Correlation of Dental Maturity with Skeletal Maturity from Radiographic Assessment: A Review

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There have been many attempts to correlate dental development with skeletal growth. The relationship is generally considered to be moderate at best. However, there is evidence that hand-wrist radiographic interpretation of remaining growth can be augmented by taking into account the developing dentition. In addition, the practicality of evaluating routine dental radiographs and avoiding additional radiation is advantageous. To this point, no system has been described to match apical development by Demirjian's stages and compare it to skeletal development and remaining growth. This study reviewed articles pertinent to the relationship between developing teeth and skeletal maturity and remaining growth, and a system is proposed to give practitioners an additional assessment for growth and development.

Keywords*: dental maturity, skeletal maturity, cervical vertebrae maturity, mandibular third molar*
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INTRODUCTION

Accurate evaluation of patient's growth is important in many fields of dentistry. The practitioner placing implants needs to know that skeletal growth is complete.[1,2] The orthodontist benefits from assessing the amount of skeletal growth already completed in planning orthopedic treatment.[3] Surgeons likewise assess growth before planning surgeries involving growing structures.[4] Hand-wrist radiographs are accepted as the standard for skeletal growth evaluation, but require additional time and exposure of the patient to additional radiation.[5] For this reason, investigators have searched for additional ways to assess growth with commonly taken radiographs, such as periapical, panoramic and cephalometric radiographs.[3]

Dental formation has long been employed as a method to assess chronological age and skeletal development.[6] Eruption of the dentition was investigated but it is influenced by systemic and local factors whereas root development is not.[7] Children and adolescents have multiple teeth to evaluate development, as most of the teeth are still forming. About the age of 14, most of the teeth cease development at the apex except third molars.[8] The third molars are the last to begin development and finish development, and are thus of interest in evaluating the growth of mid to late teens.[9] This paper reviews articles using dental development to assess skeletal growth from routine dental radiographs.

PubMed was searched for the following keywords: skeletal maturity, skeletal growth, cervical vertebra maturity, hand-wrist radiographs, dental maturity, tooth development, dental staging, dental radiographic stage assessment, dental mineralization, third molar development, and orthopantogram. In addition, hand searches from the references of relevant studies were performed. All studies were gathered and reviewed for similarities and differences.

RADIOGRAPHIC EVALUATION OF DENTAL AND SKELETAL MATURITY

Hand-wrist radiographs

There are three main radiographic means to determine skeletal development: hand-wrist radiographs; cephalometric radiographs; and panoramic or periapical radiographs. Skeletal evaluation of the hand can be evaluated by observing changes in the epiphysis in different joints of the hand, fusion of plates, and the presence of the sesamoid bone. Generally, the proximal, middle and distal phalanx of the third finger, middle phalanx of the fifth finger, sesamoid bone and the radius are analyzed. Skeletal maturity indices (SMI) from 1–11 have been described by Fishman (Table I).[10-12] These stages are useful in determining remaining growth potential. These 11 stages are divided into four categories including ephiphyseal widening (SMI 1-3), ossification of the sesamoid of the thumb (SMI 4), capping of the third and fifth finger epiphyses over their diaphyses (SMI 5–7), and finally fusion the third finger epiphyses and

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diaphysis and radius (SMI 8–11). The clinician can quickly gauge the remaining growth by first viewing whether the adductor sesamoid bone of the thumb is present. If it is not, then the epiphyses of the third and fifth finger can be viewed for widening at select points, and the appropriate stage determined. If the sesamoid bone is present the third and fifth finger can be viewed for capping. If there is no capping, then the individual is in the ossification stage. The capping stages can be determined from the select points of the third and fifth finger. If the sesamoid is present and capping is completed, the third finger and radius can be viewed for fusion.[11,12] The peak growth spurt of an individual is between stages 5–6.[13,14]

Accuracy of hand-wrist predictions is greater right around the peak growth spurt and when different time points are viewed, which may require repeated radiographic exposure.[15] In addition, single ossification events are not as accurate as bone staging.[16]

Hand-wrist radiographs are not difficult to assess or acquire. However, to decrease radiographic exposure to patients and when other indications may be utilized for rough estimates, hand-wrist films may not be practical.[17] Many orthodontists can get adequate estimations of growth from patient questionnaires, observed growth changes in patients, and cervical vertebral changes on lateral cephalograms.

Hand-wrist films and the developmental patterns from the bones are regarded as the standard for evaluating growth. In original publications, hand-wrist coordinated growth to statural height, and this has been validated by other studies.[18,19] It is reported, though, that the correlation between hand-wrist and remaining statural growth is around r = 0.7, and predicting growth of the face is even lower r = 0.52.[17] Another study measured mandibular growth in three groups of individuals during acceleration, peak and decelerating phases of puberty (determined from hand-wrist radiographs) and found that there were no statistical differences between the groups.[20] There was, however, an acceleration of mandibular growth during the peak growth spurt. The mandibular growth has also been shown to be different in early or late maturers, and in molar classifications (Class I, II and III).[21,22] In addition, ethnic variations can introduce variability in growth patterns, complicating the interpretation of hand-wrist films.[23] In contrast, Sidlauskas *et al*[24] reported a close correlation between hand-wrist films and mandibular and maxillary growth. Growth may be difficult to determine from hand-wrist radiographs during final stages, such as determining whether an orthognathic patient is ready for surgery.[25] Thus, additional information that can be easily acquired should be considered in evaluating remaining growth.[26]

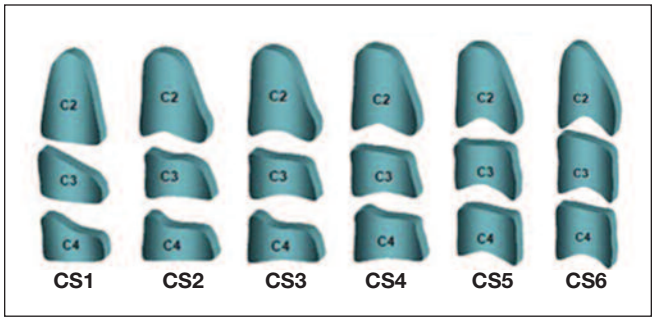


Figure 1. Cervical Maturation Stages. Remaining growth can be assessed from the morphology of the vertebrae 2-4. As growth occurs, the vertebrae bodies grow more vertically than horizontally, and deeper concavities are observed on the lower borders.

Lateral cephalometric radiographs (cervical vertebral maturation)

Lateral cephalograms show the cervical vertebrae, and their morphologic changes in size and shape as an individual grows. These changes are divided into 6 major stages (Figure 1 and Table I). The vertebrae increase vertically and horizontally during the stages, and the concavities become more pronounced as growth occurs.[27] The cervical vertebral maturation (CVM) stage 1 is correlated with initial of growth (85-100% remaining); stage 2 with acceleration of growth (65-85% remaining); stage 3 with transition of growth (25-65%); stage 4 with deceleration of growth (10–25%); stage 5 with maturation of growth (5-10%); and stage 6 with completion of growth (0%).[13] Some have questioned the reproducibility of staging cervical vertebra, and intra- and inter-observer consistency is questioned.[28] This technique has been modified by Bacetti *et al*[29] to include 5 stages on the basis that it is difficult to differentiate between cervical stage (CS) 1 and 2.[29] Reproducibility of this modified CVM technique is reportedly as high as 98.6%. With the use of thyroid collars, CVM1 was revised to include only the

Table I. Relationships between skeletal and dental maturity and their association with growth

Remaining Pubertal Growth	Velocity of Growth	SMI	CS	Dental Stage G-H	Mandibular Third Molar
85%-100%	Slow	1-2	1	1st molars and central incisors	No bud, or radiolucent bud
65%-85%	Moderate	3-4	2	1st molars and central incisors	Radiolucent bud
25%-65%	Peak	5-6	3	Mandibular canines	Crown formation beginning
10%-25%	Moderate	7-8	4	2nd premolars	Crown calcification complete
5%-10%	Slow	9-10	5	2nd molars	Root formation beginning
0%	Slow	11	6	All teeth complete except third molars	Root formation 1/3 to 2/3

SMI, skeletal maturity index according to Fishman;[10] CS, cervical stage according to Hassel and Farman;[13] Demirjian dental stages modified by Krailissari *et al*.[53]

2–4th vertebrae, as the 5-6th were no longer imaged.[13] Despite criticisms, CVM stages are consistently correlated with skeletal maturity indicators in the hand.[30-32]

Gu and McNamara[33] measured mandibular growth and cervical maturation. They determined that peak mandibular growth occurs between CS2 and CS3. Average intervals between stages were 16-17 months, except CS5-CS6, which was 12 months. Bacetti *et al*[29] also investigated CVM and determined peak mandibular growth and found peak growth between cervical vertebral maturation stage (CVMS) II and CVMS III (CS3-CS4). Postpubertal craniofacial growth prediction from CVM is modestly effective.[34]

The cervical vertebrae as maturational indicators offer several advantages and disadvantages. There is reduced radiation exposure, and cephalograms are routinely taken in an orthodontic office. Proper interpretation of the stages of CVM can be problematic, as illustrated in a study where clinicians trained in CVM interpretation only agreed with themselves 62% of the time on repeated analysis.[28] The same study showed an improvement when there are two longitudinal radiographs to review. However, the clinician should be aware of any and all indicators of growth when treatment planning, as each individual has their own pattern of growth.

Panoramic or periapical radiographs (dental development)

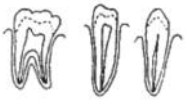
As the teeth develop, the roots undergo similar morphological stages. These stages have been described by several authors, and compared to other growth indicators, such as hand-wrist radiographs and cervical vertebrae. Some common morphological categories were reviewed.[35-39] Among these, Olze *et al*[40] reported that Demirjian *et al*[36] offers the most reproducible assessment of mandibular third molar development and is thus employed frequently in staging the third molar development. Furthermore, Dhanjal *et al*[41] reported intra-observer agreement was highest using Demirjian's method. The development stages described by Demirjian are described in Table II.

Teeth vary in development.[42] This can be due to ethnicity, sexual differences and on an individual basis. Some develop early dentally and late skeletally, or vice versa.[43] Dental maturity is generally accepted in the literature to be variable and the relationship to skeletal development is reported as moderate.[15,44-46] While some authors have reported high correlations between skeletal growth and dental development,[7,47-49] others findings have demonstrated low correlations.[50]

There is no denying that observing the developing dentition is the quickest and most accessible test for maturity that is available without additional exposure. For this reason, several studies have suggested using routine radiographs for a first estimate or adjunct, and if more detailed information is needed about growth, additional sources can be utilized.[3,5,15,51]

The mandibular canine is of interest because just before its apex calcifies it is correlated to other events of puberty.[43–45,48] This can be useful for an indicator of an impending growth spurt. The first molar and central incisor is finishing development at the root apex during cervical vertebral stage (CVS) 1 and 2, just before or at the beginning of pubertal growth.[7] By the end of growth, all teeth except third molars are likely to be finished or near finished in apical development.[52]

Table II. Stages of tooth development by Demirjian *et al*[36] modified by Krailassiri *et al*[53] (Used with permission from The Angle Orthodontist)

Molar Premolar Canine	Stage	Morphologic Characteristics
	A	Calcification of single occlusal points without fusion
	B	Fusion of mineralization points
	C	Enamel formation completed at the occlusal surface, dentin formation started
	D	Crown formation complete to the CEJ, root formation commenced
	E	Root length less than crown height, bifurcation commenced calcification
	F	Root length equal or greater than crown height, roots have distinct form
	G	The walls of the root canal are parallel, apical end open
	H	The root apex is completely closed, periodontal ligaments are uniform throughout

The mandibular second premolar has shown a high correlation with skeletal markers of the hand, substantiated by several investigators.[51-53] Basaran *et al*[7] demonstrated that the second premolar was nearing completion of apex formation at the CS4.

Mandibular third molars are useful especially in determining the remaining growth of a patient over the age of 14, and offer a unique perspective because their development lasts an extended period of time.[52,54] Also, in determining remaining skeletal growth of an orthodontic patient, the third molar is the only remaining tooth to undergo development during final growth.[54]

The correlation between mandibular third molar development and skeletal development was investigated in several studies, and some showed a strong relationship between third molar development and skeletal maturity.[47-49,54,55] In contrast, some studies have reported poor relationships.[50,55] Third molars vary in development by ethnicity and sex, and this should be considered when evaluating their development.[5,7,53,56] Relationships between skeletal, cervical, and dental maturity associated with growth are summarized in Table I.

PRACTICAL APPLICATION

Dental development is variable. Similar to height measurements, the current number or category may not be as important as the change. Thus, evaluating the dentition over a period of time may indicate an individual pattern. If an individual is clearly an early dental developer, the teeth finishing apical development may differ from those listed in the chart. This is one of the difficulties of assessing growth – it may be different for each patient, and skeletal growth can be different than growth of the dentition or face. All helpful information should be considered when evaluating growth.[25]

Developing tooth apices have been correlated with stature and menarche.[57] Stature is correlated with skeletal development.[58] In fact, serial height measurements are a good way to estimate growth patterns, with a reported high correlation to height change and skeletal development.[59] In females, menarche does not always happen before peak height velocity, though it is a fairly good indicator of accelerating growth.[60] It does not appear to be strongly correlated with dental development. In males, prepubertal to male voice change can be used with other factors as an indicator for pubertal growth spurt.[61] Insulin-like growth factor 1 (IGF-1) has also shown promise for use in assessing growth.[62]

Planning orthopedic treatment for orthodontics is important. McNamara *et al*[63] reported that in patients treated with the Frankel appliance, greater increase of mandibular length was observed during ages closer to puberty. Pancherz and Hagg[64,65] reported greater effects of Herbst appliance therapy during peak growth periods. Malmgren *et al*[66] reported similar findings with an activator and high pull headgear. Treating just before and during the time of peak growth allows for more skeletal than dental change.[53]

It is generally accepted that orthognathic surgery must be planned to occur after growth has been completed according to a survey of orthodontists.[67] Often cleft palate patients undergo surgical intervention during growth, and decreased postsurgical development of the maxilla has been documented.[68] This decreased growth and the potential for changes deviant from the final surgical position can be avoided by assessing growth and timing treatment when it is complete.[69] It may be difficult to determine final stages of growth from hand-wrist. For this reason, it is recommended that other indicators of growth such as serial cephalometric radiographs and vertical height changes be viewed, especially for Class III patients with condylar hyperplasia.[25]

Likewise, implant placement requires careful timing. The ideal treatment for missing teeth may involve either substitution or single tooth implant placement.[70] Timing and treatment is best determined by an interdisciplinary team and outcomes are improved through a team approach.[71,72] In the case of a growing patient, space must be managed carefully for the final implant, which should only be placed when a patient's growth is completed. It is recommended that implants be placed after vertical growth is complete, which is in the second decade of life.[73] Nevertheless, mature adults may exhibit vertical growth similar to adolescents and vertical steps due to growth have been observed.[74] In some cases, such as ectodermal dysplasia, implant placement in a growing patient may be appropriate.[75] Thus, growth determination is vital to various interdisciplinary treatment planning.

VARIABILITY

Environmental factors may influence the development of teeth, but generally root formation is not affected by malnutrition, or other processes that interfere with growth.[76] Care should be taken when the patient has any endocrine disorders, or conditions that may cause delayed development of the dentition. In categorizing dental formation, multiple stages of development used for dental maturity assessment and the method of evaluating skeletal maturity introduce variability.[41] Although Demirjian *et al*[36] offers good intraobserver agreement, developing crowns of molars may be angled so that differing crown stages is not very practical. In addition, in classification systems the more stages the greater chance for error.[56] In an effort to increase accuracy, more stages have been added, but this may make classifying the stages more difficult.[41,77]

Different radiographic techniques may introduce variables. Accurate radiographs are important in assessing both the skeletal and dental development structures. It is interesting to note that a study using periapical radiographs of the third molars had a higher correlation than other studies using panoramic radiographs.[76] Some advantages are seen with improved imaging techniques like digital panoramic radiographs.[78] Cone-beam computed tomography (CBCT) imaging systems may further assist assessment of morphological changes of developing teeth.

Each person has their own individual growth pattern, and they do not necessarily follow the averages. Skeletal growth of the long bones of the body does not always correlate strongly to facial skeletal growth, which should be considered when treatment planning.

CONCLUSIONS

Hand-wrist examination is the gold standard for evaluating remaining growth, yet it clearly can be augmented with additional information such as dental development. Cervical vertebrae morphology can also be evaluated for remaining growth as it correlates strongly with skeletal maturity indicators. The relationship between dental maturity and skeletal maturity is reported to be strong, yet should not be the only evaluation done in assessing growth when more detailed information is required. There is some promise for using the dentition as a rough estimator and an adjunct in evaluating patients for skeletal growth and development. In addition, in some situations it may obviate the need for additional exposure for hand-wrist radiographs.

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