Tooth mineralization stages as a diagnostic tool for assessment of skeletal maturity

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Introduction: The objective of this study was to determine whether dental calcification can be used as a first-level diagnostic tool for assessment of skeletal maturity. Methods: A total of 150 healthy subjects (79 boys, 71 girls; mean age, 12.19 ± 2.03 years; range, 8-16 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 modified middle phalanx of third finger (MP3) stages method on digital radiographs. Results: Diagnostic ability was evaluated according to the dental maturation stages for each tooth for identification of the MP3 stages and the growth phases (prepubertal, pubertal, postpubertal) using positive likelihood ratios. Dental maturation stage E of the first premolars and the combination of canine stage F, first premolar stage E, second premolar stage E, and second molar stage D (FEED) gave the highest values for identification of the prepubertal growth phase, and stage H of the second molar had the highest value for identification of the postpubertal growth phase. Conclusions: Dental maturation assessment is only useful for diagnosis of the prepubertal and postpubertal growth phases. (Am J Orthod Dentofacial Orthop 2014;145:7-14)

Treatment timing has a significant role in the outcome of all dentofacial orthopedic treatments for dentoskeletal disharmonies in growing patients. Prior knowledge of the amount of growth remaining would be extremely useful for forecasting treatment outcome, taking advantage of growth when necessary and trying to minimize growth when undesirable. For growth modification to be successful, it is absolutely essential that it start at the right time. Optimal timing for treatment is different in various malocclusions. According to Bacetti et al, treatment protocols aimed to enhance or restrain maxillary growth take advantage of treatment performed before the adolescent growth spurt, whereas treatment regimens aimed to enhance or restrain mandibular growth produce greater effects when the pubertal growth spurt is included in the treatment interval.

The relationship between dental and skeletal maturity has been investigated. Tooth emergence as a marker of skeletal maturity has been shown to be poorly correlated with skeletal maturity. However, dental calcification stages detected through radiographic methods appear to be highly correlated to skeletal maturity. The relationship between dental and skeletal maturity has been investigated. Tooth emergence as a marker of skeletal maturity has been shown to be poorly correlated with skeletal maturity. However, dental calcification stages detected through radiographic methods appear to be highly correlated to skeletal maturity.

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

A high correlation coefficient does not provide information about whether the dental maturation stage is satisfactory for diagnostic identification of the skeletal maturation stage on an individual basis. Perinetti et al analyzed the diagnostic ability of the dental maturation phases for the skeletal maturation phases using the cervical vertebral maturation stages and concluded that although dental and skeletal maturity are highly correlated, their diagnostic ability is limited.

In a pediatric patient, the use of a thyroid collar is mandatory while taking cephalometric radiographs. However, Wiechmann et al and Sansare et al concluded that the thyroid collar masks landmarks mainly used for analysis of skeletal maturity. Madhu et al studied the correlation between the developmental stages of the middle phalanx of the third finger (MP3) as seen on an intraoral periapical radiograph and cervical vertebral stages, and they concluded that the MP3 can be used as the sole indicator for skeletal maturity.
Rajagopal and Kansal14 and Ozer et al15 correlated the cervical vertebral maturation stages with modified MP3 stages and concluded that the MP3 stages can be used to assess a subject’s skeletal maturation. Rajagopal and Kansal showed that recording the modified MP3 stages using periapical x-ray films can be an accurate, simple, practical, and economical growth indicator for making decisions on treatment planning.

Hence, the aim of this study was to determine whether dental calcification can be used as a first-level diagnostic tool for assessment of skeletal maturity with the MP3 stages.

MATERIAL AND METHODS

This study has a cross sectional design. With a 95% confidence interval (CI) and 80% test power, a sample size of 150 was calculated. We enrolled 79 boys and 71 girls in the age group of 8 to 16 years (mean age, 12.19 ± 2.03 years). Informed consent was obtained from all the subjects, and the study protocol was approved by the ethical committee of Meenakshi Ammal Dental College, Chennai, Tamil Nadu, India. The subjects had no history of congenital, developmental, or hormonal disturbances that could affect their growth. They had no impacted teeth, transposed teeth, or history of trauma or injury to the face and hand and wrist regions.

The subjects were scheduled for enrollment at their first clinical examination, when digital dental panoramic radiographs were taken. Digital radiographs of the MP3 region were taken using the procedure described by Abdel-Kader16 (Fig 1).

Assessment of dental maturity was carried out through the calcification stages according to the method of Demirjian et al17 from the panoramic radiographs of the left mandibular posterior teeth. Briefly, these stages are defined as follows.

Stage D is when (1) crown formation is complete down to the cementoenamel junction; (2) the superior border of the pulp chamber in uniradicular teeth has a definite curved form and is concave toward the cervical region, and 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 is when (1) the walls of the pulp chamber form straight lines, the continuity of which is broken by the pulp horns, which are larger than in the previous stage; and (2) the root length is less than the crown height.

Stage F is 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 is when the walls of the root canal are parallel and its apical end is still partially open.

Stage H is 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.

A trained postgraduate dental student (S.M.), 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 skeletal maturity was carried out with the modified MP3 method described by Rajagopal and Kansal14 (Fig 2) from the digital radiographs. This method comprises 6 stages, defined as follows.

1. MP3-F stage is the start of the curve of pubertal growth spurt: the epiphysis is as wide as the metaphysis; the ends of the epiphysis are tapered and rounded; the metaphysis shows no undulation; and the radiolucent gap (representing the cartilaginous epiphyseal growth plate) between the epiphysis and the metaphysis is wide.

2. MP3-FG stage is the acceleration of the curve of the pubertal growth spurt: the epiphysis is as wide as the metaphysis; a distinct medial and lateral border of the epiphysis forms a line of demarcation at a right angle to the distal border; the metaphysis begins to show a slight undulation; and the radiolucent gap between the metaphysis and the epiphysis is wide.

3. MP3-G stage is the maximum point of the pubertal growth spurt: the sides of the epiphysis have thickened and cap its metaphysis, forming a sharp distal edge on at least 1 side; marked undulations in the
metaphysis give it a “Cupid’s bow” appearance; and the radiolucent gap between the epiphysis and the metaphysis is moderate.

4. MP3-H stage is the deceleration of the curve of the pubertal growth spurt: fusion of the epiphysis and the metaphysis begins; at least 1 side of the epiphysis forms an obtuse angle to the distal border; the epiphysis is beginning to narrow; a slight convexity is seen under the central part of the metaphysis; the typical “Cupid’s bow” appearance of the metaphysis is absent but a slight undulation is distinctly present; and the radiolucent gap between the epiphysis and the metaphysis is narrower.

5. MP3-HI stage is the maturation of the curve of the pubertal growth spurt: the superior surface of the epiphysis has a smooth concavity; the metaphysis shows a smooth, convex surface, almost fitting into the reciprocal concavity of the epiphysis; there is no undulation in the metaphysis; and the radiolucent gap between the epiphysis and the metaphysis is insignificant.

6. MP3-I stage is the end of the pubertal growth spurt: fusion of the epiphysis and the metaphysis is complete; there is no radiolucent gap between the metaphysis and the epiphysis; and a dense, radiopaque epiphyseal line forms an integral part of the proximal portion of the middle phalanx.

A trained postgraduate dental student (M.S.), who was blinded to the dental maturation stages, assessed the subjects’ skeletal maturity. The postgraduate student was trained in the calibration process before the study. The student was given 10 radiographs for the first week; in the second, third, and fourth weeks, another 10 radiographs were given for staging each week. Then the student was given a week’s interval before staging the final set of 10 radiographs. A 90% agreement had to be achieved, meaning that at least 9 of 10 radiographs had to be staged correctly. This training was overseen by an experienced orthodontist (E.T.). If 90% agreement was not achieved, the cycle was repeated. Once the examiner was trained and after intraexaminer reliability was assessed, the study began.

Statistical analysis

For each tooth under investigation and within each dental maturation stage, the prevalence of the MP3 stages was calculated. To determine the degree of correlation between the 2 maturational indexes, the Spearman rank correlation coefficient was used. Moreover, to establish the diagnostic ability of each dental maturation stage and also its combinations to identify each MP3 stage, positive likelihood ratios were calculated (Greenhalgh\textsuperscript{18}). These positive likelihood ratios provide estimates of how much a given dental maturation stage changes the odds of having a given MP3 stage. A threshold of a positive likelihood ratio of 10 or more (Deeks and Altman\textsuperscript{19}) was considered for the assessment of satisfactory reliability of any dental maturation stage for the identification of an MP3 stage. Moreover, in these cases (positive likelihood ratios of 10 or more), only comprehensive diagnostic ability analyses were performed (Greenhalgh), which included sensitivities, specificities, and positive predictive values. These analyses were performed for the whole sample and for each sex separately.

Fig 2. Developmental stages of MP3: radiographic appearance.
The percentages of agreement and kappa statistics were calculated to evaluate intraexaminer agreement. For appraisal of the phases of dentition and the MP3 stages, the kappa coefficients ranged from 0.77 to 1.0, which are reliable.

SPSS software (version 15.0; SPSS, Chicago, Ill) was used for the statistical analyses. A P value less than 0.05 was used for rejection of the null hypothesis.

**RESULTS**

The analysis carried out in each sex yielded similar results, and the data are therefore presented here as 1 sample (n = 150).

The distributions of the dental maturation stages according to the skeletal maturation stages (as either MP3 stages or growth phase) are quantified with the Spearman rho correlation coefficient.

<table>
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<tr>
<th>Tooth</th>
<th>Dental maturation stage</th>
<th>n</th>
<th>MP3-F</th>
<th>MP3-FG</th>
<th>MP3-G</th>
<th>MP3-H</th>
<th>MP3-HI</th>
<th>MP3-I</th>
<th>Across MP3 stages</th>
<th>Across growth phases</th>
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<td>–</td>
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<td>–</td>
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<td>–</td>
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<td>G</td>
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<td></td>
<td>H</td>
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<td>H</td>
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<td>–</td>
<td>–</td>
<td>6.3</td>
<td>12.5</td>
<td>81.2</td>
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Correlations between dental and skeletal maturation stages (as either MP3 stages or growth phase) are quantified with the Spearman rho correlation coefficient.

*P < 0.001.
maturation stages that gave positive likelihood ratios of 10 or more are shown in Tables IV and V for the prepubertal and postpubertal growth phases, respectively. According to the 4 parameters of sensitivity, specificity, positive predictive value, and positive likelihood ratios, the first premolar (stage E) showed the highest diagnostic ability for identification of the prepubertal growth phase, with specificity and positive predictive values of 99.21% and 92.31%, respectively. The combination of dental stages FEED, which includes premolar stage E, also showed a specificity of 99.21% and a positive predictive value of 85.71%.

**DISCUSSION**

The diagnostic ability of the circumpubertal maturation stages of the 4 mandibular teeth individually and their combinations were investigated for the identification of the skeletal maturation stages. The data showed that in spite of the high correlation coefficients, the clinical usefulness of the dental maturational stages for the identification of individual skeletal maturity is limited in both sexes.

Because of calcified structures that superimpose on the maxillary teeth, the mandibular teeth have been reported to be the best for identification of the maturity stages based on panoramic radiographs. In our study, only the canine, the first and second premolars, and the second molar were investigated, since their maturation occurs in the circumpubertal growth phases.

The correlation coefficients between the dental and skeletal maturity phases were generally high for all teeth investigated (Table I) and are similar to those of previous investigations that reported significant and high correlation coefficients between dental and skeletal maturities for several mandibular teeth, including the canine, 6,7,20 the second premolar, 6,7,20 and the second molar. 6,7,20

Dental stages D, E, and F (and G for the canine) showed clear distributions that were limited to prepubertal stages MP3-F and MP3-I. Dental stages H and G for the second molar and the second premolar showed distributions limited to the postpubertal stages. Other stages of dental maturation were widely distributed across the MP3 stages (Table I).

In spite of the correlations between the dental and skeletal maturation stages, the overall diagnostic ability of the former for the identification of the pubertal growth spurt is generally low according to the positive likelihood ratios. Even combinations of dental maturation stages used for diagnostic performance of the pubertal growth spurt were limited.

When considering each MP3 stage, only a few of the maturation phases of the teeth investigated gave positive likelihood ratios of 10 or more, and only for MP3-F and MP3-I. In particular, stage F of the canines,
Stage E of the first premolars, and stage D of the second molars gave positive likelihood ratios of 17.9, 63.0, and 15.8, respectively, for identification of the prepubertal growth phase (MP3-F) (Table I). The highest positive likelihood ratio was seen for the first premolar stage E alone, which gave a likelihood ratio of 63 compared with the combination of FEED (likelihood ratio, 31.5) for the identification of MP3-F. Hence, first premolar stage E alone has a better predictive value than the combination for identification of the MP3-F stage. The MP3-FG stage could only be identified by the combination GGFE with a likelihood ratio of 10. Hence, the respective stages of all the 4 teeth alone can identify MP3-FG. Second molar stage H alone can be used to identify the MP3-I stage because its combination HHGG also gave the same likelihood ratio of 17.3. MP3-H stage can only be identified by the combination HHGG, which gave a likelihood ratio of 10.6, since no stage alone could identify it.

Similar results were obtained by Perinetti et al., who assessed diagnostic ability of individual teeth for identifying skeletal maturity among Italian subjects, and the results showed high positive likelihood ratios for the identification of the prepubertal growth phase, with the highest value for the first premolar. Second molar stage H showed reliable diagnostic performance for identification of the end of the pubertal growth spurt.

The full diagnostic performance parameters included sensitivities, specificities, and positive predictive values for the canine (stage F), first premolar (stage E), second premolar (stage D) combinations FEED and GGFE for the prepubertal growth phase, and second molar (stage H) combinations HHGG and HHGH for the postpubertal growth phase (Tables IV and V). The highest values were for premolar stage E for the prepubertal growth phase and second molar stage H for the postpubertal growth phase. Combinations of dental maturation stages showed similar values to individual teeth, but the results are not better when compared with individual teeth for assessing MP3-F and MP3-I; however, combinations of dental stages alone could identify stages MP3-FG and MP3-H. The overall results show that these dental maturation stages are not sufficiently reliable for the assessment of all 6 MP3 stages. Only the prepubertal and postpubertal growth phases can be identified by dental maturation stages.

This study is the only one to make a direct comparison between MP3 stages and combinations of dental maturation stages. Combinations of dental maturation stages can be used to identify MP3 stages, and they had a similar predictive value as individual teeth in this study.

The limitations of this study include a small sample size. Future studies with larger samples and combinations of the dental maturation stages can be done to verify the greater diagnostic ability of the dental maturation stages. This study showed some promise for using the dentition as a rough estimator and as an adjunct for evaluating patients’ skeletal growth and development. In some situations, this method might obviate the need for additional hand-wrist or cervical radiographs.

### Table III. Positive likelihood ratios for combinations of dental maturation stages for diagnosis of the skeletal maturation stages (n = 150)

<table>
<thead>
<tr>
<th>Combinations of dental maturation stages</th>
<th>Skeletal maturation stage positive LHR</th>
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<tbody>
<tr>
<td></td>
<td>MP3-F</td>
</tr>
<tr>
<td>EEDD</td>
<td></td>
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<tr>
<td>EEED</td>
<td></td>
</tr>
<tr>
<td>EDED</td>
<td></td>
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<td>FDDD</td>
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<td>FFFG</td>
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<td>GFFE</td>
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</tr>
<tr>
<td>GGGG</td>
<td>1.8</td>
</tr>
<tr>
<td>HHHH</td>
<td>0.1</td>
</tr>
</tbody>
</table>

LHR, Likelihood ratio; –, null value or <0.1.
*Sequence is canine, first premolar, second premolar, second molar.
1Positive LHR of 10 or more.
Despite the high correlations seen here and in previous studies between dental and skeletal maturity values, the diagnostic performance of dental maturity for identification of the specific stages of skeletal maturity is limited. MP3-F stage occurs at least 2 years and MP3-FG stage occurs 1 year before the pubertal growth spurt. 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 indexes, as Class II treatment is most effective when it includes the peak of mandibular growth. However, Class III treatment with maxillary expansion and protraction is effective when it is performed before peak growth (MP3-F and FG stages). According to Baccetti et al, treatment timing of rapid maxillary expansion before the peak in skeletal growth velocity can induce more changes at the skeletal level.

Dental indexes can be used as diagnostic tools for growth modification procedures that start at the prepeak period, as for correction of Class III malocclusions and transverse maxillary deficiencies.

**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 prepubertal and postpubertal growth phases, with no reliable indications for the onset of the pubertal growth spurt.

3. The clinical usefulness of the determination of dental maturity for the assessment of treatment timing for a skeletal malocclusion would thus be limited to growth modification procedures that start before the peak of the pubertal period, such as correction of Class III malocclusions and transverse maxillary deficiencies.

**REFERENCES**


