al.*, 2002; Uysal *et al.*, 2004; Basaran *et al.*, 2007). However, while the correlation coefficients do not fully account for diagnostic performance, the very large 95 per cent confidence interval (5.5–280.7) seen herein for stage E of the first premolar for the identification of the pre-pubertal growth phase has to be taken into account. Finally, none of the teeth investigated showed reliable diagnostic performance for the identification of the end of

the pubertal growth spurt (Tables 2 and 3), with the exception of the second molar (stage H, full development), which showed a positive LHR just below 10 for identification of the post-pubertal growth phase (Table 3).

Clinical implications

Despite the high correlations seen herein and in previous studies between dental and skeletal maturity, the diagnostic performance of the dental maturity for identification of specific stages of skeletal maturity would be limited. The developmental status of the mandibular canine, the first and second premolars, and the second molar might only be useful in diagnosis of the pre-pubertal growth phase. Moreover, reliable differential diagnosis between the two pre-pubertal stages, i.e. CS1 and CS2, is not possible. Considering that CS2 occurs 1 year before the pubertal growth spurt, while CS1 occurs at least 2 years before the pubertal growth spurt (Petrovic *et al.*, 1990; Baccetti *et al.*, 2005), precise information about the timing of the onset of the growth spurt, with the relevant clinical implications in the treatment of skeletal Class II subjects, is not provided by these dental indices. Moreover, none of the teeth investigated would have a satisfactory degree of reliability for identification of the end of the pubertal growth spurt, with the exception of the second molar, which was close to a satisfactory level.

Similarly, despite the high diagnostic performance of the teeth selected and the stages seen herein for the identification of the pre-pubertal growth phase, the clinical usefulness of dental maturation assessments remains low considering that the diagnostic accuracy of the early mixed and intermediate mixed dentition for the identification of the pre-pubertal growth phase has been demonstrated (Bjork and Helm, 1967; Hagg and Taranger, 1982; Franchi *et al.*, 2008). Therefore, dental emergence can be used instead of dental maturation, thus avoiding the need for an X-ray, at least for the identification of the pre-pubertal growth phase.

Conclusions

1. Dental and skeletal maturity are highly correlated, although the diagnostic performance of dental maturity for the identification of any stage of skeletal maturity is limited.
2. The dental maturation stages of the mandibular teeth show satisfactory diagnostic performance only for the identification of the pre-pubertal growth phases, with no reliable indications for onset of the pubertal growth spurt.
3. The clinical usefulness of the determination of dental maturity for the assessment of treatment timing for skeletal malocclusion would thus be limited.

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