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Original article

Evaluation of skeletal maturity using maxillary canine, mandibular second and third molar calcification stages

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Summary

Objective: The objective of this study was to evaluate whether the calcification stages of maxillary canine, mandibular second molar, and mandibular third molar can be used for assessment of growth phase.
Materials and methods: The study group consisted of 274 subjects. Pre-treatment digital panoramic and lateral cephalometric radiographs of the patients were analysed. The patients' age was ranging from 7 to 19 years. Right maxillary canine, mandibular second molar and third molar were used as a sample. The teeth mineralization was assessed using modification of Gleiser and Hunt method. The skeletal maturation was assessed by the cervical vertebrae maturation (CVM) method.
Results: A significant association was found between CVM stage 2 and maxillary canine (UC) stage 4, mandibular second molar (LM2) stage 4, and mandibular third molar (LM3) stage 1. CVM stage 3 corresponded with UC stage 5, LM2 stage 5, LM3 stage 2. CVM stage 4 matched with UC stage 5, LM2 stage 6 and LM3 stage 3. The highest correlations between CVM and calcification stages were in the group of the maxillary canine ($r = 0.812$, $P < 0.01$) and mandibular second molar ($r = 0.824$, $P < 0.01$).
Limitations: Limitation of our study was that the study sample was not very big and the distribution value in the groups was very high, so it was impossible to check more statistical parameters.
Conclusions: The calcification stages of UC, LM2, and LM3 as indicators of skeletal maturity could be clinically used with caution, until this method is verified with a larger sample group.

Introduction

In orthodontics and dentofacial orthopedics skeletal maturity stage can have a considerable influence on diagnosis, treatment goals, treatment planning, and the outcomes of orthodontic treatment. Optimal treatment time is different in various malocclusions and treatment mechanics. For example maxillary protraction and rapid maxillary expansion are more effectively performed at the pre-pubertal stage. The functional jaw orthopedics is more effective when the growth spurt is included in the treatment. Skeletal maturation is also estimated considering extraction versus non-extraction treatment (1).

Considerable variations in the development among individuals of the same chronological age have led to the concept of assessing biological or physiological maturity. The concept of physiological age is based upon the maturation degree of different tissue systems (2). The most commonly used methods for growth evaluation are: the somatic (based on the general body changes along with the development of the secondary sex characteristics) and the radiological ones (assessment of the hand-wrist radiographs or serial lateral cephalometric radiographs).

Cervical vertebral maturation (CVM) method has been proved to be effective for the estimating of the growth phase according to the morphological characteristics of the second, third, and fourth cervical vertebrae in the lateral cephalometric radiographs (3). When specific training is provided along with precise guidelines in assessing visually each stage, CVM method proves to be accurate and repeatable to a satisfactory level (4). This method has advantages over the hand-wrist method, which additionally requires hand-wrist radiograph and experience of the observer to evaluate growth indicators in it. Moreover, most of the bones of the body are preformed in the cartilage and later are developed by endochondral ossification, while the facial bones are formed by intramembranous ossification. Therefore, growth of the face may be regulated by other factors than those responsible for the growth of the long bones (5).

Even though CVM method is a reliable method for the evaluation of the growth phase, it requires a lateral cephalometric radiograph, which is not always compulsory pre-treatment record for every patient. An increasing awareness of the risks associated with X-rays has led clinicians to re-evaluate the indications for taking a lateral cephalometric radiograph. Although the majority of orthodontists judge that lateral cephalometric radiograph is important for producing a treatment plan, despite that, it does not seem to have an influence on orthodontic treatment planning (6). Recently, McCabe and Rinchuse in a survey of orthodontic practitioners regarding the routine use of lateral cephalometric radiographs established that in orthodontic treatment 60.34% orthodontists reported always taking pre-treatment lateral cephalometric radiographs and only 38.53% reported always performing a cephalometric analysis on pre-treatment lateral cephalometric radiographs. They concluded that there is a current trend toward the decrease in the amount of practitioners routinely tracing lateral cephalometric radiographs (7). Furthermore, in some cases, optimal treatment timing is delayed after the diagnosis, making a later re-evaluation of the growth phase necessary. Therefore, lateral cephalometric radiographs are not taken routinely, whereas panoramic radiographs are routinely available in orthodontic practice and are useful to assess dental maturity.

So as an alternative to CVM method, dental development has also been widely investigated as a potential predictor of the growth phase (8–14). Generally, dental development can be assessed either by the phase of tooth eruption, or the stage of tooth calcification, with the latter being more reliable (15, 16).

The aim of this investigation was to evaluate whether the calcification of maxillary canine, mandibular second molar, and mandibular third molar are useful to determine the growth phase.

Materials and methods

A cross-sectional study was approved by the ethical committee of Lithuanian University of Health Sciences. The study group consisted of 274 orthodontic patients (164 females, 110 males), treated in the Clinic of Orthodontic, Lithuanian University of Health Sciences. Pre-treatment digital panoramic and lateral cephalometric radiographs were analysed. The patients' age was ranging from 7 to 19 years (mean age 12.34 ± 2.71 years). The selection criteria were as follows: Caucasians with the chronological age ranging from 7 to 19 years; normal growth and development, no congenital anomalies or syndromes; no congenitally missing teeth; good quality pre-treatment panoramic and lateral cephalometric radiographs, taken at the same day.

The calcification stages of maxillary canine, mandibular second and third molars were evaluated. We choose the maxillary canines, because usually these teeth are the last teeth which erupt after the loss of primary teeth in the upper arch and complete the period of the mixed dentition. The maxillary canines should erupt at the same time or a little bit earlier than the second molars. Mandibular second and third molars were included in the study because it was easier to evaluate their radices in the panoramic radiographs and to determine their calcification stages.

Calibrated examiners (orthodontists) assessed calcification stages of the teeth in the digital panoramic radiographs. The calcification of molars was scored according to the modified method of Gleiser and Hunt, which was simplified from 10 to 6 calcification stages (17) (Figure 1.). The canine calcification was estimated according to the analogous method, which was simplified to five stages (Figure 2). The growth phase was assessed using the CVM method proposed by Baccetti *et al.* (18) (Figure 3).

Teeth calcification stages and cervical vertebrae maturation were estimated by two trained orthodontists separately and blindly. Examiners were calibrated for inter-examiner reliability by means of Kappa statistics. The kappa values for interobserver agreement of the teeth calcification stages (0.81–0.85) and CVM stages (0.82–0.85) showed almost perfect agreement. As there were no statistically significant differences between teeth calcification stages on the right and left sides, only right maxillary canine (UC), mandibular second (LM2) and third molar (LM3) were used as a sample.

All statistical analyses were performed using the statistical software package 'SPSS 17.0 for Windows'. Hypotheses of interrelations between characteristics were verified using the χ^2 criterion method and Spearman correlation coefficients (r). A P-value of <0.01 was considered statistically significant.

Results

In the female group the mean age was 12.66 ± 2.76 years. In the male group the mean chronological age was 11.87 ± 2.6 years. The percent distributions for the relationship between the teeth stages and the stages of skeletal maturity are presented for the total male and female sample (Tables 1–3).

CVM stage 1 corresponded with the root length equal to or greater than the crown height of the maxillary canine (stage 3, $P < 0.01$), the formation of mandibular second molar's radicular bifurcation (stage 3, $P < 0.01$) and enamel formation at the occlusal surface of the third molar (stage 1, $P < 0.01$).

The pre–peak of pubertal growth spurt (CVM stage 2) corresponded with maxillary canine root canal still partially opened (stage 4, $P < 0.01$) and mandibular second molar roots' lengths equal to or greater than the crown height (stage 4, $P < 0.01$). At this stage the mandibular third molar crown enamel formation was completed at the occlusal surface (stage 1, $P < 0.01$).

The peak of pubertal growth spurt (CVM stage 3) corresponded with the closure of the maxillary canine root apex (stage 5, $P < 0.01$). The mandibular second molar's roots' canals were with parallel walls and the apical ends were still partially opened (stage 5, $P < 0.01$). The crown formation of the mandibular third molar was completed to the cementoenamel junction (stage 2, $P < 0.01$).

CVM stage 4 (deceleration of growth spurt) matched with the maxillary canine's root completed formation, with the closure of the apical end of the second molar's roots (stage 6, $P < 0.01$) and formation of the pulp chamber and radicular bifurcation of the mandibular third molar (stage 3, $P < 0.01$).

CVM stage 5 corresponded with the completed formation of maxillary canine and mandibular second molar and with the third molar roots length being equal to or greater than the crown height (stage 4, $P < 0.01$).

At the CVM stage 6 the apical ends of the lower third molar roots were still partially open (stage 5, $P < 0.01$).

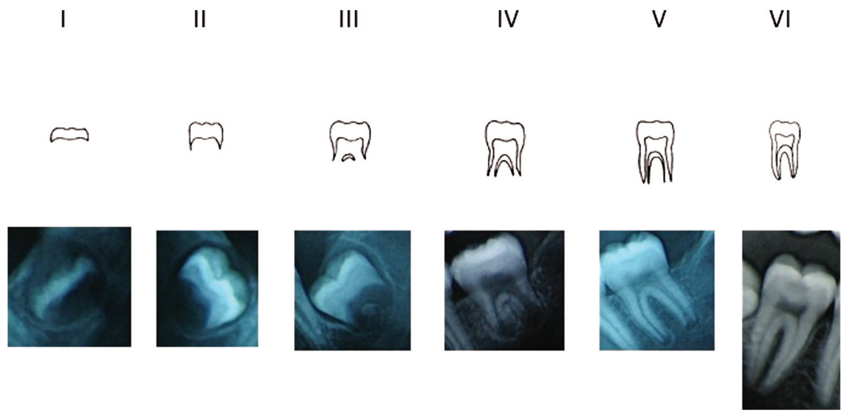

Figure 1. Representation of the calcification stages for molars (17). I—enamel formation is complete at the occlusal surface; dentinal deposition has commenced; II—crown formation is complete to the cementoenamel junction; III—walls of the pulp chamber are straight and the pulp horns are more differentiated; the root length is less than the crown height; radicular bifurcation is visible. IV—root length is equal to or greater than the crown height; bifurcation is developed sufficiently to give roots a distinct outline with funnel shaped endings; V—the walls of the root canal are parallel and apical end is still partially open; VI—the apical end of root canal is completely closed; the periodontal membrane has an uniform width around the root and the apex.

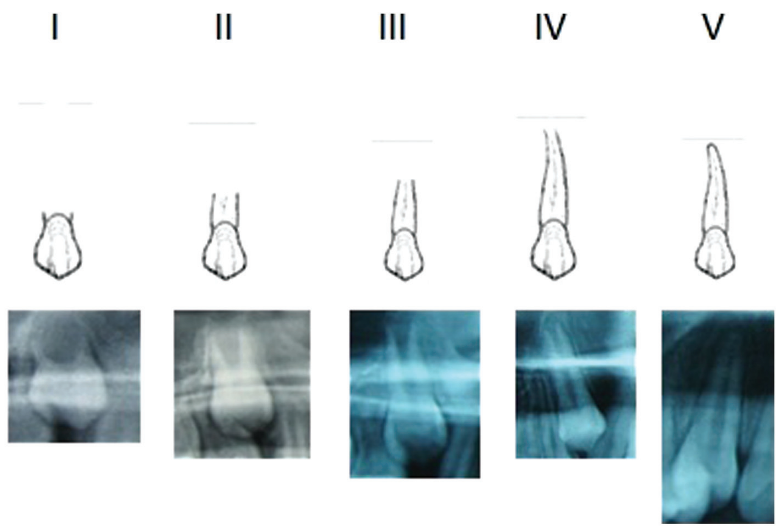

Figure 2. Representation of the calcification stage for canine. I—crown formation is complete to the cementoenamel junction; II—walls of the pulp chamber are straight and the pulp horn is more differentiated; the root length is less than the crown height. III—root length is equal to or greater than the crown height; root with funnel shaped ending; IV—the walls of the root canal are parallel and its apical end is still partially open; V—the apical end of root canal is completely closed; the periodontal membrane has a uniform width around the root and the apex.

The highest correlations between CVM and dental calcification stages were in the groups of maxillary canine ($r = 0.812$, $P < 0.01$) and mandibular second molar ($r = 0.824$, $P < 0.01$). In the group of mandibular third molar correlations between CVM and dental calcification stages were less ($r = 0.735$, $P < 0.01$).

The novelty of the study

The novelty of our study was, that mineralization of the teeth was assessed using another method for the estimation of teeth calcification stages (Gleiser and Hunt method) and this method was simplified and adapted to the orthodontists, so it was easy to use in the clinical practice (17). Furthermore, one more tooth-maxillary canine was included into the study sample. Although because superimposition of the structures on the panoramic radiographs, the mandibular teeth are usually evaluated for the identification of the maturity stages (this was done in the previous studies), the visibility of maxillary canines is quite good comparing to other maxillary teeth and it can be used for easy estimation of the teeth calcification stages.

Discussion

Nowadays, there are many methods for the accurate prediction of growth phase. However, studies show contradictory results between dental and skeletal maturation (19, 20). The purpose of this study was to determine whether the calcification of the maxillary canine, mandibular second molar and mandibular third molar were useful for the determining of growth phase.

The results of the studies searching correlation between the different teeth mineralization stages and skeletal maturity are very controversial. The mandibular teeth have been reported to be the best for identification of the maturity stages because of the superimposition of the calcified structures on the maxillary teeth in the panoramic radiographs. Most studies investigated skeletal maturity on the hand-wrist radiographs and calcification of the teeth was rated according to the system of Demirjian.

Only several studies showed strong correlation between the third molars and the skeletal maturity stage. In the study done by Sun-Mi *et al.*, relationship between mandibular third molar calcification and skeletal maturity was investigated using Demirijian index, skeletal maturation, and CVM indicators. Upon examination of the intercorrelations, each showed a statistically significant correlation, with a slightly higher correlation existing between skeletal maturation and Demirijian index (r = 0.64) than cervical maturation and Demirijian index (r = 0.59). Authors pointed out that the end of the growth spurt coincides with formation of the pulp chamber, root length being equal to or greater than the crown height of the third molar (21). Such findings correspond to those of Chertkow and Fatti (13), and Engstrom *et al*. (12) also reporting strong correlation between third molar formation and skeletal maturity, though in the studies done by Krailassiri *et al*. (22) and Uysal *et al*. (23) the third molar demonstrated the poorest correlation.

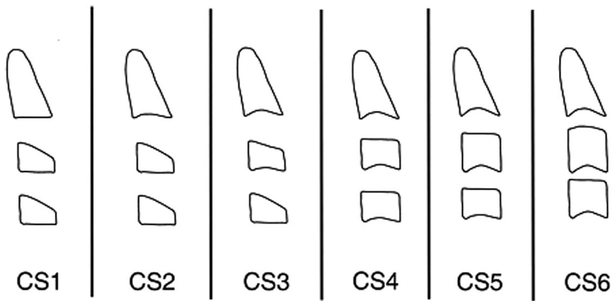

Figure 3. Morphologic features of vertebrae *C2* through *C4* (18). CS-1—The lower borders of all three vertebrae (C2–C4) are flat. The bodies of C3 and C4 are trapezoid in shape. CS-2—A concavity is present at the lower border of C2 in 80% of cases. The bodies of both C3 and C4 are trapezoid in shape. CS-3—Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 can be either trapezoid or rectangular horizontal in shape. CS-4—Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of C3 and C4 are rectangular horizontal in shape. CS-5—The concavities at the lower borders of C2, C3, and C4 still are present. At least one body of C3 or C4 is square in shape. If not square, the body of the other cervical vertebrae still is rectangular horizontal. CS-6—The concavities at the lower borders of C2, C3, and C4 still are present. At least one body of C3 or C4 is rectangular vertical in shape. If not rectangular vertical, the body of the other cervical vertebrae is square.

Some studies have found the maturity of the mandibular canines to be closely related to the peak adolescent height velocity (8, 12). The findings of Chertkow and Fatti showed a close relationship between mandibular canine calcification stage G and various skeletal indicators of the pubertal growth spurt. However, Krailassiri *et al*. (22) suggested that the interpretation of the relationship between the stage of dental and skeletal development of the canine teeth and the late stages of skeletal maturity was not meaningful.

Nevertheless, lower second molar and lower second premolar usually were identified as the best predictors of skeletal maturity. Uysal *et al*. (23) in a study had approved that the calcification stage of the second molar had the highest correlation with the skeletal maturity stage. In Turkish subjects, the tooth sequence in order of the lowest to the highest correlation was: third molar, canine, first premolar, second premolar, and second molar. Authors concluded that the completion of root formation of the mandibular canine and first premolar may be used as a maturity indicator of the pubertal growth spurt.

In a similar study done by Krailassiri *et al.* the relationship between the calcification stages of the mandibular canines, premolars, second, third molars, and skeletal maturity stages among Thai individuals was investigated. The second premolar was the tooth showing the highest correlation (r = 0.66 in male subjects, r = 0.69 female subjects). The third molar demonstrated the poorest correlation (22). The tooth sequence in order of the lowest to the highest correlation for male subjects was: the third molar, the canine, the second molar, the first premolar, and the second premolar; the corresponding sequence in female subjects was: the third molar, the first premolar as well as the canine, the second molar and the second premolar.

Perinetti *et al*. assessed the dental maturity of the mandibular canine, the first and second premolars, and the second molars. The correlation coefficients for the dental maturation stages with the growth phases were similar and ranged from 0.67 to 0.72 for the

Table 1. Correlation between the mineralization stage of maxillary canine and cervical vertebrae maturation (grey column $P < 0.01$, $r = 0.812$).

Maxillary canine (UC) calcification stage	Cervical vertebrae maturation stage					
	CS-1	CS-2	CS-3	CS-4	CS-5	CS-6
UC-1	2 (3.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
UC-2	12 (19.4%)	4 (15.4%)	2 (4.5%)	0 (0%)	0 (0%)	0 (0%)
UC-3	**26 (41.9%)**	4 (15.4%)	10 (22.7%)	0 (0%)	0 (0%)	0 (0%)
UC-4	14 (22.6%)	**12 (46.2%)**	10 (22.7%)	12 (28.5%)	6 (12.5%)	0 (0%)
UC-5	8 (12.9%)	6 (23.1%)	**22 (50.0%)**	**30 (71.5%)**	**42 (87.5%)**	**52 (100%)**
Total 274	62 (100%)	26 (100%)	44 (100%)	42 (100%)	48 (100%)	52 (100%)

Table 2. Correlation between the mineralization stage of the mandibular second molar and cervical vertebrae maturation (grey column $P < 0.01$, r =0.824).

Mandibular second molar (LM2) calcification stage	Cervical vertebrae maturation stage					
	CS-1	CS-2	CS-3	CS-4	CS-5	CS-6
LM2-1	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
LM2-2	10 (16.1%)	0 (0%)	2 (4.5%)	0 (0%)	0 (0%)	0 (0%)
LM2-3	**22 (35.5%)**	6 (23.0%)	10 (22.7%)	4 (9.5%)	0 (0%)	0 (0%)
LM2-4	20 (32.3%)	**10 (38.5%)**	10 (22.7%)	4 (9.5%)	2 (4.2%)	0 (0%)
LM2-5	8 (12.9%)	10 (38.5%)	**22 (50.0%)**	10 (23.8%)	18 (37.5%)	12 (23.1%)
LM2-6	2 (3.2%)	0 (0%)	0 (0%)	**24 (57.2%)**	**28 (58.3%)**	**40 (76.9%)**
Total 274	62 (100%)	26 (100%)	44 (100%)	42 (100%)	48 (100%)	52 (100%)

Table 3. Correlation between the mineralization stage of the mandibular third molar and cervical vertebrae maturation (grey column $P < 0.01$, $r = 0.735$).

Mandibular third molar (LM3) calcification stage	Cervical vertebrae maturation stage					
	CS-1	CS-2	CS-3	CS-4	CS-5	CS-6
LM3-1	34 (54.8%)	14(53.8%)	8 (18.2%)	1 (2.4%)	0 (0%)	0 (0%)
LM3-2	21 (33.9%)	8 (30.8%)	25 (56.8%)	10 (23.8%)	1 (2.1%)	0 (0%)
LM3-3	7 (11.3%)	4 (15.4%)	6 (13.6)	20 (47.6%)	12 (25.0%)	5 (9.6%)
LM3-4	0 (0%)	0 (0%)	5 (11.4%)	8 (19.1%)	25 (52.0%)	10 (19.2%)
LM3-5	0 (0%)	0 (0%)	0 (0%)	3 (7.1%)	8 (16.7%)	28 (53.9%)
LM3-6	0 (.0%)	0 (0%)	0 (0%)	0 (0%)	2 (4.2%)	9 (17.3%)
Total 274	62 (100%)	26 (100%)	44 (100%)	42 (100%)	48 (100%)	52 (100%)

canine, first premolar, and the second molar, respectively. However, the dental maturation stages of the mandibular teeth showed satisfactory diagnostic performance only for the identification of the pre-pubertal growth phases, with no reliable indications for onset of the pubertal growth spurt. The study showed 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 likelihood ratios (24).

In the Surendran and Thomas study dental maturity was assessed through the calcification stages from panoramic radiographs of the mandibular canine, first, second premolars, and second molar. Determination of skeletal maturity was done according to the modified middle phalanx of the third finger stages method on radiographs. Crown formation to the cementoenamel junction of the lower second molar was associated with the pre-pubertal growth spurt. The root canal closure of the second molar had the highest value for identification of the post-pubertal growth phase (25). However, authors stated that though dental and skeletal maturity is highly correlated, although the diagnostic performance of dental maturity for the identification of any stage of skeletal maturity is limited. The dental maturation stages of the mandibular teeth show satisfactory diagnostic performance only for the identification of the pre-pubertal and post-pubertal growth phases, with no reliable indications for the onset of the pubertal growth spurt.

It is important to take into account, that different samples may influence the results of the correlation between the teeth and bone maturity, especially the third ones, as they are known for their many variations based on previous studies.

The results of our study showed that maxillary canine, mandibular second molar and third molar had a high correlation with the cervical vertebrae maturation stages. Our findings corresponded with the findings of other studies, that mineralization stage of the mandibular second molar was a good predictor of skeletal maturity. Furthermore, we found that calcification stages of maxillary canines and mandibular third molars were good predictors of growth phase too and could be used in the clinical practice.

This concordance between teeth development and skeletal maturity could allow practitioners to use maxillary canines, mandibular second and third molars as an auxiliary manner to evaluate skeletal maturity stage in the growing patients from the panoramic radiographs. However, individual variations of tooth formation should be deliberated.

Limitations

Limitation of our study was that the study sample was not very big and the distribution value in the groups was very high, so it was impossible to check more statistical parameters.

Conclusions

The results of this study showed that maxillary canine, mandibular second and third molar calcification stages could be indicators of growth stage. In the clinical practice to ascertain growth spurt stage is very important for treatment timing and methods. So according to this study the indicator of pre-peak of pubertal growth spurt could be the opened apical end of the maxillary canine root. While the opened apical ends of the mandibular second molar roots could match with the peak of pubertal growth spurt. The indicator of deceleration of growth spurt could be the formation of the pulp chamber and radicular bifurcation of the mandibular third molar.

This method is easy to apply, but for the validation of it a larger sample should be checked, including early and late dental developmental groups compared with similar skeletal maturation groups.

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