CORRELATION OF DENTAL CALCIFICATION STAGES, SKELETAL MATURITY STAGES AND CHRONOLOGIC AGE OF CHILDREN OF 7-16 YEARS AGE GROUP: A CROSS SECTIONAL DESCRIPTIVE STUDY

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LIST OF ABBREVIATIONS

Sr. No.	Short Form	Full Form
1	PHV	Peak height velocity
2	SMI	Skeletal maturity indicator
3	CVMI	Cervical vertebrae maturity index
4	CVMA	Cervical vertebrae maturation assessment
5	OPG	Orthopantamogram
6	MP3	Middle phalanx of third finger
7	IOPA	Intraoral periapical radiograph
8	RVG	Radiovisiograph
9	CA	Chronological age
10	DA	Dental age
11	SA	Skeletal age
12	ALARA	As low as reasonably achievable

INTRODUCTION

Growth is a complex and dynamic process. The child's body system goes through a series of multiple changes and eventually arrives at a maturity state. Knowing the stage of maturation of a patient is important as it plays an important role in the etiology of malocclusion and also in evaluation of diagnosis, treatment planning, retention and stability. [1] The onset and completion of the pubertal growth spurt of the patient helps in assessing skeletal maturational status, which can influence the diagnosis, treatment planning and prognosis of the orthodontic treatment.

Birth date by calendar determines chronological age. Every individual matures according to his or her own biological clock leading to wide individual variation in the timing of pubertal growth spurt with respect to chronological age. The chronologic age is governed by various factors like genetic, epigenetic, environmental, nutritional, hormonal etc. Therefore, chronological age cannot be considered as a reliable indicator for the evaluation of maturity status of a child. This has led to the concept of Biological age or physiological age.[2]

The physiological age of a person is determined by the degree of maturation of the different tissue systems.[3] Stature of a person is not an indicator of maturity and therefore, additional information is required to estimate the maturation level of the individual.[4] This information can be obtained from the somatic, sexual, skeletal, dental, and pubertal development from which the physiologic age can be estimated.[2,4] Annual growth increments in height or weight determine the somatic maturity. A general growth of the skeleton is represented by measurement of height. Many studies have shown a strong correlation between the peak height velocity (PHV) and peak facial growth. Therefore, height might represent a skeletal measure that can be used to predict the timing of the facial growth spurt. Even if height is one of the powerful tools in growth assessment, it has become impractical in clinical practice as it requires longitudinal data and needs time and repeated observations.[4]

The clinical importance of evaluating skeletal maturation has been recognized by many researchers.[5,6,7] The degree of development of ossification in bone is referred to as skeletal maturation. During growth, every bone goes through a series of changes that can be seen radiologically. The sequence of changes is relatively consistent for a given bone in every person. The timing of the changes varies from person to person. But the events are reproducible enough to provide a basis for comparison between different persons.[6] The hand, foot, knee, elbow, shoulder, hip, and cervical vertebrae can be used to assess skeletal age of an individual. Out of the above-mentioned bones, cervical vertebrae and hand-wrist methods has been explored extensively as indicators of maturity.[2] Cervical vertebrae method have been explored extensively by many researchers[7,8] but the method required longitudinal follow-up for accuracy.[2] The hand– wrist region radiographs has been most frequently used for pubertal growth assessment as many centers are maturing at different rate and time. [2,9,10]

Dental age determination is required in various clinical and scientific disciplines like pediatric dentistry, orthodontics, archeology, paleodontology and forensic dentistry. Dental age represents a series of recognizable events that occur in a particular sequence and hence is a simple and useful indicator of maturity. Dental maturity can be estimated by the number of erupted and unerupted teeth, stages of dentition (deciduous, transitional or permanent); tooth calcification, the degree of tooth structure, stages of crown formation of developing teeth and stages of root formation of all erupted teeth. Dental eruption is influenced by local factors such as early exfoliation or extraction of the deciduous tooth, impaction and crowding of the permanent teeth, ankylosis etc. and hence cannot be precisely used for dental age estimation. Tooth mineralization, on the other hand, is a constant process which makes it a justified alternative method to determine dental maturation.[2]

The relation between the dental and skeletal ages has been evaluated in order to correlate the two ages with chronological age for the purpose of diagnosis and treatment planning in pediatric dentistry.[11] Also if a strong association exists between skeletal maturity and dental calcification stages, the stages of dental calcification might be used as a first level diagnostic tool to estimate the timing of the pubertal growth spurt. [12] Various such studies have been conducted in different populations all over the world as well as in different regions of India. But data correlating the chronological age with the dental and skeletal ages for Central India population is lacking.

Hence, the present study was planned to correlate the dental calcification stages, skeletal maturity stages and chronologic age in children of 7-16 years age group from Central India.

AIM AND OBJECTIVES

Aim of the study:

To estimate and correlate the dental calcification stages, skeletal maturity stages and chronologic age in children of 7-16 years age group from Central India.

Objectives:

1. To determine dental maturation by Willems method.
2. To determine the skeletal maturation by middle phalanx maturation according to the Greulich and Pyle radiographic atlas.
3. To correlate the dental and skeletal age to chronologic age.
4. To evaluate the gender differences of the dental and skeletal ages.

REVIEW OF LITERATURE

Nolla CA. (1960)[13] did a study to organize a technique for the detailed appraisal of the development of the permanent dentition as revealed by the radiographs and to construct norms (tables & graphs) which will display the average development of individual teeth for boys and girls. The study was conducted by taking serial oral radiographs of 25 boys and 25 girls obtained from the Child Development Laboratories of the University of Michigan School. A detailed description of the changes in developing teeth as observed on the radiographs was described. Accordingly, developmental curves for each tooth and dental age values, both for boys and girls were obtained. Following, norms for maturation of permanent teeth was obtained in terms of numerical values for boys and girls separately. After adding the values obtained for each tooth, the sum was matched with the table for translation of developmental value into the dental age. The author concluded that the type of growth displayed by each tooth was same. There was no significant difference in the rates of development between boys and girls. Only a few differences were seen between right and left teeth of same kind.

Moorrees CF, Fanning EA, Hunt EE. (1963)[14] provided norms of the formation of ten permanent teeth, namely, the maxillary incisors and all eight mandibular teeth From the total of 134 children, the data of 48 males and 51 females. The chronology of the formation of the permanent mandibular posterior (C-M3) teeth and the later stages of the permanent maxillary and mandibular incisors was determined and presented in graphic form. The charts were designed specifically for determining the dental maturation of an individual child for each tooth separately.

Demirjian A, Goldstein H, Tanner JM. (1973) [3] gave a new method for estimation of dental age, by reference to the radiographic appearances of the 7 teeth on the left side of the mandible. Panoramic radiographs of 1446 boys and 1482 girls of French Canadian parentage were used. Each tooth was rated according to the developmental criteria (amount of dental deposit, shape change of pulp chamber, etc) rather than the changes in size. Eight stages A-H were derived, defined from the first appearance of calcified points to the closure of the apex. The sum of the scores of all seven teeth gave a dental maturity score which could be converted directly into a dental age. The authors concluded that the present system was applicable in 3 to 17 year age group. The maturity scoring system was universally applicable but the maturity score and the dental age depends on the population considered.

Fishman LS. (1979) [15] conducted a study to investigate the comparison that exists between chronological and skeletal ages within a population, to make some judgment as to the reliability of using cephalometric standards based on chronological age as it was commonly practiced and to study the diagnostic value of using skeletal age for cephalometric evaluation. A mixed longitudinal series of lateral cephalogram and hand-wrist radiograph were taken on 60 boys and 68 girls randomly selected ranging from chronological ages of 7½ to 15 years. Records were taken concurrently at approximately six month intervals. Standing height without shoes was recorded in centimeters. Skeletal age determinations were established on the basis of hand-wrist radiographs. Both Greulich and Pyle, Waterhouse and Greulich hand wrist radiograph atlases were utilized for this purpose. The skeletal and chronologic ages of the selected children showed significant correlation. Individual's comparisons of facial changes were made relative to respective chronologic and skeletal ages. The significance of skeletal vs. chronologic age discrepancy and its relation to the timings of facial growth was demonstrated.

Hägg U, Taranger J. (1980) [16] did a prospective longitudinal study to investigate the pubertal growth spurt and dental, skeletal, and pubertal in a 212 randomly selected Swedish children by means of maturation level indicators suitable for use in clinical orthodontics. The sample was examined from birth to adulthood and included a representative proportion of early-, average-, and late-maturing subjects. They concluded that the dental development in relation to the pubertal growth spurt was more advanced in boys than in girls, but the individual variation was great in both sexes. Skeletal development at the beginning and peak was more advanced in girls than in boys, whereas at the end of the pubertal growth spurt the skeletal development was more advanced in boys. Dental development, determined by means of dental emergence stages (DES), was not useful as an indicator of the pubertal growth spurt. The peak and end but, not the beginning of the pubertal growth spurt could be assessed by means of indicators taken from the skeletal development of the hand and wrist and the pubertal development (menarche and voice change).

Demirjian A, Buschang PH, Tanguay R, Patterson DK. (1985)[17] studied the interrelationships among 5 measures of physiologic maturity which were menarche, peak height velocity (PHV), 75% skeletal maturity, the appearance of ulnar sesamoid and 90% dental development of 50 French Canadian girls between 6 to 15 yr of age visiting Montreal Human Growth Research center and were followed longitudinally from 1967 to 1976. The age of menarche was obtained by asking the exact age at the date of menarche. Age of PHV was estimated graphically for each girl's longitudinal series by means of rules predicted upon the relative positions of the 3 points adjacent to peak velocity. Age of appearance of ulnar sesamoid was estimated from hand-wrist films. Dental age was obtained from panoramic radiographs following the tooth rating system of Demirjian, Goldstein, and tanner. They found that PHV was the most variable index followed closely by the appearance of the ulnar sesamoid. Menarche and 90% dental maturation were the least variable indices. They concluded that the skeletal, somatic and sexual maturities are interrelated whereas the dental development is unrelated to any other developmental systems. Hence the mechanisms controlling dental development are independent of somatic and/or sexual maturity.

Koshy S, Tandon S. (1998)[18] did a study to determine the dental developmental stages in the South Indian children and to test the applicability of Demirjian's criteria for maturity scoring in the dental age assessment of the same, to compile a new maturity score for the South Indian population and test its applicability and to find the interrelationship between the obtained dental age with the respective skeletal ages. One hundred and eighty-four children consisting of 93 males and 91 females were selected from ages 5 to 15 years. An orthopantomogram of each child was taken and scored according to the criteria given by Demirjian et al. A hand and wrist radiograph of the right and left side in a postero–anterior view was taken and assessed according to the criteria given in the ‘‘Radiographic Atlas’’ by Greulich and Pyle. Comparison between the skeletal ages of the males and females in the present study showed that the females had a higher skeletal age assessment indicating an early maturation in Indian females. In the present study, the Demirjian conversion of maturity score to dental age was not applicable to south Indian children. They stated that although various methods of age assessment are used, the applicability can vary due to the wide ethnic differences between populations which can influence the tooth formation, development, and eruption upon which the assessment parameters are based. It is therefore imperative, that the population to be tested has to be assessed on a scale devised on the same population group. The authors also stated that the assessed skeletal age did not relate to the dental age indicating that the determination of one of the ages is not a satisfactory method of knowing the other age.

Liversidge HM, Speechly T, Hector MP. (1999)[19] did a study to determine whether the standards of dental maturation of Demirjian et al (1973, 1976) were applicable to 521 London children of Bangladeshi and white Caucasian (English, Welsh, and Scotish) origin aged between 4 and 9 years. Dental age was assessed by the crown and root stages of seven mandibular teeth from rotational pantomographs. British children as a group were dentally advanced compared to the Canadian standards. There was no significant difference in the dental ages of the two ethnic groups of the study. They concluded that the dental maturation described by Demirjian et al (1973, 1976) was not suitable for British children.

Willems G, Van Olmen A, Spiessens B, Carels C. (2001)[20] did a study to evaluate the accuracy of Demirjian's dental age estimation in 2523 (1265 boys and 125 girls) Belgian Caucasian population and to adapt the scoring system in case of a significant overestimation as frequently reported. On average, 4 OPGs were selected for each age class of 1 yr 15 age classes in total) from 3-1 yr of age. A second sample of Belgian Caucasian population consisted of 355 OPGs (195 boys and 160 girls). The second sample was used to evaluate and compare the accuracy of original and adapted dental age estimation method. The obtained data of dental age using the original and adapted method on the second sample was analyzed for statistical significance for chronologic age. Demirjian's method resulted in a consistent overestimation of dental age. Most serious overestimation was found in 9-10 yr of age for boys and 9-11 yr of age for girls. In order to try and avoid this overestimation Demirjian's maturity scores were adapted using ANOVA on the data of Belgian Caucasian sample. This resulted in new tables with age scores directly expressed in years. They stated that calculating the adapted scores for 7 mandibular teeth directly results in estimated dental age. This adapted scoring system resulted in more accurate predictions in the given population.

Krailassiri S, Anuwongnukroh N, Dechkunakorn S. (2002)[12] studied the relationship between dental calcification stages and skeletal maturity indicators in Thai individual of 7 to 19 years of age. At the same skeletal maturity stage, the dental maturational patterns of male subjects were ahead of those of female subjects. The findings of this study indicate that tooth calcification stages might be clinically used as a maturity indicator of the pubertal growth period.

Eid RM, Simi R, Friggi MN, Fisberg M. (2002)[21] did a study where they applied Demirjian's method of dental age evaluation to the Brazilian children aged 6-14 yr in order to obtain dental maturity curves for each sex, to compare this data with that obtained by Demirjian, and to determine whether there is a significant correlation between dental maturity and body mass index. This was a retrospective study which reviewed the OPGs, height and weight measurements of 689 healthy children. They concluded that the Brazilian children were significantly more advanced in dental maturity compared to Demirjian's French Canadian children.

Madhu S, Hegde AM, Munshi AK. (2003)[22] did a study to assess the reliability of using the developmental stages of middle phalanx of the third finger (MP3) method in a standardized manner, and comparing it with a known standard method like CVMA (Cervical vertebrae maturity assessment). Sixty-seven (67) patients, (35 boys, 10 to 18 years and 32 girls, 8 to 16 years), who required skeletal maturity assessment, from the Department of Pedodontics and Preventive Children Dentistry, A.B. Shetty Memorial Institute of Dental Sciences, Mangalore, were selected for the study. Two radiographs namely lateral cephalogram and MP3 region radiograph using an IOPA film were used for the study. The method proposed by Lamparski and modified by Hassel and Farman was used for the assessment of cervical vertebrae. Stages proposed by Hagg and Taranger were used for the assessment of MP3 developmental stages. The authors found the method of skeletal maturity assessment using MP3 radiographs to be simple, highly reliable and less expensive and they concluded that it could be conveniently used as a simple diagnostic tool by all dental practitioners for an effective treatment planning.

Uysal T, Sari Z, Ramoglu SI, Basciftci FA. (2004)[23] investigated for the relationships between the stages of calcification of various teeth and skeletal maturity stages among Turkish 500 subjects (215 males and 285 females) from dental panoramic and hand-wrist radiographs in which the calcification of the mandibular canines, first and second premolars, and second and third molars was rated according to the system of Demirjian. To evaluate the stage of skeletal maturation of each hand-wrist radiograph, nine ossification events were determined according to the systems of Bjork, and Grave and Brown. Statistically significant relationships were determined between dental calcification and skeletal maturity stages according to Spearman rank-order correlation coefficients. The dental development and skeletal maturity were correlated. The second molar showed the highest correlation and the third molar showed the lowest correlation for female and male subjects. For both sexes, root formation of the canine, as well as the first premolar, was completed in the majority of the subjects at the MP3cap, PP1cap, Rcap stages. The study suggested that tooth calcification stages from panoramic radiographs might be clinically useful as a maturity indicator of the pubertal growth period. The authors concluded that it was appropriate to put these skeletal and dental maturation relationships into daily orthodontic diagnostic practice when treating a Turkish patient.

Mani SA, Naing LI, John J, Samsudin AR. (2008)[24] did a study to test the applicability of the two methods, namely Demirjian and Willems, for age estimation in a Malay population, and to find the correlation between body mass index and the difference between the dental age and the chronological age in 214 boys and 214 girls. Both the methods overestimated the dental age in boys and girls. In boys, the body mass index was significantly correlated to the difference in age using Willems method. The authors concluded that further modification of either method is indicated for dental age estimation among the Malay population.

Hareesha KB, Babu NC. (2010)[25] studied the relationships between canine calcification and skeletal maturity and whether the stages of calcification of mandibular canine can be used as a first level diagnostic tool. This study was based on hand-wrist radiographs and orthopantomographs of the children of both sexes. 50 children, 25 boys and 25 girls, within the age group of 10-15 years were selected for the study. Skeletal age was determined from hand-wrist radiographs according to the methods described by Fishman LS. The development of the mandibular canine was assessed according to Demirjian's stages of dental calcification. The middle phalanx of the third finger showed the highest relationships with canine maturity for both sexes. The middle phalanx of the fifth finger shows the highest relationships with canine maturity. Third distal phalanx shows the highest relationship with canine maturity in girls but in boys, it was significant. Third proximal phalanx showed the highest relationships with canine maturity in girls but it was not significant in boys. The adductor sesamoid showed the highest relationship with canine maturity for boys and girls respectively.

Bala M, Pathak A, Jain RL. (2010)[26] did a study to assess the correlation amongst the skeletal, dental and chronologic ages by using MP3 and hand-wrist radiographs to determine the skeletal age. The study was done in 160 North Indian healthy children in age group 8-14 yr, comprising an equal number of males and females. Skeletal age was assessed from MP3 and hand-wrist radiographs according to the standards of Greulich and Pyle. Dental age was assessed from IOPA radiographs of right permanent maxillary canine based on Nolla's calcification stages. They concluded that skeletal age from MP3 and hand-wrist radiographs showed high correlation in all age groups for both sexes. Females were advanced in skeletal maturation than males. Skeletal age showed high correlation with dental age in 12-14 yr age group. They suggested that MP3 radiographs can be used for skeletal age assessment as hand-wrist radiographs. They also concluded that dental and chronologic ages are poor indicators of developmental status.

Hegde DY, Baliga S, Yeluri R, Munshi AK. (2012)[27] evaluated the reliability of the digital radiograph of the middle phalanx of the third finger (MP3) in skeletal maturity assessment **i**n 50 children (24 girls and 26 boys) between 8-18 yr. To ensure that the subjects were within or close to the circumpubertal period, girls between 8–16 years and boys between 10–18 years were selected. The method proposed by Lamparski and modified by Hassel and Farman was used for the assessment of the cervical vertebrae. The cervical vertebrae development was compared with the MP3 stages. The digital MP3 radiographic method of skeletal maturity assessment was reliable, with results comparable to the standards CVMI method. The authors stated that by examining the MP3 digital radiograph, the clinician can evaluate the skeletal maturity of the patient at that point in time and have a reasonable idea as to how much growth should be factored into the proposed treatment. Thus the authors concluded that digital MP3 radiography is a simple, reliable, cost-effective and time-saving technique for assessment of skeletal maturity.

Perinetti G, Contardo L, Gabrieli P, Baccetti T, Di Lenarda R. (2012)[28] did a study to analyze the diagnostic performance of circumpubertal dental maturation phases for the identification of individual-specific skeletal maturation phases in 354 healthy subjects, 208 females and 146 males. Dental maturity was assessed through the calcification stages from panoramic radiographs of mandibular canine, first and second permanent premolar and second molar. Skeletal maturity was determined according to the cervical vertebrae maturation (CVM) method on lateral cephalograms. They concluded that though dental and skeletal maturity is highly correlated, dental maturation stages of mandibular teeth show satisfactory diagnostic performance only for the identification of the prepubertal growth phases, with no reliable indications for the onset of pubertal growth spurt.

Grover S, Marya CM, Avinash J, Pruthi N. (2012)[29] did a study to determine the accuracy of dental age estimation and its comparison with chronological age by two methods: Demirjian's and Willems' on 215(102 boys and 113 girls) healthy children aged 6–15 years selected by convenience sampling, from patients of the Sudha Rustagi College of Dental Sciences & Research, Faridabad. Chronological age was considered as mentioned by the parents. Tooth development was assessed in seven left mandibular teeth from orthopantomograms (OPGs) and was staged according to Demirjian's and Willems scales. Both the methods showed overestimation of age when compared with chronological age, but Willems' method was more accurate than Demirjian's method in both the genders and the result was significant (overall overestimation by Willems method was 0.30 years but for Demirjian's method it was 0.61 years). The mean overestimation for both methods was less for girls as compared with boys, but the results were not statistically significant. The authors stated that both the dental age estimation methods were seen to be strongly correlated with chronological age, implying the potential applicability of both the methods of dental age estimation in the North Indian population; however, overestimation of the actual chronological age supported the need for population-specific standards in both the methods, for further application in forensic sciences.

Shilpa PH, Sunil RS, Sapna K, Kumar NC. (2013)[11] studied the estimation and comparison of dental, skeletal and chronologic age in Bangalore south school going children and concluded that Demirjian's method of dental age estimation and Greulich and Pyle's method of skeletal age estimation shows accuracy in only a certain age groups. This may be due to the differences in the genetic ancestry with the interbreeding of the populations. Therefore, the environmental and genetic makeup of an individual plays a considerable influence on the maturation of dentition and skeleton and estimation of physiologic age.

Kundu GK, Das M, Chandra B. (2013)[30] did a review of the assessment of skeletal maturation using middle phalanx of the third finger of hand from 37 papers published between 1950 and 2013. The article states the importance of skeletal maturation and age. It states that the same pattern of skeletal growth can be found in almost every individual, but the initiation, duration and amount of growth vary considerably during pubertal growth spurts. The article further states the 5 stages of MP3 according to Greulich and Pyle atlas and specified the age for a particular stage. The review article presents the studies which reveal a highly significant association between MP3 stages in determining the skeletal age. The authors concluded that MP3 method may be a simple and practical tool for prediction of growth spurt as well as age detection and can be used in the clinical practice of pedodontics and orthodontics. The simple procedures can be done with IOPA and RVG depending on the availability. The method is valuable in determining the exact age of a patient with unknown age proof and in medico-legal and forensic interest.

Erdem PA, Yamac E, Erdem MA, Sepet E, Aytepe Z. (2013)[31] did a study to evaluate the accuracy of Demirjian's method to estimate the dental age in Turkish children and to estimate the validity of Demirjian's standards for the studied population. The study was carried out in a sample group of 345 females and 411 males of age 5-13 yr. their panoramic radiographs, chronologic age, and gender were obtained. The dental age was estimated by the development of 7 left permanent mandibular teeth according to Demirjian stages. Scoring and age determination was done according to the standardized tables of Demirjian's method. The chronologic age was subtracted from the dental age and a positive result indicated an overestimation (acceleration of dental age), zero meant that dental and chronologic ages were identical and a negative result indicated an underestimation (delayed dental development). For both genders, statistically, significant differences were found between the estimated dental ages and chronologic ages. The authors found that Turkish children were generally delayed in dental maturity. To develop a new method for evaluating northwestern Turkish children, a scatter plot was drawn to verify how the different factors were related mathematically. Based on distribution equation a new formula for calculating the dental age was established for the first time. The authors concluded that by using their approach, the standards established would allow accurate evaluation of dental age in accordance with Demirjian's method. They stated that the methods for determining dental age must have population-specific standards.

Prasad M, Ganji VS, George SA, Talapaneni AK, Shetty SK. (2013)[32] did a study to determine whether the six modified MP3 stages described by Rajagopal and

Kansal could be correlated with the six stages of cervical vertebrae maturation indices (CVMI), as described by Hassel and Farman. To evaluate the feasibility of recording MP3 stages using standard dental radiographic film for assessment of skeletal maturity. To assess the correlation among the chronological age, cervical vertebral maturity indicators, and MP3 maturity stages. A sample of 200 subjects (100 males and 100 females) of Nellore, Indian origin boys aged between 10 to 19 years and girls aged between 8 to 16 years were selected for the study. The radiographs of left hand Middle Phalanx of the third finger - MP3 and Lateral cephalogram were evaluated. There was a good concordance between six stages of CVMI (Hassel and Farman) and the six stages of MP3 (Rajagopal and Kansal). Physiological maturity was earlier in females than in males when compared to the individuals of opposite sex of same chronological age. Chronological age was not a valid predictor of assessing the skeletal maturity because of significant variations in the distribution of CVMI and MP3 stages with respect to individual chronological age distribution. The authors concluded that MP3 indicator can be a better choice for predicting skeletal maturity of an individual because of its simplicity, reliability and reduced radiation exposure to an individual

Ambarkova V, Galić I, Vodanović M, Biočina-Lukenda D, Brkić H. (2014)[33] did a study to evaluate the applicability of Demirjian and Willems methods for calculating the dental age of children in the Former Yugoslav Republic of Macedonia. They analyzed panoramic radiographs of 966 children (485 female and 481 male), aged 6–13 years, treated at the University and Community Dental Clinics in Skopje using four Demirjian methods and a Willems method for determining dental ages. The authors concluded that their research proved that Willems method for age estimation is suitable and recommended for Former Yugoslav Republic of Macedonia population of children including the 13 years of age.

Mohammed RB, Krishnamraju PV, Prasanth PS, Sanghvi P, Lata Reddy MA, Jyotsna S. (2014)[34] estimated the dental age in different age groups and correlated it to chronologic age in south Indian population using Willems method in 332 subjects (116 males and 116 females) form 6-16 yr. the tooth development staging was done according to Demirjian et al method. The developmental status of the particular tooth was calculated in years on the basis of tables given by Willems et al. the present study underestimated the age in south Indians in all age groups except 6-7.99 yr. the study also showed a significant correlation between DA and CA in both males and females and in the entire sample. The authors concluded that Willems method seemed to be applicable in estimating age in south Indian population.

Medina AC, Blanco L. (2014)[35] conducted a study to compare the applicability of the Demirjian and Willems methods for dental age estimation in a group of Venezuelan children. Panoramic radiographs of 238 Venezuelan children aged 5-13 years were used to assess dental age using the methods described by Demirjian and Willems. The authors concluded that Willems method was more accurate than the Demirjian method for assessing dental age in Venezuelan children.

Perinetti G, Perillo L, Franchi L, Di Lenarda R, Contardo L. (2014)[36] studied the diagnostic agreement on an individual basis between the third middle phalanx maturation (MPM) method and the cervical vertebral maturation (CVM) method in Four hundred and fifty-one Caucasian subjects. Although slight differences exist, when compared with the cervical vertebral method, the maturational staging of the middle phalanx of the third finger appears to be a valid indicator of the onset and the end of pubertal growth spurt in individual subjects.

Pinchi V, Norelli GA, Pradella F, Vitale G, Rugo D, Nieri M. (2012)[37] did a study to compare the four age estimation methods which were the Demirjian's, the Willems', the Cameriere's and Haavikko's methods in the Italian population. The sample consisted of 244 males and 257 females, almost equally divided in age cohorts from the age of 11 years (4015days) to 15 years and 364 days (5839 days). The OPGs of the individuals were analyzed by three expert forensic odontologists who were blinded to the chronological age. The authors concluded that the Willems and Demirjian methods were more accurate than Cameriere and Haavikko, but they tended to overestimate the age. The Cameriere method largely underestimated the age (~1 year) for both genders and with all the operators. The Haavikko method was not suitable for dental age estimation in this population. The Willems and Demirjian methods yielded high sensitivity but low specificity, thus producing consistent rates of false positive cases.

Mohammed RB, Srinivas B, Sanghvi P, Satyanarayana G, Gopalakrishnan M, Pavani BV. (2015)[38] did a study to compare the accuracy of Demirjian's 8 teeth method for age prediction in 660 south Indian children (330 male and 330 females). The chronologic age of an individual was calculated by subtracting the birth date from the date on which the radiographs were exposed. Dental age was calculated according to Demirjian's method and total maturity scores were substituted in the regression formulas given by Chaillet and Demirjian (2004) and Acharya (2010) to estimate the age of an individual. The calculated ages by Chaillet and Demirjian and Acharya were compared. Demirjian's method underestimated the DA by 1.66 yr for males and 1.55 yr for females and 1.61 in total. Acharya's method overestimated DA by 0.21 yr for boys and 0.85 yr for girls and 0.53 yr in total. But the authors concluded that both methods tested using Demirjian's 8 teeth method were found to be reliable in assessing age, with Indian method as the most accurate for predicting the age of South Indian children of 9-20 yr age groups.

Priya E. (2015)[39] did a pilot study to test the applicability of Willem's method of dental age assessment in South Indian children at the threshold of 14 years considering the prohibition of employment of children. The sample consisted of 30 males and 30 females. Chronological age was recorded as decimal years using the date of birth mentioned by the parents and the date on which the panoramic radiographs were taken. The dental age estimation was performed by two blinded examiners using Willem's method. The accuracy of Willem's method of age assessment was measured by the difference between the chronological age and estimated dental age. It was seen that there was an underestimation of age in both males and females. The difference was greater in females than in males i.e. -0.29 years and -0.23 years respectively. The author concluded that this pilot study reported the comparatively high accuracy of Willem's method at 14 years threshold. The scores of dental maturation described by Willems were suitable for South Indian children and the study would be extended in a larger population for validation of this method in the said population.

Akkaya N, Yilanci HÖ, Göksülük D. (2015)[40] evaluated the applicability of five dental methods including Demirjian's original, revised, four teeth, and alternate four teeth methods and Willems method for age estimation in a sample of Turkish children. Panoramic radiographs of 799 children (412 females, 387 males) aged between 2.20 and 15.99 years were examined by two observers. For all five methods (A: Demirjian's original method, B: Demirjian's revised method, C: Demirjian's four teeth method and D: Demirjian's alternate four teeth method, and E: Willems method), each of the seven left permanent teeth of the mandible was assessed, and maturity scores were determined according to developmental criteria (A–H) by two observers. Among all of the five methods tested in this study, Willems method gave relatively better results than the others. Demirjian's four teeth methods showed lower overestimation than the seven teeth methods. Moreover, Demirjian's four teeth and alternate four teeth methods gave similar results with Willem's method at most of the ages in males. It was concluded that Willems method is more suitable than Demirjian methods for dental age estimation and therefore can be used for forensic procedures in Turkish children.

Hegde RJ, Khare SS, Saraf TA, Trivedi S, Naidu S. (2015)[1] did a study to determine the nature of inter-relationship between chronologic and DA in 197 children (115 boys and 82 girls) in Navi Mumbai. Chronologic age was calculated from the birth records and dental age by Demirjian's method. Significant positive correlation was found between the two ages. The difference found between chronologic and dental ages for given population was 2 days for boys and 37 days for girls. The authors concluded that Demirjian method showed high accuracy when applied to Navi Mumbai population.

Patel PS, Chaudhary AR, Dudhia BB, Bhatia PV, Soni NC, Jani YV. (2015)[41] studied the applicability of Demirjian's and Willem's dental age assessment methods as well as Greulich and Pyle skeletal age assessment method in children residing in Gandhinagar district. The study consisted of randomly selected 180 subjects (90 males and 90 females) ranging from 6 to 16 years age and residing in Gandhinagar district. Chronological age was calculated from date of birth. Dental age estimation was performed from radiovisiograph (RVG) images of mandibular teeth of left quadrant by both Demirjian's and Willem's methods. Skeletal age estimation was done from right hand wrist radiograph by Greulich and Pyle method. Amongst the age estimation methods used in this study, the athors stated that Willem's dental age estimation method was the most accurate and consistent.

Sharma K, Kahlon SS, Boparai CS, Mehta V, Jassal NS, Sandhu AS. (2015)[42] did a study to evaluate skeletal age using CVMI (Hassel and Farman)and dental age using Willem's method , compare and correlate cervical vertebrae maturity indicator and dental calcification stages with chronological age in 100 patients (57 Male and 43 Female) ranging in age from 9 to 16 years. Two radiographs namely Lateral Cephalogram, Panoramic radiograph were taken on the same date for selected subjects There was a strong and significant correlation between all the parameters and highly significant correlation of the dental age using Willem's method with the chronological age (r=0.801) followed by CVMI (r=0.618). The authors concluded that dental age using Willem's method was more closely related to the chronological age followed by CVMI.

Akbar A, Chatra L, Shenai P, Veena KM , Rao PK , Prabhu RV. (2016)[43] did a study to estimate the Dental Age (DA) in different age groups by assessing the developmental stages of mandibular seven teeth by using Willems method and evaluate the possible correlation between DA and Chronological Age (CA) by using Digital Orthopantomograms (OPGs) of 30 subjects. Mandibular teeth from central incisor to the second molar were selected, and DA was assessed using Willems method. The study showed a significant correlation between estimated DA and CA. The study concluded that digital radiographic assessment of mandibular teeth development can be used to generate DA by using Willems method and also the estimated age range for an individual of unknown CA.

Palanisamy V, Rao A, Shenoy R, Baranya SS. (2016)[44] did a retrospective study to find out whether dental age estimation can be replaced for skeletal age estimation in 104 Dakshina Kannada population in 9-14 yr age group. Chronologic age was calculated by subtracting date of birth from the date on which radiographs were taken. Dental age was calculated according to Demirjian’s method and skeletal age assessment was done using hand and wrist radiographs using Fishman's SMI. The correlation between dental and skeletal age and chronologic age was found to be statistically significant. Due to this strong correlation, the authors stated that dental age can be considered as a replacement for the study population and suggested studies with a larger sample size to be carried out for more reliable results.

Chaudhry K, Agarwal A, Rehani U. (2010)[45] conducted a study to investigate the applicability of Demirjian method for estimation of dental age in rural and urban female children (80 girls) between 8-14 yr age coming to the department of Pedodontics and Preventive Dentistry, Subharti Dental College, Meerat which were randomly selected. Dental age was calculated from OPG by using Demirjian's method. Chronologic age was calculated by subtracting the birth date from the particular individual. In comparison, they found that the dental age maturation of Meerat girls was faster than French Canadian girls. It was also found that Demirjian's method was more applicable in 11-14 yr urban female children with a minimum difference of 18 days only and was not applicable to 8-11 yr rural girls.

Sathawane R S, Agrawal N. (2017)[46] did a study to evaluate the applicability of Chaillet-Demirjian's and Willems methods in Chhattisgarh population, and if needed, to derive a specific formula for the highest accuracy. The study was conducted on 284 individuals out of whom 210 individuals (103 male and 107 females) were selected according to the inclusion-exclusion criteria. Panoramic radiographs were taken, the teeth of the third quadrant were traced and scores were given according to both the methods by two observers. The chronological age was calculated according to the date of birth. Chaillet-Demirjian's method seem to underestimate the age by 0.81years in every age group, while Willem's method showed slight overestimation of the age by 0.33years in two groups (10.00- 11.99 & 12.00- 13.99 years) and slight underestimation of age by 0.1year in other two groups (7.00- 9.99 & 14.00- 16.0 years). Both the methods showed close relation with the chronological age, but with a remarkable difference between them. Due to this regression analysis was carried out and separate equations for calculating chronological age were derived for males, females and overall population. The proposed equations in this study were dependent on the Chaillet- Demirjian's, and Willems methods and hence regarded as a modification of these methods.

Saadé A, Baron P, Noujeim Z, Azar D. (2017)[47] did a retrospective study of 260 orthodontic patients (124 males, 136 females to evaluate the applicability of Greulich and Pyle (1959) and Fishman (1982) methods of bone age assessment and the applicability of Demirjian (1973) and Willems (2001) methods of DA assessment for Lebanese children. The date of birth of the study subjects were obtained from the records. All OPGs and hand-wrist radiographs were scored separately by two observers. Results of the present study suggested a strong correlation between both dental and skeletal assessment methods and CA; Willem's method was more suitable to assess DA in both genders for this population; Greulich and Pyle's method is accurate for SA assessment in males and females between 8 and 10 years, while it significantly overestimated age in all the other female groups. The authors concluded that further investigations with a larger sample would improve these findings and suggested specific charts applicable to Lebanese individuals.

MATERIALS AND METHOD

The present study was conducted in the department of Pediatric and Preventive dentistry of the concerned dental college. Ethical committee clearance was obtained prior to the commencement of the study. 204 children were randomly selected from among the patients who visited the said dental college for orthodontic treatment. Parents of the child selected for the study were explained the purpose and methodology of the study in local vernacular language and a signed informed consent was obtained **(Annexure 1, page no i).** The digital orthopantomograms (OPGs) of the selected children were obtained from the department of Oral Diagnosis Medicine and Radiology and radiovisiographs (RVGs) of the middle finger were done in the department of Pediatric and Preventive Dentistry.

A child was included in the study based on the following criteria:

Inclusion criteria

1. To ensure that the subjects were within or close to circumpubertal period, children between 7 to 16 years were included in the study[4,]
2. All permanent teeth present (erupted or unerupted). [1,41]
3. Well- nourished cooperative child with normal dental conditions [41]

Exclusion criteria

1. Children with any congenital, systemic, endocrine or nutrition disorder. [1, 27]
2. Children with any past prolonged illness.[27,41]
3. Previous history of trauma to the face and hand. [1,6]
4. Impaction and transposition of teeth. [1]
5. Children with a history of orthodontic treatment and extraction of permanent teeth.[1,27, 41]

Out of 207 children 1 child was excluded due to the congenitally missing mandibular central incisors, 1 due to congenitally missing mandibular second premolars and 1 due to trauma.

Equipments used:

1. Kodak 8000C Digital Panoramic & Cephalometric Extraoral Imaging System **(Colour plate I, Fig 1, page no 33)**
2. Dental x-ray machine (Aditya Medical Systems Ltd, India Model no: AMS 6010)
3. Dental RVG sensor (Kodak RVG 5100 Digital Radiography) **(Colour plate I, Fig 2, page no 33)**

Method of examination:

Children coming for orthodontic treatment to the said college were examined on a dental chair using artificial illumination. The OPGs and RVGs were taken together on the same day.

The chronological age (CA) was determined by subtracting the date of birth from the date of examination. The chronologic age thus obtained was in years, months and days. This was converted to chronologic age in decimals (up to two decimal points) [31].

Every selected case was advised an OPG before undergoing orthodontic treatment and hence were not unnecessarily exposed to radiation for study purpose. Kodak 8000C Digital Panoramic & Cephalometric Extra-oral Imaging System was employed to record OPG. To minimize errors, all the OPGs were obtained using the same machine under standardized parameters (71 kV, 12mA, 13.2 sec). A digital copy of it was obtained from the Department of oral diagnosis, medicine, and radiology.

Method for taking radiovisiograph (RVG) **(Colour plate I, Fig 3 and 4, page no 33)** : The child was instructed to place his/her left hand with palm downward on a flat surface and with the middle phalanx of the third finger straight and centered on a 27.5 x 37.7 mm periapical sensor (Kodak RVG 5100 Digital Radiography).The long cone of the dental x-ray machine (Aditya Medical Systems Ltd, India Model no: AMS 6010) was positioned in light contact with the middle phalanx and perpendicular to dental x-ray sensor.[27] To minimize errors, all the RVGs were obtained using the same X- ray machine under standardized parameters (60 kV,7mA, 0.25 sec).

All the OPGs and RVG images were stored in a computer database, so that evaluation of calcifications could be carried out on a computer 14 inches (35.6 cm) monitor screen.[31] This method enabled magnification of selected regions of interest to achieve a more accurate evaluation of developmental stages of teeth. All the images were assessed in Microsoft office picture manager at 50% magnification.

The OPG and RVGs obtained were coded with a numerical identity number by a non-examiner in order to avoid bias during scoring of the radiographs. Both the OPG and RVG were assigned the same code for one child. These OPGs and RVGs were assessed by two examiners separately. The examiners did not know the chronologic age of the children while assessing the radiographs.

Dental age (DA) was calculated with the help of OPG, by Willems method. OPGs were assessed for developmental stages of 7 teeth (central incisor to the second molar) in the third quadrant using Demirjian's method. The stages were allotted according to the Demirjian's method **(Annexure 2, page no iv).** The developmental stage of each tooth was converted into a score using the conversion table given by Willems based on the Demirjian's stages separately for boys and girls **(Annexure 3, page no vii)**. The Willems' scores for all the seven teeth were summed up to obtain a dental age in years. [20]

The skeletal age was assessed by the middle phalanx maturation and the radiovisiographs of MP3 region were assessed according to the "Radiographic Atlas" by "Greulich and Pyle".[9] The RVG of a subject was compared to standard values of the same sex as in the atlas **(Annexure 4, page no viii)**. The standard radiograph in the atlas with the closest resemblance to the subject's RVG was selected and a particular age was assigned as the skeletal age (SA). The staging of the MP3 was done as modified by **Hagg U and Taranger J.**[16] **(Annexure 5, page no x)**.

General information of the patient and the determination of chronological age were done in the proforma part A by the non investigator. The dental and skeletal age estimation was done as per the proforma part B, by two examiners separately. The complete proforma part A and part B used for the study has been annexed as **Annexure 6 (page no xi).** If there was any difference in the rating of stage or score and age by the two examiners then such readings were discussed by the two examiners and the same were resolved to one particular stage or score and age with consensus of both the examiners. The representative OPGs and RVGs of the girls and boys included in the study are being annexed as various age group **colour plates no II to X (page no. 34-42)**

10% of the total OPGs and RVGs i.e. 20 OPGs and RVGs each were selected randomly and were evaluated by both the examiners for reproducibility.[41,48] Same 10% of the total OPGs and RVGs were re-evaluated by both the examiners after four weeks to assess the intra-examiner reproducibility. [12, 35,41, 48].

Following is an example of calculation of chronological age of a patient, whose date of birth is 7th April 2004 and the date of examination is 2nd December 2016.

Calculation of chronological age[49]

	Years	Months	Days
Date of examination	2016	12	2
Date of birth	2004	4	7
Chronological age			

Here, the number of days is more in the date of birth. Hence, I subtract 1 from the date of test months and add 30 to the date of test days.

	Years	Months	Days
Date of examination	2016	11 (12-1)	32 (2+30)
Date of birth	2004	4	7
Chronological age	12	7	25

The dental and skeletal age is determined in decimals as per the respective formulas. In order to determine statistical significance with dental and skeletal age, the chronological age of the child obtained in years months and days was converted into a chronological age in decimals.

The chronological age in decimal of the above child was determined as follows:

1 year = 365 days, and 1 month= 30 days

Therefore, 7 months = 7 ×30 = 210 days

210 + 25 = 235 days, 235÷ 365= 0.64 years

Hence, chronologic age in decimal = 12.64 years

Equipments used in the study

Figure 1: Patient positioning during OPG (Kodak 8000C Digital Panoramic & Cephalometric Extraoral Imaging System)

Figure 2: Dental RVG sensor (Kodak RVG 5100 Digital Radiography)

Figure 3: Positioning of the third finger of the left hand on RVG sensor

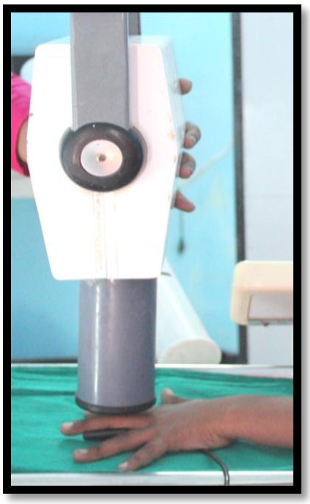


Figure 4: Positioning of the X ray cone for RVG of MP3 region

7-8 year age group children

Photo 1 A **Photo 1 B**

Child # 27, girl with chronological age of 7.27 years showing the OPG (**Photo 1 A**) with dental age 6.57 years and the RVG of MP3 region **(Photo 1 B**) of stage MP3-F and skeletal age 7.10 years

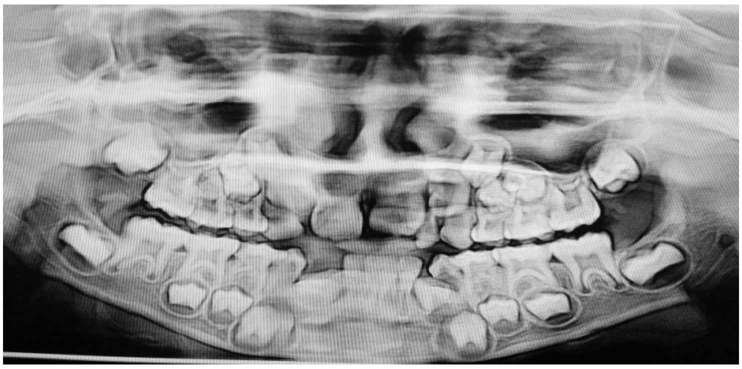


Photo 2 A **Photo 2 B**

Child # 53, boy with chronological age of 7.58 years showing the OPG (**Photo 2 A**) with dental age 7.95 years and the RVG of MP3 region (**Photo 2 B**) of stage MP3-F and skeletal age 7 years

8-9 year age group children

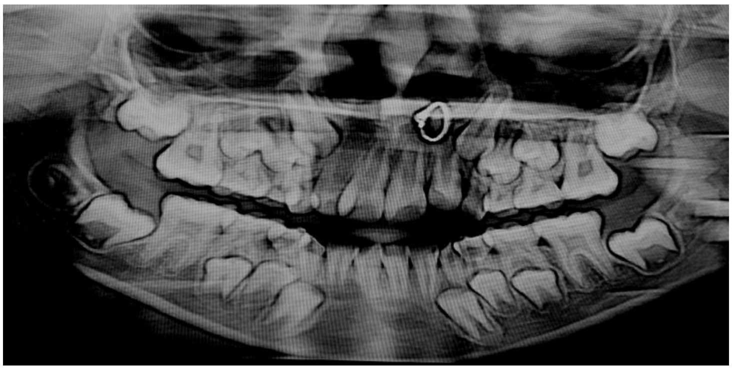



Photo 3 A **Photo 3 B**

Child # 51, girl with chronological age of 8.86 years, showing the OPG (**Photo 3 A**) with dental age 8.74 years and the RVG of MP3 region (**Photo 3 B**) of stage MP3-FG and skeletal age 10 years

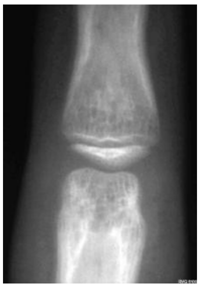



Photo 4 A **Photo 4 B**

Child # 6, boy with chronological age of 8.33 years, showing the OPG (**Photo 4 A**) with dental age of 8.74 years and the RVG of MP3 region **Photo 4 B**) of stage MP3-F and skeletal age 8 years

9-10 year age group children

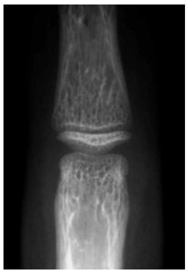


Photo 5 A **Photo 5 B**

Child # 77, girl with chronological age of 9.36 years, showing the OPG (**Photo 5 A**) with dental age of 9.41 years and the RVG of MP3 region (**Photo 5 B)** of stage MP3-FG and skeletal age 8.10 years

Photo 6 A **Photo 6 B**

Child # 42, boy with chronological age of 9.83 years, showing the OPG (**Photo 6 A**) with dental age of 10.24 years and the RVG of MP3 region (**Photo 6 B)** of stage MP3-F and skeletal age 9 years

10-11 year age group children

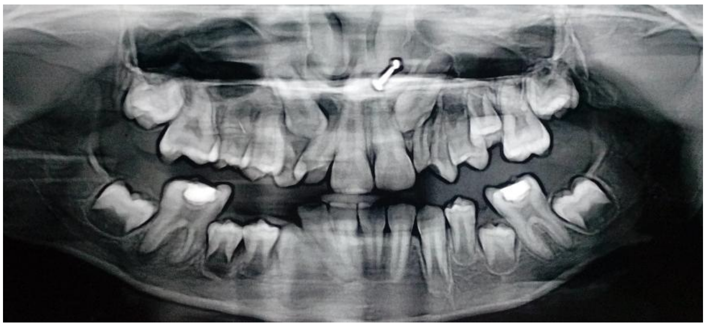


Photo 7 A **Photo 7 B**

Child # 54, girl with chronological age of 10.33 years, showing the OPG (**Photo 7 A**) with dental age of 9.07 years and the RVG of MP3 region (**Photo 7 B**) of stage MP3-FG and skeletal age 10 years

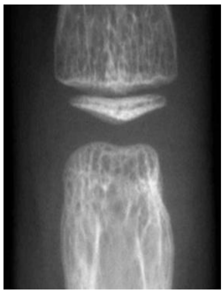


Photo 8 A **Photo 8 B**

Child # 72, boy with chronological age of 10.25 years showing the OPG (**Photo 8 A**) with dental age of 10.93 years and the RVG of MP3 region (**Photo 8 B**) of stage MP3-FG and skeletal age 9 years

11-12 year age group children

Photo 9 A **Photo 9 B**

Child # 121, girl with chronological age of 11.23 years, showing the OPG (**Photo 9 A**) with dental age of 10.98 years and the RVG of MP3 region (**Photo 9 B**) of stage MP3-FG and skeletal age 10 years

Photo 10 A **Photo 10 B**

Child # 187, boy with chronological age of 11.91 years, showing the OPG (**Photo 10 A**) with dental age of 11.81 years and the RVG of MP3 region (**Photo 10 B**) of stage MP3-G and skeletal age 12.6 years

12-13 year age group children

Photo 11 A **Photo 11 B**

Child # 185, girl with chronological age of 12.33 years, showing the OPG (**Photo 11 A**) with dental age of 11.48 years and the RVG of MP3 region (**Photo 11 B**) of stage MP3-G and skeletal age 13.6 years

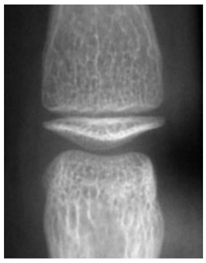


Photo 12 A **Photo 12 B**

Child # 103, boy with chronological age of 12.16 years, showing the OPG (**Photo 12 A**) with dental age of 10.24 years and the RVG of MP3 region (**Photo 12 B**) of stage MP3-G and skeletal age 11.6 years

13-14 year age group children

Photo 13 A

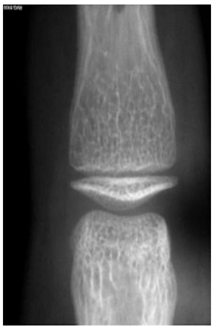


Photo 13 B

Child # 111, girl with chronological age of 13.46 years, showing the OPG **Photo 13 A**) with dental age of 12.6 years and the RVG of MP3 region (**Photo 13 B**) of stage MP3-G and skeletal age 13.6 years

Photo 14 A

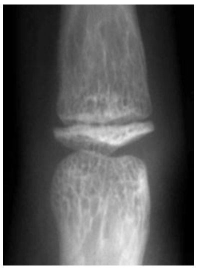


Photo 14 B

Child # 112, boy with chronological age of 13.83 years, showing the OPG (**Photo 14 A**) with dental age of 12.84 years and the RVG of MP3 region (**Photo 14 B**) of stage MP3-G and skeletal age 13.6 years

14-15 year age group children

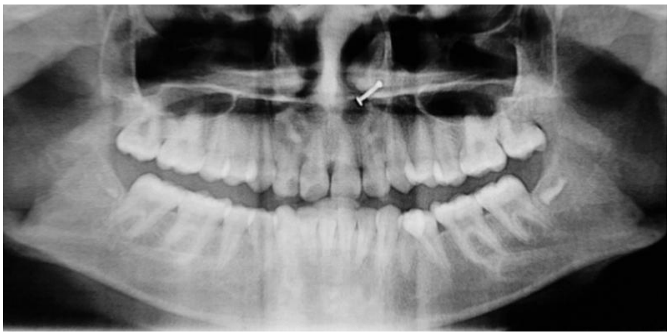


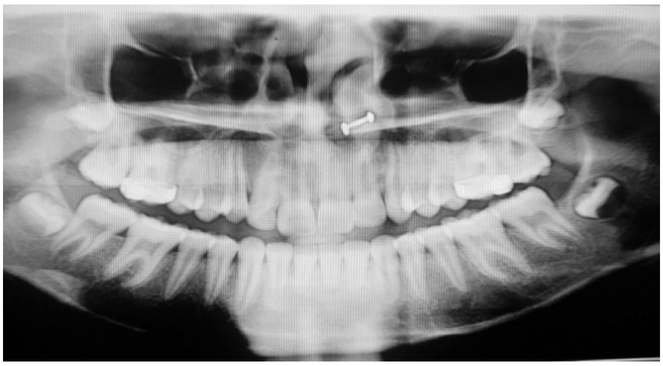
Photo 15 A **Photo 15 B**

Child # 188, girl with chronological age of 14.35 years, showing the OPG (**Photo 15 A**) with dental age of 13.84 years and showing the RVG of MP3 region (**Photo 15 B**) of stage MP3-H and skeletal age 14 years

Photo 16 A **Photo 16 B**

Child # 192, boy with chronological age of 14.16 years, showing the OPG (**Photo 16 A**) with dental age of 14.34 years and the RVG of MP3 region (**Photo 16 B**) of stage MP3-G and skeletal age 15 years

15-16 year age group children



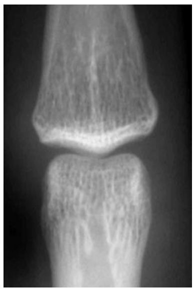


Photo 17 A **Photo 17 B**

Child # 122, girl with chronological age of 15.75 years, showing the OPG (**Photo 17 A**) with dental age of 15.79 years and the RVG of MP3 region **Photo 17 B**) of stage MP3-I and skeletal age 17 years

Photo 18 A **Photo 18 B**

Child # 195, boy with chronological age of 15.66 years, showing the OPG (**Photo 18 A**) with dental age of 16.03 years and the RVG of MP3 region (**Photo 18 B**) of stage MP3-H and skeletal age 16 years

RESULTS

A total of 207 children of age group between 7- 16 years were examined, out of which 3 children, (1 child each due to the congenitally missing mandibular central incisors, mandibular second premolars and 1 child due to trauma) were excluded. The data on chronological age, dental and skeletal maturation stages of children included in the study were obtained. The comparison of chronological age with dental and skeletal ages was performed using paired t-test. The analysis was performed independently for boys, girls and combined group. Also the difference of means between dental and skeletal age were assessed using paired t-test. Further, linear prediction formulae were obtained for dental and skeletal age using regression analysis. The formulae were obtained independently for boys and girls. So also prediction formulae for determination of chronological age were also obtained. The R^2 value was referred as a measure of goodness of fit of the formulae. All the analyses were performed using SPSS version 20.0 (IBM Corp) and the statistical significance was tested at 5% level.

The details of the statistical methods used are as below:

If x_1, x_2,…x_n are the observations on random variable X, then

Sample mean for a set of observations is given by

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard deviation for a set of observations in given by

$$s = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where x_i = observation on each object

n = number of objects

Paired t-test

The method is typically used for assessing the effectiveness of an experimental procedure that makes use of related observations resulting from dependent samples. The hypothesis test based on this type of data is known as *paired comparison test*.

For n sample differences computed from n pairs of measurements, which are distributed normally, the test statistic for testing hypothesis about population mean difference μ_d is given by:

$$t = \frac{\bar{d} - \mu_d}{s_d / \sqrt{n}}$$

where $\bar{d}$ is the sample mean, μ_d is the hypothesized population mean difference, s_d is the standard deviation of sample difference. Under the assumption that H_0 is true, the test statistic is distributed as *Student's t* with *n*-1 degrees of freedom.

Simple linear regression

Simple linear regression is a method that describes the relationship between single independent continuous variable and the continuous dependent variables. If Y is the dependent variable taking values y_1, y_2,…y_n and X is the independent variable taking values x_1, x_2,…x_n, then the simple linear model is defined as:

$y_i = b_0 + b_1x_i + \varepsilon_i$ for i=1, 2, …, n

where b_0 is the intercept and b_1 is the regression coefficient of the independent variable X. The parameters are estimated using least square estimation method.

$$b_1 = \frac{\sum_{i=1}^{n} x_i y_i - \bar{x} \times \bar{y}}{\sum_{i=1}^{n} (xi - \bar{x})^2}$$

where

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \text{ and } \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

and

$$b_0 = \bar{y} - \hat{b}_1\bar{x}$$

204 selected children were distributed in 9 groups in either sex as depicted in **Table 1 (page no. 81)** and **Graph 1 (page no. 90).** In boys the age groups 7-8 years, 9-10 years, 11-12 years and 12-13 years consisted of 12 children each while the rest of the age groups consisted of 11 children each. In girls the age groups 7-8 years and 15-16

years consisted of 12 children each while the rest of the age groups consisted of 11 children each.

All the OPGs and RVGs were evaluated by the two examiners. 10% of the sample i.e. 20 OPGs and RVGs were selected randomly for assessing the inter and intraexaminer reproducibility. The assessment of interexaminer reliability and quantification of the agreement between two examiners using Intra-class correlation coefficient (ICC) is given in **Table 2 (page no. 81)**. For dental age, ICC obtained was 0.978[95% CI: 0.944 – 0.991], while for skeletal age, ICC was 0.985 [95% CI: 0.963 – 0.994]. The percentage of agreement for dental age was 97.8% which indicated P-value of <0.001 and for skeletal age, percentage of agreement was 98.5% resulting into the P-value of <0.001. This indicated excellent agreement between the two examiners.

The same 20 OPGs and RVGs were re- examined by both the examiners after an interval of 4 weeks. In the assessment of intraexaminer reliability using ICC for first examiner, for dental age, the ICC obtained was 0.994 [95% CI: 0.984 – 0.997], while for skeletal age, the ICC was 0.996 [95% CI: 0.990 – 0.998] indicating excellent consistency in the ratings by first examiner. For dental age, percentage of agreement was 99.4% and for skeletal age the agreement was 99.6% and the P-value was <0.001. **(Table 3, page no. 82)**

In the assessment of intraexaminer reliability using ICC for second examiner, for dental age, the ICC obtained was 0.986 [95% CI: 0.965 – 0.995], while for skeletal age, the ICC was 0.985 [95% CI: 0.962 – 0.994] indicating excellent consistency in the ratings by second examiner. For dental age, percentage of agreement 98.6% and for skeletal age the agreement was 98.5% and the P-value was <0.001. **(Table 4, page no. 82)**

The comparison of chronological age with dental and skeletal age was performed using paired t-test. The analysis was performed independently for boys, girls and combined group. Also the difference of means between dental and skeletal age were assessed using paired t-test.

The overall mean chronological age of girls and the corresponding mean dental age were 11.51±2.69 and 11.11±2.74 respectively. The overall mean difference between DA and CA was -0.40 which was not statistically significant **(Table 5, page no. 83)**. The statistical significant difference between CA and DA was noted only for two age groups i.e. 7-8 years and 10-11 years. In the age group of 7-8 years, mean chronological age was 7.33±0.23 years and mean dental age was 6.92±0.32 years. There was significant mean difference in chronological and dental age as indicated by t-value of 3.578 and P-value of 0.002. Further, in the age group of 10-11 years, mean chronological age was 10.40±0.26 years and mean dental age was 9.69±0.83 years. The mean difference between both the ages was significant as indicated by t-value of 2.723 and P-value of 0.018. For remaining age groups, the mean difference between chronological and dental age of girls was insignificant as indicated P-value > 0.05. **Graph 2 (page no. 90)** represents a column chart showing the mean chronological and dental age for girls according to age groups.

The overall mean chronological age of boys and the corresponding mean dental age were 11.42±2.59 and 11.14±2.63 respectively. The overall mean difference between DA and CA was -0.28 which was not statistically significant **(Table 6, page no. 83)**. In the age group of 9-10 years, mean chronological age was 9.74±0.52 years and mean dental age was 9.17±0.67years. The mean difference between chronological and dental age was significant with t-value of 2.358 and P-value of 0.028. For remaining age groups, the mean difference between chronological and dental age of boys was insignificant as indicated by P-value > 0.05. **Graph 3 (page no. 91)** represents a column chart showing the mean chronological and dental age for boys according to age groups.

The overall mean chronological age of all children and the corresponding mean dental age were 11.47±2.63 and 11.13±2.68 respectively. The overall mean difference between DA and CA was -0.34 which was not statistically significant **(Table 7, page no. 84)**. The statistical significant difference between CA and DA was noted only for three age groups i.e. 9-10 years 12-13 years and 14-15 years. In the age group of 9-10 years, mean chronological age was 9.68±0.47 years and mean dental age was 9.25±0.72 years. The mean difference between chronological and dental age was significant as indicated by t-value of 2.351 and P-value of 0.024 (< 0.05). In the age group of 12-13 years, mean chronological age was 12.42±0.53 years and mean dental age was 11.79±1.18 years. The mean difference between both age groups was significant as indicated by t-value of 2.334 and P-value of 0.026. Also in the age group of 14-15 years, mean chronological age 14.52±0.35 and mean dental age was 13.99±0.91. The mean difference was statistically significant with t-value of 2.585 and P-value of 0.015 (< 0.05). For remaining age groups, the mean differences were statistically insignificant as indicated by P-values > 0.05. **Graph 4 (page no. 91)** represents a column chart showing the mean chronological and dental age for all children according to age groups.

The overall mean chronological age of girls and the corresponding mean skeletal age were 11.51±2.69 and 11.60±3.21 respectively. The overall mean difference between SA and CA was 0.09 which was not statistically significant **(Table 8, page no. 84)**. The statistically significant difference between CA and SA was noted only for two age groups i.e. 7-8 years and 15-16 years. In the age group of 7-8 years, mean chronological age was 7.33±0.23 years and mean skeletal age was 6.89±0.59 years. The mean difference between chronological and skeletal age was significant as indicated by t-value of 2.379

and P-value of 0.032 (< 0.05). In the age group of 15-16 years, mean chronological age was 15.45±0.43 years and mean skeletal age was 16.33±0.49 years. The mean difference between both age groups was significant as indicated by t-value of -4.689 and P-value of <0.001. For remaining age groups, the difference between the two groups was insignificant as indicated by P-value > 0.05. **Graph 5 (page no. 92)** represents a column chart showing the mean chronological age and mean skeletal for girls according to age.

The overall mean chronological age of boys and the corresponding mean skeletal age were 11.42±2.59 and 11.41±2.89 respectively. The overall mean difference between SA and CA was -0.01 which was not statistically significant **(Table 9, page no. 85)**. The statistical significant difference between CA and SA was noted only for two age groups i.e. 9-10 years and 14-15 years. In the age group of 9-10 years, mean chronological age was 9.74±0.52 years and mean skeletal age was 9.25±0.62 years. The mean difference between chronological and skeletal age was significant as indicated by t-value of 2.109 and P-value of 0.047 (< 0.05). In the age group of 14-15 years, mean chronological age was 14.41±0.27 years and mean skeletal age was 15.04±0.66 years. The mean difference between both age groups was significant as indicated by t-value of -3.020 and P-value of 0.010 (< 0.05). Remaining age groups showed statistically insignificant mean difference as indicated P-value > 0.05. **Graph 6 (page no. 92)** represents a column chart showing the mean chronological age and mean skeletal for boys according to age.

The overall mean chronological age of all children and the corresponding mean skeletal age was 11.47±2.63 and 11.50±3.05 respectively. The overall mean difference between SA and CA was 0.03 which was not statistically significant **(Table 10, page no. 85)**. The statistical significant difference between CA and SA was noted for four age groups i.e. 7-8, 9-10, 14-15 and 15-16 years. In the age group of 7-8 years, mean chronological age was 7.39±0.26 years and mean skeletal age was 6.94±0.60 years. The mean difference between chronological and skeletal age was significant as indicated by t-value of 3.270 and P-value of 0.003 (< 0.05). In the age group of 9-10 years, mean chronological age was 9.68±0.47 years and mean skeletal age was 9.03±1.01 years. The mean difference between both age groups was significant as indicated by t-value of 2.795 and P-value of 0.009 (< 0.05). Also in the age group of 14-15 years, mean chronological age was 14.52±0.35 years and mean skeletal age was 15.03±0.77 years. Comparing mean of chronological and skeletal age resulted into statistically significant difference as indicated by t-value of -2.829 and P-value of 0.008 (< 0.05). In the age group of 15-16 years, the mean chronological age was 15.45±0.38 years and mean skeletal age was 15.91±0.73 years. The mean difference between the two groups was statistically significant as indicated by t-value of -2.706 and P-value of 0.011 (< 0.05). For remaining age groups, the mean difference between chronological and skeletal age of children was insignificant as indicated by P-value > 0.05. **Graph 7 (page no. 93)** represents a column chart showing the mean chronological age and mean skeletal for all children according to age.

The overall mean dental age of girls and the corresponding mean skeletal age were 11.11±2.74 and 11.60±3.21 respectively. The overall mean difference between DA and SA was 0.49 which was not statistically significant **(Table 11, page no. 86)**. The statistical significant difference between DA and SA was noted for four age groups i.e. 10-11, 12-13, 14-15 and 15-16 years. In the age group of 10-11 years, mean dental age was 9.69±0.83 years and mean skeletal age was 10.60±1.09 years. The mean difference between dental and skeletal age was statistically significant as indicated by t-value of -2.205 and P-value of 0.040 (< 0.05). In the age group of 12-13 years, mean dental age was 11.89±1.09 years and mean skeletal age was 13.13±1.11 years. The mean difference between age groups was significant as indicated by t-value of -2.638 and P-value of

0.016 (< 0.05). Also in the age group of 14-15 years, mean dental was 13.64±1.17 years and mean skeletal age was 15.00±0.89 years. Comparison resulted into statistically significant mean difference as indicated by t-value of -3.063 and P-value of 0.006. In the 15-16 years category, mean dental age was 15.22±1.05 years and mean skeletal age was 16.33±0.49 years. The mean difference between groups was significant as indicated by t-value of -3.309 and P-value of 0.005 (< 0.05). Remaining age groups showed statistically insignificant difference between groups as indicated by P-values > 0.05. **Graph 8 (page no. 93)** represents a column chart showing the mean dental age and mean skeletal age for girls according to age.

The overall mean chronological age of boys and the corresponding mean skeletal age were 11.14±2.63 and 11.41±2.89 respectively. The overall mean difference between DA and SA was 0.27 which was not statistically significant **(Table 12, page no. 86)**. In the age group of 14-15 years, mean dental age was 14.33±0.30 years and mean skeletal age was 15.04±0.66 years. The mean difference between dental and skeletal age was significant as indicated by t-value of -3.311 and P-value of 0.005 (< 0.05). Remaining age groups showed statistically insignificant mean difference as indicated P-value > 0.05. **Graph 9 (page no. 94)** represents a column chart showing the mean dental age and mean skeletal age for boys according to age.

The overall mean chronological age of all children and the corresponding mean skeletal age were 11.13±2.68 and 11.50±3.05 respectively. The overall mean difference between DA and SA was 0.38 which was not statistically significant **(Table 13, page no. 87)**. The statistical significant difference between DA and SA was noted for three age groups i.e. 12-13, 14-15 and 15-16 years. In the age group of 12-13 years, mean dental age was 11.78±1.17 years and mean skeletal age was 12.78±0.97 years. The mean difference between dental and skeletal age was significant as indicated by t-value of -

3.129 and P-value of 0.003 (< 0.05). In the age group of 14-15 years, mean dental age was 13.98±0.91 years and mean skeletal age was 15.03±0.77 years. The mean difference between both age groups was significant as indicated by t-value of -4.115 and P-value of <0.001. Also in the age group of 15-16 years, mean dental age was 15.11±1.16 years and mean skeletal age was 15.91±0.73 years. Comparison of dental age and skeletal age resulted into statistically significant difference as indicated by t-value of -2.783 and P-value of 0.008 (< 0.05) For remaining age groups, the mean difference was insignificantly different than zero as revealed by P-value > 0.05. **Graph 10 (page no. 94)** represents a column chart showing the mean dental age and mean skeletal age for all children according to age.

Table 14 (page no. 88) provides the comparison of chronological age, dental age and skeletal age for different age categories for girls, boys and all children together. In the age group of 7-8 years, for girls, the mean difference between chronological and dental age was statistically significant with P-value of 0.002 and the mean difference between chronological and skeletal age was statistically significant for girls and overall population with P-value of 0.032 and 0.003 respectively. In the age group of 9-10 years, the mean difference between the chronological and dental age for boys and combined population were statistically significant with P-value of 0.028 and 0.024 respectively. Similarly, the mean difference between the chronological and skeletal age for boys and combined population was statistically significant with P-value of 0.047 and 0.009 respectively. In the age group of 10-11 years, the mean difference between the chronological and dental age for girls was statistically significant with P-value of 0.018. In the same age group, the mean difference between the dental and skeletal age for girls was statistically significant with P-value of 0.040. In the age group of 12-13 years, the mean difference between the chronological and dental age for combined population was statistically significant with P-value of 0.026. In the same age group, the mean difference between the dental and skeletal age for girls and combined population was statistically significant with P-value of 0.016 and 0.003 respectively. In 14-15 years age group, the mean difference between chronological and dental age for combined population was statistically significant with a P-value of 0.015. The mean difference between chronological and skeletal age for boys and combined population was statistically significant with a P-value of 0.010 and 0.008 respectively. The mean difference between dental and skeletal age for boys, girls and combined population was statistically significant with a P-value of 0.005, 0.006 and <0.001 respectively. For the age group of 15-16 years, the mean difference between chronological and skeletal age for girls and combined population was <0.001 and 0.011 respectively. For the same age group, the mean difference between dental and skeletal age was statistically significant for girls and combined population with a P-value of 0.005 and 0.008 respectively. For overall age group of 7 to 16 years boys, girls and all children there was no statistical significant difference observed for CA and DA, CA and SA and DA and SA. However for overall age groups the dental age was underestimated by 0.28, 0.40 and 0.34 years in boys, girls and total children respectively. As regards the SA is concerned it was found to be underestimated by 0.01 in boys whereas it was found to be overestimated by 0.09 and 0.03 years in girls and all children respectively.

Linear prediction models were obtained for dental and skeletal age using regression analysis. The chronological age was an independent variable while dental and skeletal ages were dependent variables. The models were obtained independently for boys and girls. The R^2 value was referred as a measure of goodness of fit of the models. **(Table 15, page no. 89)**

The overall regression equation with dental age as dependent variable and chronological age as independent variable was obtained as:

DA= 0.165+0.955×CA with R^2 value 88.3%, indicating a good fit of linear model.

On similar lines, the overall expression for skeletal age based on chronological age was obtained as:

SA= -1.148+1.103×CA with a R^2 value of 91.1% indicating a good fit of the model.

The overall expression for chronological age based on dental and skeletal age was obtained as:

CA=1.181+0.924×DA with R^2 value of 88.4% indicating a good fit of the model.

CA=1.966+0.826×SA with R^2 value of 91.1%

Similarly, analysis was performed for boys with expressions obtained as:

DA= 0.258+0.952×CA with a R^2 value of 88.5 %

SA= -0.705+1.059×CA with a R^2 value of 90.7 %

CA=1.064+0.930×DA with R^2 value of 88.5%

CA=1.655+0.857×SA with R^2 value of 90.8%

The expressions obtained for girls were as follows:

DA= 0.066+0.959×CA with a R^2 value 88.1%

SA= -1.561+1.143×CA with a R^2 value of 91.6%

CA=1.291+0.920×DA with R^2 value of 88.3%

$CA=2.208+0.801\times SA$ with R^2 value of 91.6%

DISCUSSION

Review of literature shows that studies in different part of India have been carried out to determine the dental and skeletal ages and their correlation with chronological age in children and adolescents.[11,34,41,50] However data for same is lacking for the Central India population. Therefore this study was undertaken to establish the dental and skeletal ages and to correlate with chronological age in children and adolescents from Central India. The study metropolitan city is situated in the state of Maharashtra and is surrounded by three states. Three national highways are passing through the city. People from other states speaking other various languages and of different religious faiths are settled in the said city thus making it a cosmopolitan city. Children who were born and brought up and their parents being residents of the city since one generation were included in the present investigation. Therefore the children included in the study can be considered as representative of Central India.

The sample for the present study comprised of 204, 7 to 16 years age children. The sample size was in accordance with the previous studies[1,11,27.41] and was finalized after consultation with the statistician.

To determine the correct chronological age of a child, it is imperative to record the exact date of birth. Every effort was made to record the correct date of birth of children included in the study by interviewing the child and parents. In case of doubt, the date of birth was confirmed from the document related to birth wiz. Birth certificate, school identity card etc. Children whose correct date of birth could not be obtained were not included in the study. In order to get correct CA, we reviewed the literature for method of calculation. The National Association of Special Education Teachers (NASET- USA) [49] described correct method of estimating chronological age. The Willems method and Greulich and Pyle radiographic atlas calculates respective dental and skeletal age in decimals. These dental and skeletal decimal ages cannot be correlated with the calendar age (chronological age). We searched the literature regarding method of conversion of calendar age into decimals. None of the studies have mentioned method of conversion of chronological age into decimals. In order to calculate accurate decimal age of the child, we followed the procedure as described in the materials and method at page no. 32.

The dental calcification stages in the present study were determined by the method described by **Demirjian A et al.** [3] in 1973 and the dental age was estimated as proposed by **Willems G et al. (2001)**[20]. Out of all the dental age estimation methods, Demirjian's method is used widely because of its simplicity. They proposed the dental age estimation method for French Canadian population, by reference to the radiographic appearances of the 7 mandibular teeth on the left side. On panoramic radiographs each tooth was rated according to the developmental criteria i.e. amount of calcification, change of pulp chamber shape, etc rather than the changes in size. Eight stages A to H were derived, defined from the first appearance of calcified points to the closure of the root apex. Each tooth was given a score depending on its stage. The sum of the scores of all seven teeth gave a dental maturity score which could be converted directly into a dental age using appropriate table of standards.[3] This method was applicable in 3 to 17 year age group. The maturity scoring system is universally applicable but the maturity score and the dental age depends on the population considered. The advantage of the Demirjian's method is that the objective criteria describing stages of tooth development have been illustrated with line diagrams and radiographic images in a clear-cut manner, leaving the clinician not much space for guessing.[51] The criteria of the method comprise the shape and proportion of root length (using the relative value to crown height rather than absolute tooth length) and thus the influence of radiographic projection is minimal.[12] The disadvantage of this method is that it cannot be used in cases of bilaterally missing teeth. It is possible that Demirjian's method of assessing dental maturation may not be suitable at the lower limit of its range (between 3 and 4 years of age). Its reliance on several permanent teeth also makes it unsuitable for studies of fragmentary remains. **Demirjian A et al.** have also reported a possibility that the standards they obtained from the French-Canadian origin children may not be valid in other populations and that perhaps adaptations would have to be made for other population groups. Demirjian's method was found to be highly reliable in certain populations such as Finnish[52], Norwegian[53], Swedish [54] and Belgaum (Karnataka, South India) children.[55] Various studies reported that the Demirjian's method showed consistent overestimation when applied to various populations worldwide like Northwestern Turkish,[31] Dutch,[56] Bosnian-Herzegovian (BH) children,[57] Saudi, [58] and Tibetan populations.[59] **Liversidge HM et al.**[19] in **1999** stated that the Demirjian's method was not entirely suitable for younger children in British population. Demirjian's method of age assessment was also not applicable for children in Davangere (Karnataka- South India),[60] Vishakhapatnam (South India) [34] and Merrut (Uttar Pradesh- North India).[45]

In a study by **Willems G et al. (2001)**[20], Demirjian's method resulted in a consistent overestimation of the dental age when applied to the Belgian Caucasian sample. In order to overcome this, maturity scores obtained from the total Belgian Caucasian sample were analyzed with a weighted ANOVA in order to create an adapted method for dental age estimation. New tables were created in which the maturity scores were directly expressed in years. This resulted in higher accuracy as compared to the original method in Belgian Caucasians. Also the authors stated that dental maturation was rather independent from overall maturation in contrast to other maturational processes like skeletal or secondary sex character maturation. This modification has been evaluated among various communities and has been reported to be more accurate compared with the original Demirjian's method. The advantage of this method is that the cumbersome step of conversion of maturity score to dental age is deleted, making it simpler. Yet, the advantages of the Demirjian's technique are retained. This method reduced the overestimation of dental age considerably, leaving it to be more accurate in various populations like Malay, [24] Former Yugoslav Republic of Macedonia,[33] Venezuelan,[35] Turkish[40], Labenese, [47] and Japenese[61] population. Willems method was also found to be more accurate in various Indian populations such as Faridabad (Haryana),[29] Vishakhapatnam (Andhra Pradesh),[34,50] Kanchipuram (Tamil Nadu),[39] Gandhinagar (Gujrat)[41], Mangalore(Karnataka)[43] and Rajnadgaon (Chhattisgarh)[46]. **Mani SA et al. (2008)**[24] in their study stated the fact that a significant difference between chronologic and dental ages, when dental age was estimated using the Demirjian method may imply that either there has been a positive secular trend in growth over the 30 years since the standards have been published in a French Canadian population or that the standards cannot be applied to other populations. **Akkaya N et al. (2015)**[40] stated that Willems maturity scores were closer to the present time. This implies that recently created standards, like the Willems method, should be applicable in various populations.[24]

The Demirjian method is found to have good reproducibility in estimating dental calcification stages. The Willems method, a modification of Demirjian's method, is found to be more accurate in estimating the dental age compared to the Demirjian method.[24] Hence, in the present study, the choice for dental age estimation method was the Willems method.

The Demirjian's or Willems method utilizes Orthopantomograms (OPGs) for estimation of the dental calcification stages. In young, nervous children the OPGs are easy to obtain compared to IOPA X rays as used in Nolla's method. An OPG gives a complete developmental status of the dentition. The radiation exposure required for an OPG is comparatively less than that required for several periapical radiographs.[50] Thus the evaluation of calcification stages of teeth from OPGs is the most suitable method for estimation of dental age.[24] There is 3 to 10% of enlargement in OPGs. But it is not a drawback because the Demirjian's rating system is based on sharp criteria and relative values rather than on absolute lengths.[50] As the digital application has been introduced in radiology including OPG, the assessment and evaluation of the images can be done more accurately and may be improved with the application of image magnification.

Erdem AP et al. (2013)[31] and **Akbar A et al. (2016)**[43] stated that using digital OPGs allows wide range of magnification of the particular area of the images to achieve a more accurate evaluation of developmental stages of teeth as well as making the assessment easier. The disadvantages of using OPG films are that they require processing and proper storage which are overcome by digital OPG images. Hence, in the present study, digital OPG images were used for evaluation of dental calcification stages.

Skeletal maturity is closely related to sexual and somatic maturity and is perhaps the most commonly used index in routine clinical dentistry.[17] The clinical importance of evaluating skeletal maturation has been recognized as early as 1976 by **Grave KC et al.**[5]; in 1980 by **Hägg U. and Taranger J.**[16], in 1995 by **Hassel B. and Farman AC.**[6] Since skeletal maturity and the appearance of the ulnar sesamoid are related, correlations between the appearance of the ulnar sesamoid and menarche are also consistently high.[17] During growth, every bone goes through a series of maturational changes, which can be observed radiologically. The sequence of changes is relatively consistent for a given bone. The hand, foot, knee, elbow, shoulder, hip, and cervical vertebrae can be used to assess skeletal age of an individual. Out of the above mentioned bones, hand-wrist method has been explored extensively as indicator of maturity[2]. The hand– wrist region radiographs has been most frequently used for pubertal growth assessment as many centers are maturing at different rate and time. [2,9,10]

The skeletal age estimation can be obtained using **Greulich and Pyle (1959)**[9] and **Tanner JM et al. (1975)** [10] radiographic atlases. The **Tanner JM et al. (1975)** [10] technique for skeletal age estimation requires thorough familiarity with the rating process, is time consuming and needs experience.[18] The **Greulich and Pyle ‘‘Radiographic Atlas’’ (1959)**[9] is preferred for skeletal age estimation since it is less time consuming and shows greater reproducibility between observers.[41] The atlas can be used by a non- specialist dental practitioner and can give a good degree of confidence for practical purposes.[18]

Garn SM et al. (1960)[62] stated that during early childhood the carpals are used for age assessment, while during late childhood and puberty the changes occurring in the metacarpals and phalanges provide better information. By examining the middle phalanx of the third finger (MP3) the clinician can evaluate the skeletal maturity of the patient at that point of time and have a reasonable idea as to how much growth should be factored into the proposed treatment.[27]

There are six anatomical sites located on the thumb, third finger, fifth finger & radius which follow orderly sequences of maturation. Like other sites middle phalanx also undergoes the four sequential stages- epiphyseal widening, ossification, capping, & lastly the fusion. Widening of the epiphysis relative to its diaphysis is a progressive process. In capping stage the lateral margins of the epiphysis begin to flatten & point toward the diaphysis, with an acute angle. Fusion between the epiphysis & diaphysis follows capping. It begins centrally & progresses laterally to become a single bone.[16]

Hagg U and Taranger J. (1980)[16] did a study to determine the timing of ten specified skeletal stages in a representative prospective longitudinal sample of Swedish children and to describe the relationship in the time between these ten skeletal stages and the pubertal growth spurt. Eight out of the ten stages that were used were defined earlier and two new stages (MP3-FG and R-IJ) were added by the authors of the above study to improve orthodontic treatment planning. The new stage MP3-FG was selected as an indicator of the acceleration period of the pubertal growth spurt and the new stage R-IJ as an indicator of late adolescent growth. They stated that more information can be obtained if the maturation indicator is one of a series of discrete stages (as in MP3 stages), especially if the indicators are of brief duration. They concluded that the stages of ossification of middle phalanx of the third finger of the hand follow the pubertal growth spurt.

Madhu S et al. (2004)[22] stated that the developmental stages of the middle phalanx of the third finger (MP3) could be used as a sole indicator to assess pubertal growth spurt for effective treatment planning in pediatric orthodontics. The method of skeletal maturity assessment using MP3 radiographs was found to be simple, highly reliable and less expensive as a standard dental x-ray machine and an IOPA film are commonly available in all private dental clinics and hospitals. **Abdel-Kader HM et al. (1999)**[63] studied the scope of the digital dental radiographic technique to record the MP3 stages, and the possibilities of the image manipulation by zooming and viewing the image at different densities to enhance image viewing and results, thus improving inter and intraexaminer reproducibility. **Hegde DY et al. (2012)**[27] also used the digital images of the MP3 and stated that this method is a simple and noninvasive which fulfills the principle of 'as low as reasonably achievable' (ALARA), according to which the patient should be subjected to only that amount of radiation that is absolutely necessary for diagnostic purpose. With an exposure time five times less than that used in the conventional approach, this method showed great ability to provide high-quality digitized radiographic images of the growth indicator under investigation. The disadvantages of using IOPA x-rays are that they require processing and proper storage which are overcomed by RVG images.

Hence, RVGs of MP3 region were used in the present study and the stages as described by **Hagg U and Taranger J. (1980)** [16] were used for the staging of MP3 (middle phalanx of third finger) of left hand and the age was estimated as per the **Greulich and Pyle ''Radiographic Atlas'' (1959)**[9].

The Monaco (1906) and Geneva (1912) Conferences of Physical Anthropologists stated the international agreement for the unification of anthropometric measurements in living subjects be made of the left rather than the right side of the body and of the left extremities. It was stated that in case of right and left extremities, the number of right handed person in a population is much larger than the left handed ones and therefore left hand is somewhat less likely to be maimed or injured than the right hand. Hence, the left hand MP3 and left side 7 mandibular teeth were considered in the present study.[11]

Training and calibration of both the examiners was done for assessment of dental calcification stages of 7 mandibular teeth in the third quadrant of digital OPG images as per the Demirjian’s method (1973), and MP3 skeletal ages by Greulich and Pyle radiographic atlas method (1959) to get consistent judgments of scoring. Accordingly 10% of total OPGs and RVGs were analyzed by both the examiners and the interexaminer agreement for the above two recordings was highly significant which being 97.8% and 98.5% for estimation of dental and skeletal ages respectively. Intraexaminer reproducibility for assessment of dental and skeletal ages after a period of 4 weeks for assessment of the same 10% of total OPGs and RVGs was found to be 99.4% and 99.6% respectively for examiner 1 and 98.6% and 98.5% respectively for examiner 2. This means the intraexaminer validity of scoring over a period of time was highly accurate and reproducible for both examiners. Therefore the assessment done by both examiners may be considered as valid and acceptable.[48]

Erdem AP et al. (2013)[31] has stated that accuracy of dental age estimation is defined by how closely chronological age could be predicted and was measured as the difference between chronological age and dental age. **Priya E. (2015)**[39] stated that the mean difference is considered to be more appropriate measure of accuracy than others, including correlation coefficient because it allows understanding the difference between the chronological age and estimated dental age in units, i.e., in decimal years. In the present study, the chronological age was subtracted from the dental age and a positive result indicated an overestimation (acceleration of the dental development), zero meant that dental age and chronological ages were identical and a negative result indicated an underestimation (delayed dental development).[31, 35]

In the present study, the overall mean difference between DA and CA for girls, boys and total children was -0.40 years, -0.28 years and -0.34 years respectively which was not statistically significant. Hence it was noted that Willems method of dental age estimation consistently underestimated the age in girls, boys and total children. In the study by **Mohammed RB et al (2014)**[34] also reported underestimated dental age by -0.69 years, -0.08 years and -0.39 years in girls, boys and total children respectively of which the values for boys and total children were statistically significant in contrast to present study.

In our study statistical significant difference between CA and DA was observed only for two age groups in girls i.e. 7-8 years and 10-11 years whereas **Mohammed RB et al (2014)**[34] and **Patel PS et al (2015).**[41] observed no statistical significant difference found in any of the age groups in girls. In the present study, Willems method consistently underestimated the age of girls in all the age groups except for 11-12 years. The greatest underestimation of age in girls was seen for the age group of 14-15 years. **Mohammed RB et al (2014)**[34] also reported underestimation in all the age groups for girls except for 10-11.99 years which is similar to our study. Contrary to the present study **Mohammed RB et al (2014)**[34] reported greatest underestimation of dental age 8-9.99 year girls. **Patel PS et al (2015)**[41] observed both under and overestimation of dental age. 6-6.99, 10-10.99, 13-13.99, 15-15.99 and 16-16.99 year age group girls were observed to have underestimation of dental age and the greatest underestimation being in 15-15.99 years girls. Amongst the remaining overestimated age groups, the greatest overestimation was found in the age group of 12-12.99 years. In the present study 11-12 years girls also had overestimated dental age.

In the present study, the statistical significant difference between CA and DA in boys was noted only for 9-10 years age group. **Mohammed RB et al (2014)**[34] noted statistical significant differences in 14-15.99 years boys whereas **Patel PS et al (2015)**[41] observed statistical significant difference in 8-8.99 and 13-13.99 years boys. In the present study, the greatest underestimation was seen for the 13-14 years age group. **Mohammed RB et al (2014)**[34] found underestimation in all the age groups boys except for 6-7.99 years with greatest underestimation being in 14-15.99 years. whereas **Patel PS et al (2015)**[41] observed underestimation in 11 to 14.99 years boys and greatest underestimation being in 14-14.99 years while the greatest overestimation was seen for the age group of 7-7.99 years. The overestimated dental age was observed in 7-8, 8-9 and 10-11 years boys of the present study and the greatest overestimation was seen in 10-11 years age group.

When entire sample was considered, the statistical significant difference between CA and DA was noted only for three age groups i.e. 9-10 years 12-13 years and 14-15 years. **Mohammed RB et al (2014)**[34] observed statistical significant difference between CA and DA in combined population for 8-8.99 and 14-15.99 years age groups. In the present study, Willems method consistently underestimated the age of the children in all the age groups. The greatest underestimation was seen for the age group of 12-13 years. The overall underestimation of age in the present study was in agreement with the previous studies like **Maber M et al. (2006),**[64] **Mohammed RB et al. (2014),**[34] **Patnana AK et al. (2014)**[50] and **Akbar A et al. (2016)** [43]. Willems method of dental age estimation is applicable for the population of Central India, more so for the boys (mean difference of -0.28) than for the girls (mean difference -0.40). This is in accordance with the study conducted by **Mohammed RB et al. (2014)**[34] and contrast to the studies conducted by **Patel PS et al. (2015)** [41]. In contrast to the present study **Mani SA et al. (2008),**[24] **Grover S et al. (2011)**[29] and **Medina AC et al. (2014)**[35] overestimated the dental age in Malay, Faridabad and Venenzuelan population respectively by Willems method.

In the present study, the overall mean difference between SA and CA for girls, boys and all children was 0.09, -0.01 and 0.03 respectively which was not statistically significant. Comparison between chronological and skeletal age as estimated by Greulich and Pyle method showed insignificant differences for all the age groups except 7-8 and 15-16 years girls, 9-10 and 14-15 years boys and 7-8, 9-10, 14-15 and 15-16 years in all the children. Similar findings have been reported by **Patel PS et al. (2015)**[41] who observed insignificant differences for all the age groups except 9-9.99, 10-10.99, 12-12.99, 13-13.99 and 15-15.99 years males and 11-11.99 and 12-12.99 years females.

A consistent overestimation of skeletal age was observed in all the age groups girls except 7-8, 8-9, 9-10 and 13-14 years. The greatest underestimation was seen for the age group of 9-10 years. **Shilpa PH et al. (2013)**[11] found overestimation of skeletal age in all the age groups except for 11-12 years girls. The greatest overestimation in the present study was found in 15-16 years girls whereas it was 10-11 years in **Shilpa PH et al. (2013)**[11] study. As against the present study's finding of overestimation of skeletal age, **Patel PS et al (2015)**[41] observed consistent underestimation of skeletal age in all the age groups in girls except for 6-6.99 and 16-16.99 years.

In contrast to the girls of the present study, a consistent underestimation of skeletal age was observed in all the age groups boys except 10-11, 12-13, 14-15 and 15-16 years. The greatest underestimation and overestimation was found in 9-10 years and

14-15 years boys respectively. Similar to the present study **Patel PS et al (2015)**[41] also observed underestimation of skeletal age in all the age groups in boys with the greatest underestimation being in the age group of 14-14.99 years. As against above findings **Shilpa PH et al. (2013)**[11] found overestimation in all the age groups in boys except for 6-7 and 9-10 years; and the greatest overestimation being in the age group of 15-16 years.

Overestimation of skeletal age was observed in all the age group children for the total sample except 7-8, 8-9, 9-10 and 13-14 years children. The greatest underestimation was seen for the age group of 9-10 years whereas the greatest overestimation was seen in 14-15 years. **Shilpa PH et al. (2013)**[11] reported overestimation of skeletal age in all the age groups in their study population; the greatest overestimation being in the age group of 15-16 years.

In the present study, the DA and SA estimation is done by Willems method and Greulich and Pyle method respectively. The overall mean differences between DA and SA for girls, boys and entire sample were found to be 0.49, 0.27 and 0.37 respectively which were not statistically significant. Search of the literature regarding correlation of dental and skeletal ages using above methods could not be found. **Kraillaseri S et al. (2002)**[12] observed a strong correlation between Demirjian's dental calcification stages and skeletal age assessment done by Fishman's index. **Flores-Mir C et al. (2005)**[65] have correlated skeletal and dental calcification using MP3 and mandibular canine calcification; however the author have noted dental calcification of canine only as against all left side permanent teeth in their study. Hence a true comparison with these studies cannot be ascertained since all these studies have used different criteria for dental and skeletal maturation.

The present study reveals a high correlation between dental and skeletal ages. A better correlation was seen in boys than girls. In the entire sample the children were more advanced skeletally (11.50 ±3.05 years) compared to dental age (11.13 ±2.68 years). Girls were more skeletally advanced while boys showed more dental advancement with the mean overall age being 11.60 ±3.21 years and 11.14 ±2.63 years respectively. The variations in the dental and skeletal maturation in different populations can be attributed to the environmental factors, genetic variations, racial differences, socio- economic status, nutrition, dietary habits and lifestyle.

From the above findings it may be deduced that in clinical pediatric dentistry the dental and skeletal ages of the child from Central India can be predicted from his decimal chronological age to ascertain the status of pubertal growth spurt. However to calculate the exact dental and skeletal ages of the child, proposed regression equations for boys and girls may be used with a measure of goodness of fit (R2 value) of more than 88% in children for Central India.

SUMMARY AND CONCLUSION

An investigation was carried out to estimate and correlate the dental calcification, skeletal maturity stages and chronologic age in a metropolitan city of Central India. The sample comprised of 204 children (101 girls and 103 boys) of 7-16 years representing the cross section of the population.

The decimal chronological age was derived from calendar age as determined from the date of birth of the children. The dental age was calculated by Willems modified Demirjian method using digital orthopantomograms. The skeletal age was evaluated with the help of Greulich and Pyle radiographic atlas using radiovisiographs of middle phalanx of the third finger. The stages of MP3 ossification were evaluated according to Hagg and Taranger.

Willems method of dental age estimation consistently underestimated the age of the children in all the age groups. The overall underestimation was 0.28, 0.40 and 0.34 years in girls, boys and all children respectively. The greatest underestimation was seen for the age group of 14-15, 9-10 and 12-13 years for girls, boys and all children respectively. Willems method of dental age estimation is found to be applicable, more so for the boys compared to the girls.

Greulich and Pyle method of skeletal age estimation consistently overestimated the age of the children in all the age groups except in the age groups of 7-8, 8-9, 9-10 and 13-14 years. The greatest overestimation was seen in 15-16, 14-15 and 14-15 years for girls, boys and all children respectively. The greatest underestimation was seen for the age group of 9-10 years for girls, boys and all children respectively. Greulich and Pyle method of skeletal age estimation is found to be applicable, more so for the boys compared to the girls.

A high correlation was observed between Willems method of dental age estimation and Greulich and Pyle method of skeletal age estimation. Girls, boys and all children were found to be advanced skeletally by 0.49, 0.27 and 0.37 respectively compared to the dental age. Girls were more skeletally advanced while boys showed more dental advancement.

Willems method of dental age estimation and Greulich and Pyle method of skeletal age estimation showed close relation with the chronological age. The regression analysis was carried out and equations/ formulae were derived for estimation of dental and skeletal ages and to derive chronological age in forensic dentistry for girls and boys separately for Central India population.

To conclude from the present study:

- Digital OPGs and RVGs can be conveniently utilized in routine clinical pediatric dentistry to determine the tooth calcification stages and skeletal maturity respectively.
- Willems dental age estimation method and Greulich and Pyle radiographic atlas method for skeletal age estimation are applicable for children and adolescents of Central India.
- A high correlation is found between dental and skeletal ages.

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Tables

Table 1: Distribution of sample

Age group	Boys	Girls	Total
7-8 years	12	12	24
8-9 years	11	11	22
9-10 years	12	11	23
10-11 years	11	11	22
11-12 years	12	11	23
12-13 years	12	11	23
13-14 years	11	11	22
14-15 years	11	11	22
15-16 years	11	12	23
Total	103	101	204

Table 2: Inter examiner reliability for dental and skeletal ages

Parameters	Mean	SD	α (Lower-Upper bound)	P-value*
Dental age				
Examiner 1 (n=20)	10.62	2.28	0.978 (0.944-0.991)	< **0.001 (S)**
Examiner 2 (n=20)	10.63	2.56		
Skeletal age				
Examiner 1 (n=20)	10.97	2.84	0.985 (0.963-0.994)	< **0.001 (S)**
Examiner 2 (n=20)	11.27	3.12		

Table 3: Intra examiner reliability for dental and skeletal ages for first examiner

Examiner 1	Mean	SD	α (Lower-Upper bound)	P-value*
DA (n=20)	10.62	2.28	0.994 (0.984-0.997)	< **0.001 (S)**
DA after 4 weeks (n=20)	10.68	2.39		
SA (n=20)	10.97	2.84	0.996 (0.990-0.998)	< **0.001 (S)**
SA after 4 weeks (n=20)	11.00	2.77		

Table 4: Intra examiner reliability for dental and skeletal ages for second examiner

Examiner 2	Mean	SD	α (Lower-Upper bound)	P-value*
DA (n=20)	10.63	2.56	0.986 (0.965-0.995)	< **0.001 (S)**
DA after 4 weeks (n=20)	10.64	2.48		
SA (n=20)	11.27	2.84	0.985(0.962-0.994)	< **0.001 (S)**
SA after 4 weeks (n=20)	10.96	2.77		

Table 5: Comparison of chronologic age and dental age for girls

Age group	Chronologic age	Dental age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.33±0.23	6.92±0.32	-0.41	3.578	**0.002(S)**
8-9 years	8.55±0.29	8.43±0.33	-0.12	0.967	0.345(NS)
9-10 years	9.60±0.42	9.35±0.79	-0.25	0.931	0.367(NS)
10-11 years	10.40±0.26	9.69±0.83	-0.71	2.723	**0.018(S)**
11-12 years	11.58±0.25	11.87±1.14	0.29	-0.808	0.436(NS)
12-13 years	12.59±0.69	11.87±1.09	-0.72	1.820	0.087(NS)
13-14 years	13.48±0.26	12.98±1.24	-0.50	1.298	0.221(NS)
14-15 years	14.63±0.39	13.64±1.17	-0.99	2.676	0.200(NS)
15-16 years	15.45±0.43	15.22±1.05	-0.23	0.698	0.496(NS)
Overall	11.51±2.69	11.11±2.74	-0.40	1.058	0.291 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 6: Comparison of chronologic age and dental age for boys

Age group	Chronologic age	Dental age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.44±0.28	7.45±0.44	0.01	0.009	0.993(NS)
8-9 years	8.41±0.25	8.42±0.67	0.01	-0.020	0.984(NS)
9-10 years	9.74±0.52	9.17±0.67	-0.57	2.358	**0.028(S)**
10-11 years	10.53±0.24	10.75±0.71	0.22	-0.940	0.368(NS)
11-12 years	11.38±0.28	10.87±1.02	-0.51	1.642	0.125(NS)
12-13 years	12.25±0.26	11.69±1.28	-0.56	1.456	0.171(NS)
13-14 years	13.63±0.64	13.07±1.38	-0.56	1.237	0.236(NS)
14-15 years	14.41±0.27	14.33±0.30	-0.08	0.612	0.548(NS)
15-16 years	15.44±0.33	14.99±1.32	-0.45	1.095	0.296(NS)
Overall	11.42±2.59	11.14±2.63	-0.28	0.765	0.445 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 7: Comparison of chronologic age and dental age for children

Age group	Chronologic age	Dental age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.39±0.26	7.18±0.46	-0.21	1.908	0.064(NS)
8-9 years	8.48±0.28	8.42±0.52	-0.06	0.499	0.621(NS)
9-10 years	9.68±0.47	9.25±0.72	-0.43	2.351	**0.024(S)**
10-11 years	10.47±0.26	10.19±0.93	-0.28	1.286	0.211(NS)
11-12 years	11.47±0.28	11.35±1.17	-0.12	0.504	0.504(NS)
12-13 years	12.42±0.53	11.79±1.18	-0.63	2.334	**0.026(S)**
13-14 years	13.55±0.48	13.02±1.28	-0.53	1.821	0.080(NS)
14-15 years	14.52±0.35	13.99±0.91	-0.53	2.585	**0.015(S)**
15-16 years	15.45±0.38	15.11±1.16	-0.34	1.309	0.202(NS)
Overall	11.47±2.63	11.13±2.68	-0.34	1.295	0.196 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 8: Comparison of chronologic age and skeletal age for girls

Age group	Chronologic age	Skeletal age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.33±0.23	6.89±0.59	-0.44	2.379	**0.032(S)**
8-9 years	8.56±0.29	8.35±1.14	-0.21	0.597	0.562(NS)
9-10 years	9.60±0.42	8.78±1.30	-0.82	1.987	0.070(NS)
10-11 years	10.40±0.26	10.60±1.09	0.20	-0.589	0.568(NS)
11-12 years	11.58±0.25	11.93±1.38	0.35	-0.812	0.435(NS)
12-13 years	12.59±0.69	13.13±1.11	0.54	-1.339	0.199 (NS)
13-14 years	13.48±0.26	13.42±0.35	-0.06	0.457	0.653(NS)
14-15 years	14.63±0.39	15.00±0.89	0.37	-1.248	0.233(NS)
15-16 years	15.45±0.43	16.33±0.49	0.88	-4.689	**< 0.001(S)**
Overall	11.51±2.69	11.60±3.21	0.09	-0.215	0.829 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 9: Comparison of chronologic age and skeletal age for boys

Age group	Chronologic age	Skeletal age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.44±0.28	7.08±0.67	-0.36	1.736	0.103(NS)
8-9 years	8.41±0.25	8.27±0.90	-0.14	0.492	0.632(NS)
9-10 years	9.74±0.52	9.25±0.62	-0.49	2.109	**0.047(S)**
10-11 years	10.53±0.24	10.78±0.86	0.25	-0.877	0.400(NS)
11-12 years	11.38±0.28	11.27±0.91	-0.11	0.425	0.678(NS)
12-13 years	12.25±0.26	12.47±0.74	0.22	-0.973	0.347(NS)
13-14 years	13.63±0.64	13.49±1.21	-0.14	0.345	0.735(NS)
14-15 years	14.41±0.27	15.04±0.66	0.63	-3.020	**0.010(S)**
15-16 years	15.44±0.33	15.45±0.68	0.01	-0.042	0.967(NS)
Overall	11.42±2.59	11.41±2.89	-0.01	0.039	0.968 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 10: Comparison of chronologic age and skeletal age for children

Age group	Chronologic age	Skeletal age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.39±0.26	6.94±0.60	-0.45	3.270	**0.003(S)**
8-9 years	8.48±0.28	8.31±1.01	-0.17	0.790	0.437(NS)
9-10 years	9.68±0.47	9.03±1.01	-0.65	2.795	**0.009(S)**
10-11 years	10.47±0.26	10.69±0.97	0.22	-1.001	0.327(NS)
11-12 years	11.47±0.28	11.58±1.18	0.11	-0.408	0.687(NS)
12-13 years	12.42±0.53	12.78±0.97	0.36	-1.587	0.122(NS)
13-14 years	13.55±0.48	13.45±0.87	-0.10	0.477	0.636(NS)
14-15 years	14.52±0.35	15.03±0.77	0.51	-2.829	**0.008(S)**
15-16 years	15.45±0.38	15.91±0.73	0.46	-2.706	**0.011(S)**
Overall	11.47±2.63	11.50±3.05	0.03	-0.132	0.895 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 11: Comparison of dental age and skeletal age for girls

Age group	Dental age	Skeletal age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	6.92±0.32	6.89±0.59	-0.03	0.152	0.274(NS)
8-9 years	8.43±0.33	8.35±1.14	-0.08	0.235	0.818(NS)
9-10 years	9.35±0.79	8.78±1.30	-0.57	1.237	0.233(NS)
10-11 years	9.69±0.83	10.60±1.09	0.91	-2.205	**0.040(S)**
11-12 years	11.86±1.14	11.93±1.38	0.07	-0.108	0.915(NS)
12-13 years	11.89±1.09	13.13±1.11	1.24	-2.638	**0.016(S)**
13-14 years	12.98±1.24	13.42±0.35	0.44	-1.121	0.285(NS)
14-15 years	13.64±1.17	15.00±0.89	1.36	-3.063	**0.006(S)**
15-16 years	15.22±1.05	16.33±0.49	1.11	-3.309	**0.005(S)**
Overall	11.11±2.74	11.60±3.21	0.49	-1.176	0.241 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 12: Comparison of dental age and skeletal age for boys

Age group	Dental age	Skeletal age	Mean difference	t value	P-value*
	Mean ± SD				
7-8 years	7.44±0.44	7.08±0.67	-0.36	1.567	0.134 (NS)
8-9 years	8.42±0.67	8.27±0.90	-0.15	0.423	0.677(NS)
9-10 years	9.16±0.67	9.25±0.62	0.09	-0.322	0.751(NS)
10-11 years	10.76±0.71	10.78±0.86	0.02	0.068	0.946 (NS)
11-12 years	10.87±1.02	11.27±0.91	0.40	-0.98	0.338(NS)
12-13 years	11.69±1.28	12.47±0.74	0.78	-1.800	0.089(NS)
13-14 years	13.06±1.38	13.49±1.21	0.43	-0.769	0.451(NS)
14-15 years	14.33±0.30	15.04±0.66	0.71	-3.311	**0.005(S)**
15-16 years	14.99±1.31	15.45±0.68	0.46	-1.023	0.322(NS)
Overall	11.14±2.63	11.41±2.89	0.26	-0.681	0.496 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 13: Comparison of dental age and skeletal age for children

Age group	Dental age	Skeletal age	Absolute Mean difference	t value	P-value
	Mean ± SD				
7-8 years	7.18±0.46	6.94±0.60	-0.24	1.525	0.135(NS)
8-9 years	8.42±0.52	8.31±1.01	-0.11	0.472	0.640(NS)
9-10 years	9.25±0.72	9.03±1.01	-0.22	0.879	0.385(NS)
10-11 years	10.19±0.93	10.69±0.97	0.50	-1.668	0.103(NS)
11-12 years	11.35±1.17	11.58±1.18	0.23	-0.663	0.511(NS)
12-13 years	11.78±1.17	12.78±0.97	1.00	-3.129	**0.003(S)**
13-14 years	13.02±1.28	13.45±0.87	0.43	-1.305	0.200(NS)
14-15 years	13.98±0.91	15.03±0.77	1.05	-4.115	< **0.001(S)**
15-16 years	15.11±1.16	15.91±0.73	0.80	-2.783	**0.008 (S)**
Overall	11.13±2.68	11.50±3.05	0.37	-1.328	0.185 (NS)

*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 14: Comparison of chronologic, dental and skeletal age for different age groups

Age group	Group A	Comp-arison Group B	Boys		Girls		Combined	
			Mean difference	P value*	Mean Difference	P value*	Mean difference	P value*
7-8 yrs.	CA	DA	0.01	0.993(NS)	-0.41	**0.002(S)**	-0.21	0.064(NS)
		SA	-0.36	0.103(NS)	-0.44	**0.032(S)**	-0.45	**0.003(S)**
	DA	SA	-0.36	0.134(NS)	-0.03	0.274(NS)	-0.24	0.135(NS)
8-9 yrs.	CA	DA	0.01	0.984(NS)	-0.13	0.345(NS)	-0.06	0.621(NS)
		SA	-0.14	0.632(NS)	-0.21	0.562(NS)	-0.17	0.437(NS)
	DA	SA	-0.15	0.677(NS)	-0.08	0.818(NS)	-0.11	0.640(NS)
9-10 yrs.	CA	DA	-0.57	**0.028(S)**	-0.25	0.367(NS)	-0.43	**0.024(S)**
		SA	-0.49	**0.047(S)**	-0.82	0.070(NS)	-0.65	**0.009(S)**
	DA	SA	0.09	0.751(NS)	-0.57	0.233(NS)	-0.22	0.385(NS)
10-11 yrs.	CA	DA	0.22	0.368(NS)	-0.71	**0.018(S)**	-0.28	0.211(NS)
		SA	0.25	0.400(NS)	0.20	0.568(NS)	0.22	0.327(NS)
	DA	SA	0.02	0.946(NS)	0.91	**0.040(S)**	0.50	0.103(NS)
11-12 yrs.	CA	DA	-0.51	0.125(NS)	0.29	0.436(NS)	-0.12	0.504(NS)
		SA	-0.11	0.678(NS)	0.35	0.435(NS)	0.11	0.687(NS)
	DA	SA	0.40	0.338(NS)	0.07	0.915(NS)	0.23	0.511(NS)
12-13yrs.	CA	DA	-0.56	0.171(NS)	-0.71	0.087(NS)	-0.63	**0.026(S)**
		SA	0.22	0.347(NS)	0.54	0.199(NS)	0.36	0.122(NS)
	DA	SA	0.78	0.089(NS)	1.24	**0.016(S)**	1.00	**0.003(S)**
13-14 yrs.	CA	DA	-0.56	0.236(NS)	-0.49	0.221(NS)	-0.53	0.080(NS)
		SA	-0.14	0.735(NS)	-0.06	0.653(NS)	-0.10	0.636(NS)
	DA	SA	0.43	0.451(NS)	0.43	0.285(NS)	0.43	0.200(NS)
14-15 yrs.	CA	DA	-0.08	0.548(NS)	-0.99	0.200(NS)	-0.53	**0.015(S)**
		SA	0.63	**0.010(S)**	0.37	0.233(NS)	0.51	**0.008(S)**
	DA	SA	0.71	**0.005(S)**	1.36	**0.006(S)**	1.05	**<0.001(S)**
15-16 yrs.	CA	DA	-0.45	0.296(NS)	-0.23	0.496(NS)	-0.34	0.202(NS)
		SA	0.01	0.967(NS)	0.88	**<0.001(S)**	0.46	**0.011(S)**
	DA	SA	0.46	0.322(NS)	1.11	**0.005(S)**	0.80	**0.008(S)**
Overall	CA	DA	-0.28	0.445(NS)	-0.40	0.291(NS)	-0.34	0.196(NS)
		SA	-0.01	0.968(NS)	0.09	0.829(NS)	0.03	0.895(NS)
	DA	SA	0.27	0.496(NS)	0.49	0.241(NS)	0.37	0.185(NS)

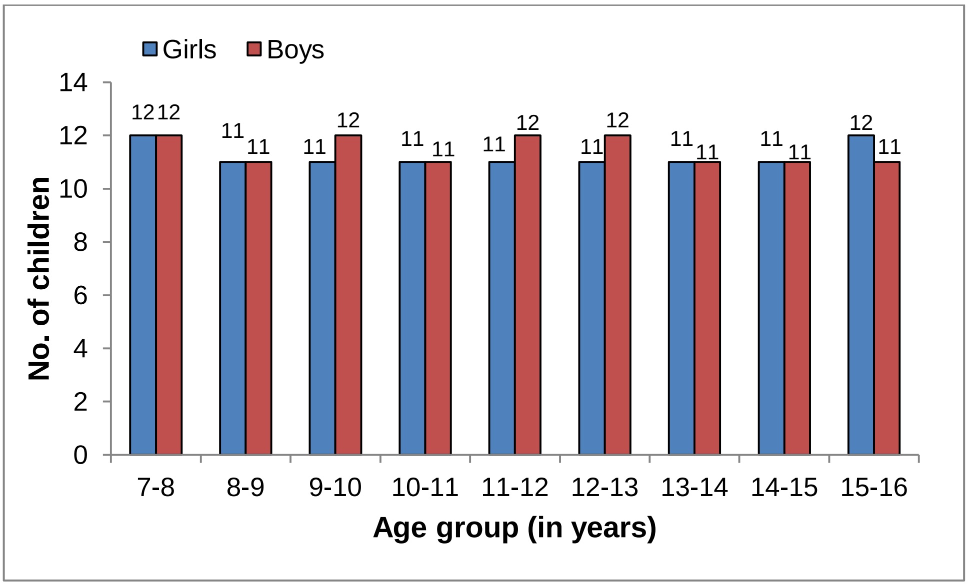
*Obtained using *independent t-test*; S: Significant, NS: Not Significant

Table 15: Linear regression

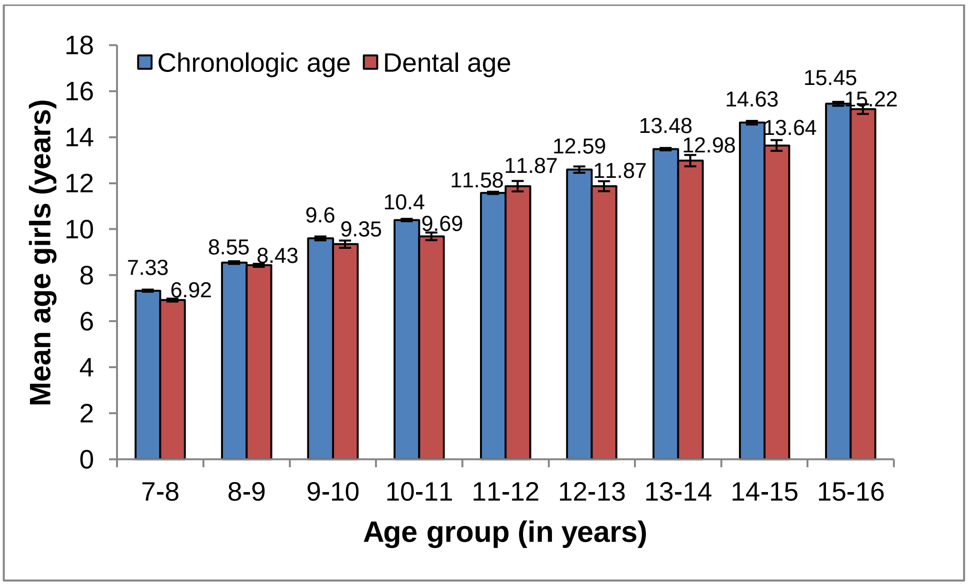
	Model	P-value	R^2
Overall	DA= 0.165+0.955 × CA	< **0.001 (S)**	0.883
	SA= -1.148+1.103 × CA	< **0.001 (S)**	0.911
	CA=1.181+0.924 × DA	< **0.001 (S)**	0.884
	CA=1.966+0.826 × SA	< **0.001 (S)**	0.911
Boys	DA= 0.258+0.952 × CA	< **0.001 (S)**	0.885
	SA= -0.705+1.059 × CA	< **0.001 (S)**	0.907
	CA=1.064+0.930 × DA	< **0.001 (S)**	0.885
	CA=1.655+0.857 × SA	< **0.001 (S)**	0.908
Girls	DA= 0.066+0.959 × CA	< **0.001 (S)**	0.881
	SA= -1.561+1.143 × CA	< **0.001 (S)**	0.916
	CA=1.291+0.920 × DA	< **0.001 (S)**	0.883
	CA=2.208+0.801 × SA	< **0.001 (S)**	0.916

Graphs

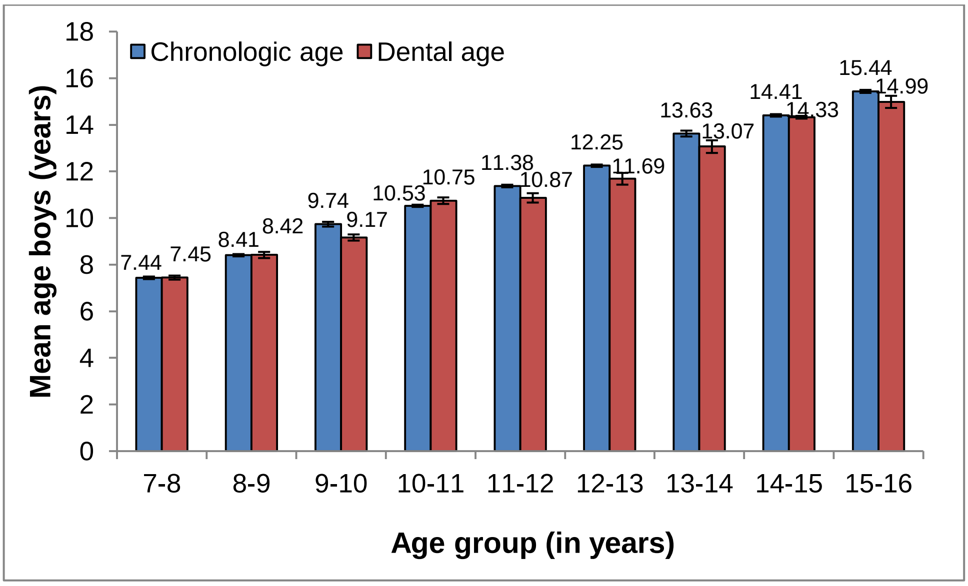
Graph 1: Column chart showing the total number of children according to chronological age



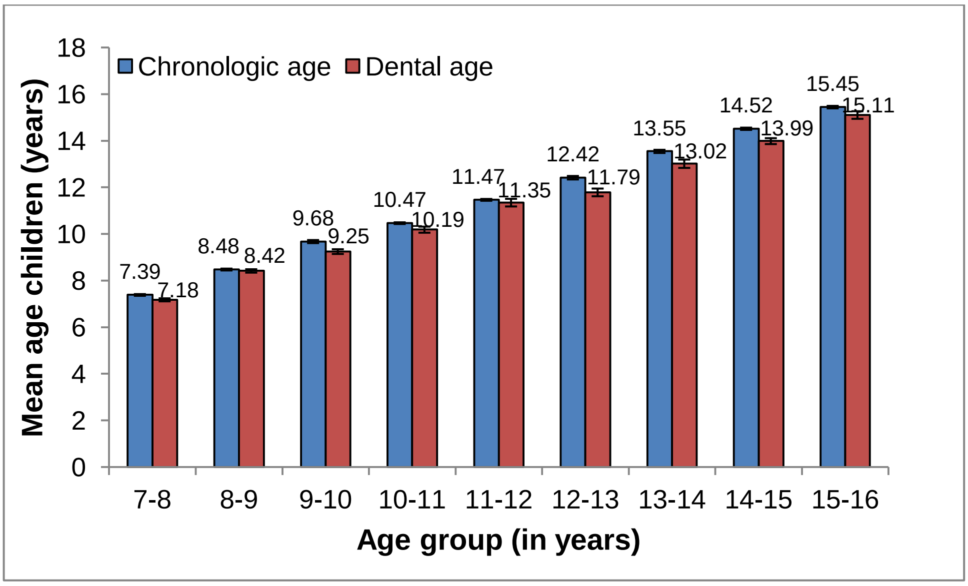
Graph 2: Column chart showing the mean chronological and dental age for girls according to age groups



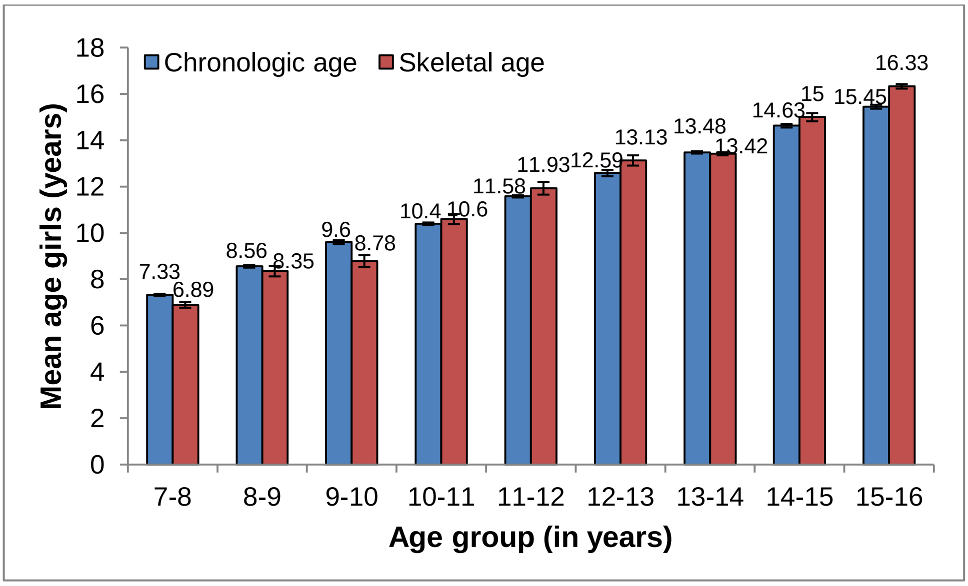
Graph 3: Column chart showing the mean chronological and dental age for boys according to age



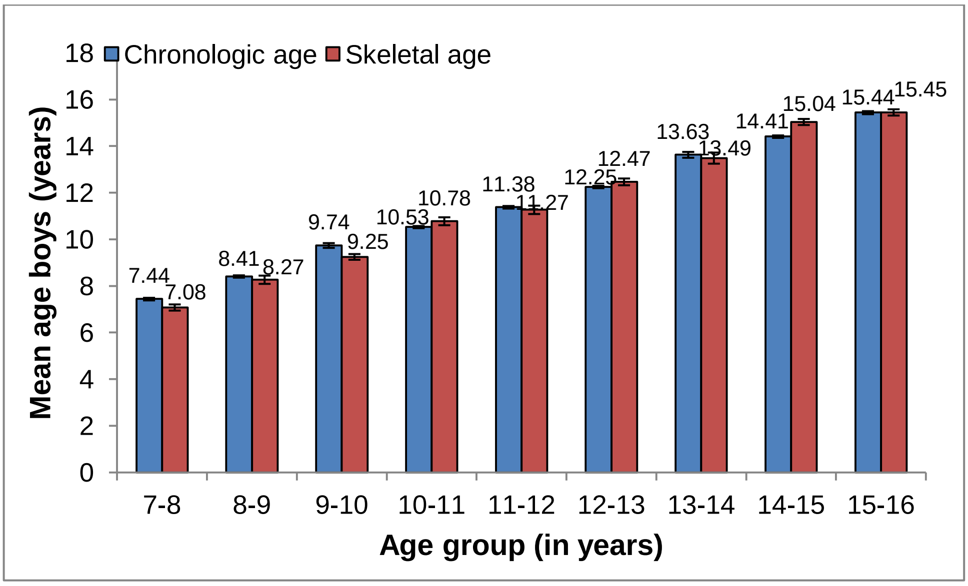
Graph 4: Column chart showing the mean chronological and dental age for children according to age



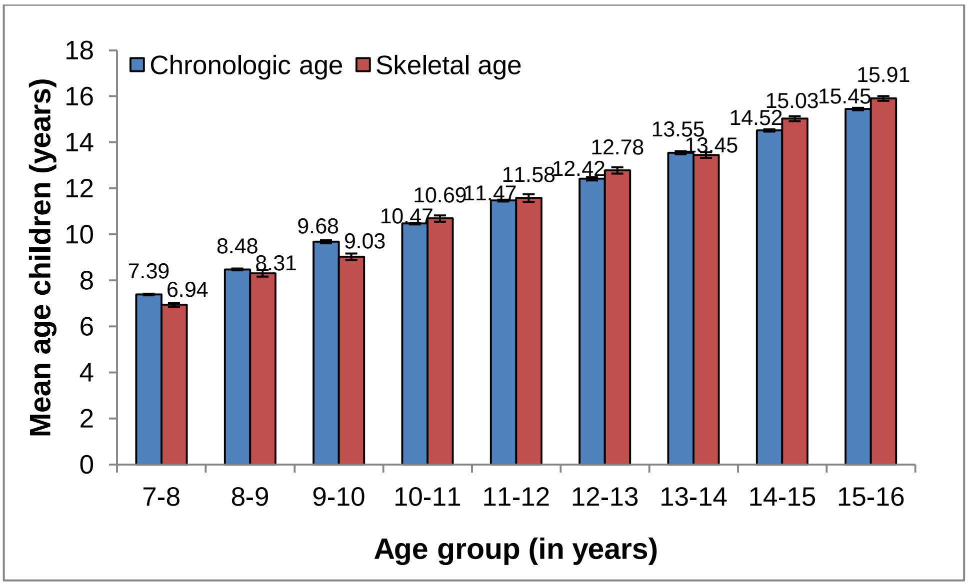
Graph 5: Column chart showing the mean chronological age and mean skeletal for girls according to age



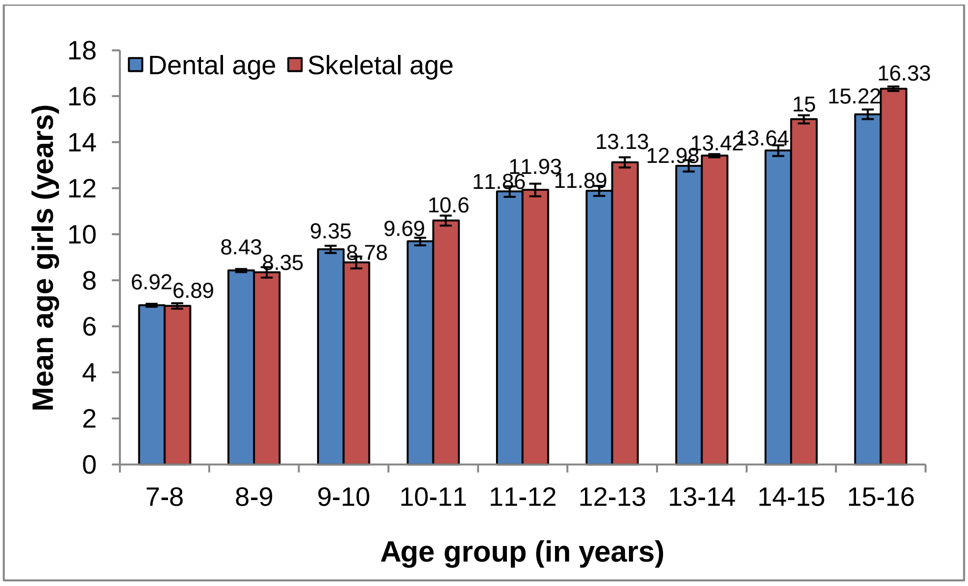
Graph 6: Column chart showing the mean chronological age and mean skeletal age for boys according to age



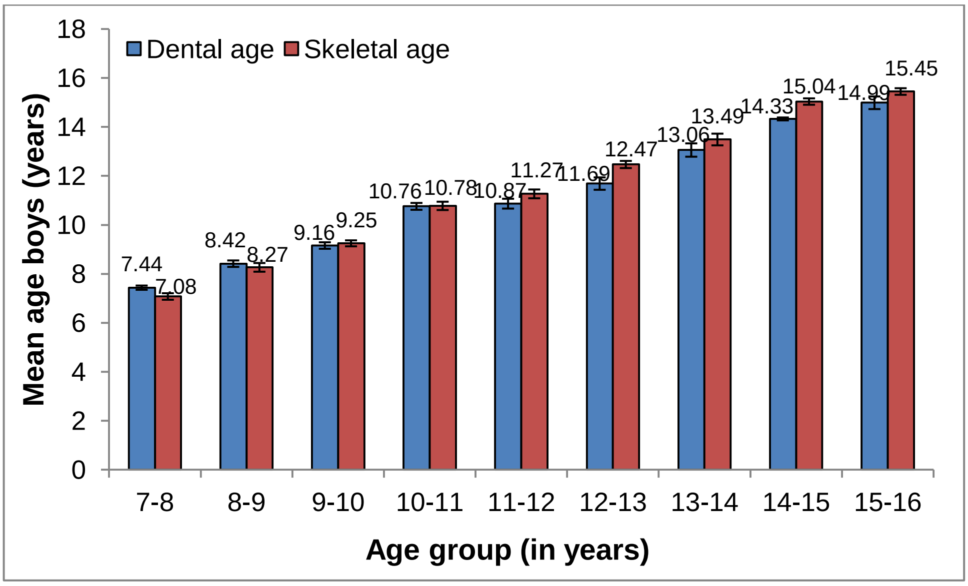
Graph 7: Column chart showing the mean chronological age and mean skeletal age for children according to age



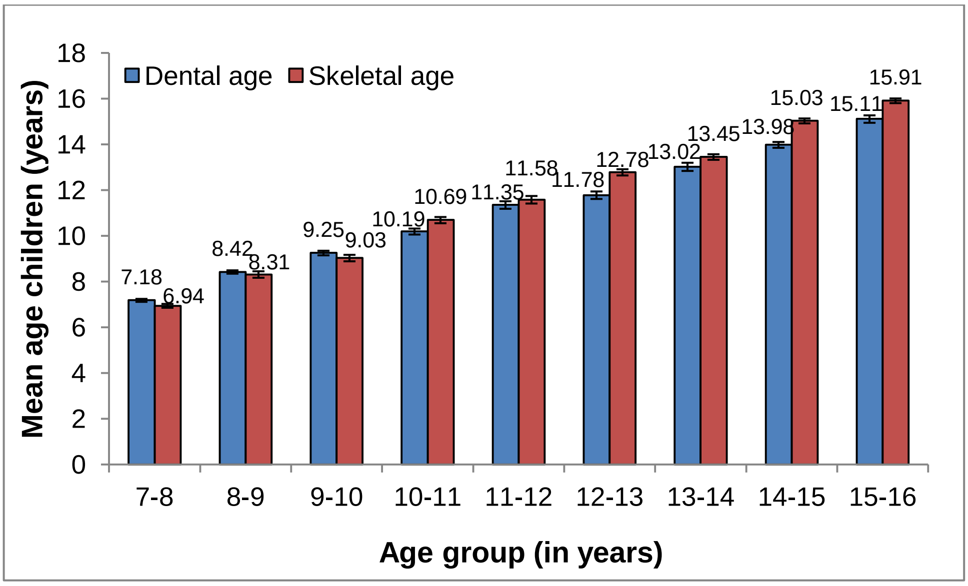
Graph 8: Column chart showing the mean dental age and mean skeletal age for girls according to age



Graph 9: Column chart showing the mean dental and skeletal age for boys according to age



Graph 10: Column chart showing the mean dental age and mean skeletal age for children according to age



Annexure 1

Information Sheet for Patient/Parent

Introduction

I, Post Graduate in the Department of Pediatric and Preventive Dentistry, is working on my Thesis titled "**Correlation of dental calcification stages, skeletal maturity stages and chronologic age of children of 7-16 years age group: A cross sectional descriptive study"** My study subjects would be children of 7-16 years of coming to concerned dental college and for orthodontic treatment.

Purpose of the research

To study the estimation and correlation of the dental calcification stages, skeletal maturity stages and chronologic age in children of age group of 7-16 years

Voluntary Participation

Your participation in this research is entirely voluntary. You can withdraw from it any time you wish. This will no way adversely affect the subsequent outcome of the treatment of your relationship with the operating doctor on inclusion to the project. Any additional expense for the project will be borne by the project fund and will not be charged to you.

Procedures and Protocol

Complete oral examination of child.

↓

Recording of data by means of radiographic images and specially designed proforma.

Confidentiality

The information that we collect from this research project will be kept confidential. Information about the patient that will be collected during the research will be put away and no-one but the researchers will be able to see it. Any information about the patient will have a number on it instead of your name.

Certificate of Consent

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

I acknowledge the “Specially designed proforma”, and also the doctor has informed me about this research project suitably and sufficiently to my satisfaction. I agree to let my child’s oral examination to be taken as required. I agree to take part in this project. I shall co-operate with the doctors, in all respects. I permit to publishing the results of my participation in this study. I shall not be given any reimbursement or compensation. I have been informed of my right to opt out of this research project at any time without giving any reason for doing so. I hereby record my consent for participation in the said project.

....
....

Parent’s/guardian’s name Signature/thumbprint Date Time

....
....

Investigator’s name Signature Date Time

If illiterate a literate witness must sign (if possible, this person should be selected by the participant and should have no connection to the research team). Participants who are illiterate should include their thumb-print as well.

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of witness______________________

Signature of witness ______________________

Date _________________________

Day/month/year

Thumb print of participant

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

"Correlation of dental calcification stages, skeletal maturity stages and chronologic age of children of 7-16 years age group: A cross sectional descriptive study"

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Name of Researcher/person taking the consent_________________________

Signature of Researcher /person taking the consent___________________________

Date ____________________________

Day/month/year

Annexure 2

Dental calcification stages by Demirjian et al (1973)

Stage	Description	Photo
		Molars Bicuspids Canines Incisors
A	In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.	
B	Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface	
C	a. Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen. b. The beginning of a dentinal deposit is seen. c. The outline of the pulp chamber has a curved shape at the occlusal border.	
D	a. The crown formation is completed down to the cementoenamel junction b. The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave towards the cervical region. The projection of the pulp horns if present, gives an outline shaped like	

	an umbrella top. In molars the pulp chamber has a trapezoidal form. c. Beginning of the root formation is seen in the form of a spicule.	
E	Uniradicular teeth a. The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than the previous stage b. The root length is less than the crown height. Molars a. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape. b. The root length is still less than the crown height	
F	Uniradicular teeth: a. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape. b. The root length is equal to or greater than the crown height Molars: a. The calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings. b. The root length is	

	equal to or greater than the crown height.	
G	The walls of the root canal are now parallel and its apical end is still partially open (Distal root in molars).	
H	a. The apical end of the root canal is completely closed (Distal root in molars). b. The periodontal membrane has a uniform width around the root and the apex.	

Annexure 3

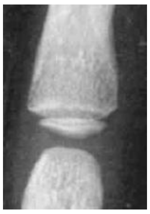
Willems scores for dental age estimation (2001)

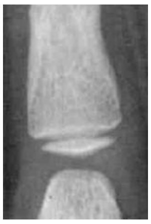
Gender	Tooth	A	B	C	D	E	F	G	H
Boys	Central incisor	-	-	1.68	1.49	1.5	1.86	2.07	2.19
	Lateral incisor	-	-	0.55	0.63	0.74	1.08	1.32	1.64
	canine	-	-	-	0.04	0.31	0.47	1.09	1.9
	First bicuspid	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
	Second bicuspid	0.08	0.05	0.12	0.27	0.33	0.45	0.4	1.15
	First molar	-	-	-	0.69	1.14	1.6	1.95	2.15
	Second molar	0.18	0.48	0.71	0.8	1.31	2	2.48	4.17
Girls	Central incisor	-	-	1.83	2.19	2.34	2.82	3.19	3.14
	Lateral incisor	-	-	-	0.29	0.32	0.49	0.79	0.7
	canine	-	-	0.6	0.54	0.62	1.08	1.72	2
	First bicuspid	−0.95	−0.15	0.16	0.41	0.6	1.27	1.58	2.19
	Second bicuspid	−0.19	0.01	0.27	0.17	0.35	0.35	0.55	1.51
	First molar	-	-	-	0.62	0.9	1.56	1.82	2.21
	Second molar	0.14	0.11	0.21	0.32	0.66	1.28	2.09	4.04

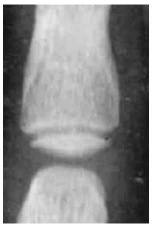
Annexure 4

Table 1.A: Standard radiographic atlas of Greulich and Pyle (1959) for MP3 region for males

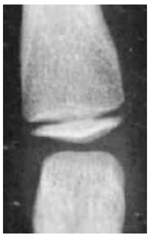

5 years


6 years


7 years


8 years


9 years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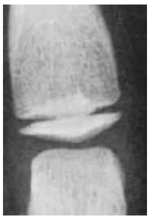
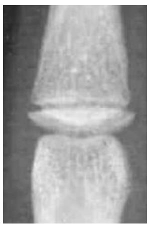
11 years

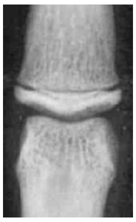

11.6 years


12.6 years


13 years


13.6 years


14 years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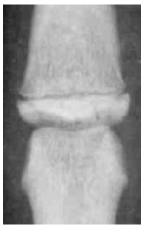
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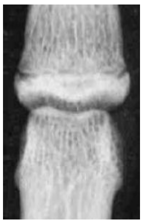
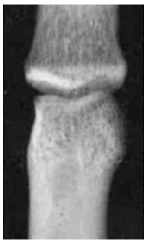

16 years

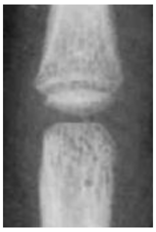

17 years


18 years


19 years

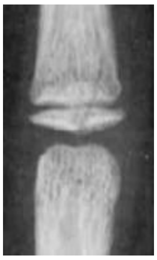
Table 1.B: Standard radiographic atlas of Greulich and Pyle(1959) for MP3 region for females


5 years


5 .9 years


6 .10 years


7 .10 years


8 .10 years


10 years


11 years


12 years


13 years


13.6 years


14 years


15 years

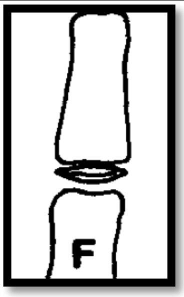
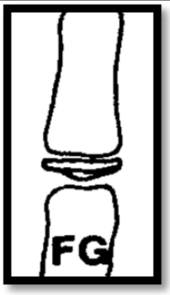
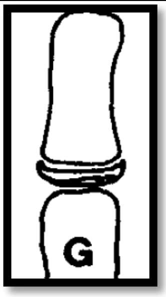
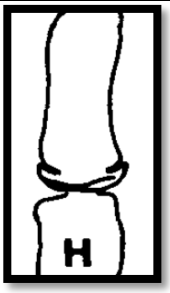
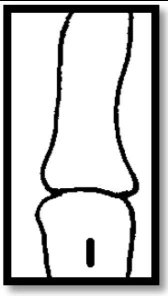

16 years


17 years


18 years

Annexure 5

MP3 stages by Hagg and Taranger (1980)

Stages	Description	Picture
Stage F	The epiphysis is as wide as the metaphysis (Starting of the curve of pubertal growth spurt)	
Stage FG	The epiphysis is as wide as the metaphysis and there is distinct medial and/or lateral border of the epiphysis forming a line of demarcation at right angles to the distal border. (Acceleration of the curve of pubertal growth spurt)	
Stage G	The sides of the epiphysis have thickened and also cap its metaphysis, forming a sharp edge distally at one or both sides. (Maximum point of pubertal growth spurt)	
Stage H	Fusion of the epiphysis and metaphysis has begun. (Deceleration of curve of pubertal growth spurt)	
Stage I	Fusion of the epiphysis and metaphysis is completed. (End of pubertal growth spurt)	

Annexure 6
Department of Pediatric & Preventive Dentistry
Proforma part A

Code no:

Date:	OPD No.
Name:	Date of Birth:
Age/Sex:	Place of Birth:
Address:	
Phone no:	
Parent's Occupation:	
Chief Complaint:	
H/O Present illness:	

Past Dental History:

Medical History:

Examination of hard tissues:

Teeth Present (FDI notation) :

Occlusal status

Molar relationship:

Terminal plane relationship:

Canine relationship:

Midline:

Overjet/Overbite:

Determination of chronological age

	Years	Months	Days
Date of examination			
Date of birth			
Chronologic age			
Chronologic age in decimals			

Annexure 6

Department of Pediatric & Preventive Dentistry
Proforma part B

Code no: **Examiner: 1 / 2**

Dental age estimation (OPG)

Tooth (FDI notation)	Demirjian stages	Willems scores
31		
32		
33		
34		
35		
36		
37		
Total score		
Age		

Skeletal age estimation

Stage/ age	Middle phalanx maturation (RVG of MP3)
Stage (According to Hagg U and Taranger J)	
Age (According to Greulich and Pyle Atlas)	

Result

Chronologic age	Dental age	Skeletal age

Master sheet of calculated chronological age into decimals of 204 children

Code no	Age	Sex	DOE	DOB	Chronological age	Chronological age
			y m d	y m d	y m d	in decimals
1	7	F	2016 05 25	2009 03 15	7 2 10	7.2
2	7	F	2016 05 30	2008 07 16	7 10 14	7.88
3	9	M	2016 06 22	2006 09 02	9 9 20	9.83
4	8	M	2016 06 26	2008 03 14	8 3 12	8.25
5	8	F	2016 06 30	2007 10 06	8 8 24	8.74
6	8	M	2016 07 11	2008 03 23	8 3 18	8.33
7	8	F	2016 07 21	2007 12 06	8 7 15	8.63
8	8	F	2016 07 28	2008 01 12	8 6 12	8.55
9	9	F	2016 08 19	2007 09 16	8 11 3	8.93
10	9	F	2016 10 10	2006 12 22	9 9 28	9.81
11	8	F	2016 10 15	2008 08 12	8 2 3	8.18
12	9	F	2016 11 02	2007 09 08	9 1 24	9.16
13	7	F	2016 11 04	2009 09 17	7 1 17	7.14
14	7	M	2016 11 06	2009 06 11	7 4 25	7.41
15	9	F	2016 11 10	2007 02 06	9 9 4	9.77
16	8	F	2016 11 16	2008 09 03	8 2 13	8.21
17	9	F	2016 11 16	2007 08 15	9 3 1	9.26
18	7	F	2016 11 17	2009 01 08	7 10 09	7.83
19	10	M	2016 11 19	2006 05 24	10 5 25	10.50
20	9	F	2016 11 24	2007 05 09	9 8 15	9.55
21	8	M	2016 11 25	2008 07 15	8 4 10	8.33
22	9	M	2016 12 03	2007 02 17	9 9 16	9.83
23	7	M	2016 12 09	2009 09 07	7 3 2	7.25
24	7	M	2016 12 09	2009 06 08	7 5 21	7.5
25	9	F	2016 12 14	2007 03 05	9 9 9	9.79
26	7	F	2016 12 16	2009 10 01	7 2 15	7.21
27	7	F	2016 12 24	2009 09 19	7 3 5	7.27
28	10	F	2016 12 26	2006 10 15	10 2 11	10.21
29	11	F	2016 12 28	2005 02 16	11 10 12	11.87
30	10	M	2016 12 28	2006 05 04	10 7 24	10.66
31	10	M	2016 12 31	2006 03 24	10 9 7	10.75
32	10	F	2017 01 13	2006 03 14	10 10 9	10.83
33	10	M	2017 01 29	2006 07 04	10 6 25	10.58
34	10	M	2017 02 03	2006 08 05	10 5 28	10.41
35	10	F	2017 02 14	2006 09 21	10 4 23	10.41
36	10	F	2017 02 15	2006 10 18	10 2 17	10.34
37	9	M	2017 02 17	2007 12 08	9 2 9	9.16
38	7	M	2017 02 17	2009 3 04	7 11 13	7.91
39	8	M	2017 02 17	2009 01 16	8 1 1	8.08
40	7	M	2017 02 22	2009 10 02	7 3 20	7.33
41	7	F	2017 03 08	2009 12 17	7 4 21	7.38
42	9	M	2017 03 17	2007 05 14	9 10 3	9.83
43	10	M	2017 03 18	2006 06 03	10 9 15	10.75
44	8	M	2017 03 21	2008 09 01	8 6 20	8.58
45	7	F	2017 03 22	2010 01 19	7 2 3	7.18
46	8	M	2017 03 25	2008 08 13	8 7 12	8.58
47	8	M	2017 04 01	2008 07 22	8 8 8	8.66
48	10	F	2017 04 06	2006 09 03	10 7 3	10.6
49	10	M	2017 04 08	2006 05 09	10 10 29	10.92
50	7	M	2017 04 12	2009 11 23	7 4 19	7.41
51	8	F	2017 04 19	2008 06 11	8 10 8	8.86
52	9	F	2017 04 19	2008 02 08	9 2 8	9.2
53	7	M	2017 04 20	2009 09 29	7 6 21	7.58
54	10	F	2017 04 24	2007 04 20	10 0 4	10.33
55	10	F	2017 04 25	2007 01 24	10 5 1	10.26
56	10	F	2017 04 26	2007 02 08	12 2 18	10.22
57	9	F	2017 04 27	2008 02 08	9 1 19	9.22
58	9	M	2017 04 27	2007 12 11	9 4 16	9.41
59	7	M	2017 05 06	2009 10 08	7 6 28	7.58
60	7	F	2017 05 15	2010 03 29	7 2 6	7.13
61	9	M	2017 05 16	2007 05 31	9 11 15	9.91
62	9	M	2017 05 19	2006 04 06	9 1 13	9.08
63	7	M	2017 06 09	2010 02 24	7 3 15	7.25
64	7	F	2017 06 12	2010 01 04	7 5 8	7.44

65	8	F	2017 06 13	2008 10 19	8 7 14	8.65
66	7	F	2017 06 15	2009 10 20	7 8 15	7.66
67	10	M	2017 06 21	2007 04 14	10 2 7	10.16
68	8	F	2017 06 24	2009 02 17	8 4 7	8.35
69	9	F	2017 06 24	2007 07 14	9 11 10	9.95
70	7	M	2017 06 30	2010 05 04	7 0 26	7.08
71	8	M	2017 07 06	2008 09 04	8 10 2	8.83
72	10	M	2017 07 14	2007 04 06	10 3 8	10.25
73	10	F	2017 07 19	2007 03 06	10 4 13	10.38
74	10	M	2017 07 21	2007 03 11	10 4 10	10.33
75	9	M	2017 07 27	2008 05 16	9 2 11	9.16
76	7	F	2017 07 28	2010 03 01	7 4 27	7.41
77	9	F	2017 07 31	2008 03 24	9 4 7	9.36
78	9	F	2017 08 05	2007 01 19	9 5 16	9.5
79	8	M	2017 08 16	2009 03 13	8 5 3	8.41
80	8	F	2017 08 21	2009 07 01	8 1 20	8.15
81	8	M	2017 08 21	2009 05 16	8 3 5	8.25
82	9	M	2017 08 24	2007 10 14	9 10 10	9.83
83	8	F	2017 09 06	2008 10 17	8 10 19	8.89
84	10	F	2017 09 07	2006 11 02	10 10 5	10.85
85	7	M	2017 09 07	2009 09 22	7 11 15	7.91
86	9	M	2017 09 11	2008 04 03	9 5 8	9.41
87	10	M	2017 09 14	2007 06 05	10 3 9	10.25
88	10	F	2017 09 14	2007 06 07	10 3 7	10.28
89	10	M	2017 09 14	2009 08 28	7 12 16	8
90	9	M	2017 09 16	2007 10 27	9 10 19	9.91
91	9	M	2017 09 23	2008 05 15	9 4 8	9.33
92	7	F	2017 10 03	2009 12 14	7 0 19	7.24
93	12	M	2016 01 04	2004 04 07	11 10 27	12.08
94	7	F	2016 05 25	2009 03 15	7 2 10	7.16
95	11	F	2016 06 27	2004 09 30	11 8 27	11.75
96	12	M	2016 07 04	2004 03 14	12 3 20	12.33
97	11	F	2016 07 21	2004 12 16	11 7 5	11.6
98	11	F	2016 11 05	2005 07 23	11 3 12	11.3
99	11	M	2016 12 05	2005 04 22	11 9 13	11.75
100	12	F	2016 12 09	2004 12 03	12 0 6	12.02
101	15	F	2016 12 10	2001 10 07	15 2 3	15.19
102	15	F	2016 12 10	2001 08 04	15 4 6	15.36
103	12	M	2016 12 14	2004 10 10	12 2 4	12.16
104	13	M	2016 12 22	2003 03 12	13 9 10	13.75
105	11	M	2016 12 28	2005 03 26	11 9 2	11.75
106	11	M	2016 12 29	2005 09 13	11 3 16	11.33
107	14	F	2016 12 29	2003 01 26	13 11 3	13.93
108	11	M	2016 12 29	2005 09 24	11 3 5	11.25
109	13	F	2016 12 30	2003 06 02	13 6 28	13.59
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111	13	F	2017 01 16	2003 08 18	13 6 18	13.42
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113	14	F	2017 03 07	2002 07 09	14 7 28	14.67
114	12	M	2017 03 07	2004 11 03	12 4 4	12.33
115	15	M	2017 03 07	2002 01 14	15 1 23	15.16
116	15	F	2017 03 18	2001 10 09	14 5 9	15.45
117	13	F	2017 03 20	2003 07 12	13 08 8	13.7
118	14	M	2017 03 20	2002 09 13	14 6 7	14.5
119	13	F	2017 03 22	2003 12 30	13 2 22	13.24
120	14	M	2017 03 24	2002 11 16	14 4 8	14.33
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122	15	F	2017 03 29	2001 07 03	15 8 26	15.75
123	15	F	2017 03 30	2001 04 26	15 11 4	15.94
124	15	F	2017 04 05	2001 11 19	15 4 16	15.39
125	14	F	2017 04 06	2002 06 19	14 10 17	14.81
126	14	F	2017 04 06	2002 06 12	14 9 24	14.83
127	13	M	2017 04 11	2004 02 19	13 2 2	13.16
128	15	M	2017 04 11	2001 05 09	15 11 2	15.91
129	15	M	2017 04 11	2002 01 16	15 2 25	15.25
130	13	F	2017 04 12	2004 01 13	13 2 29	13.25
131	13	F	2017 04 12	2004 02 10	13 2 2	13.18
132	12	M	2017 04 12	2004 08 09	12 7 3	12.58
133	14	M	2017 04 12	2003 02 16	14 1 26	14.08
134	15	M	2017 04 13	2002 01 07	15 3 6	15.25
135	12	M	2017 04 17	2005 02 23	12 01 24	12.16

136	11	F	2017 04 19	2005 08 16	11 8 3	11.68
137	13	F	2017 04 19	2003 12 26	13 3 23	13.32
138	11	F	2017 04 20	2005 06 07	11 10 13	11.88
139	12	M	2017 04 21	2004 09 14	12 7 7	12.58
140	11	M	2017 04 24	2006 02 17	11 2 7	11.91
141	14	M	2017 04 24	2003 02 15	14 2 9	14.16
142	11	F	2017 04 26	2005 09 19	11 7 7	11.61
143	13	F	2017 04 27	2003 09 17	13 7 10	13.62
144	12	F	2017 05 02	2004 10 12	12 6 20	12.56
145	12	F	2017 05 02	2005 03 12	12 2 12	12.15
146	14	F	2017 05 02	2002 09 06	14 7 26	14.66
147	13	M	2017 05 02	2004 03 17	13 3 15	13.33
148	15	F	2017 05 03	2002 02 01	15 3 2	15.26
149	11	M	2017 05 03	2005 12 30	11 5 3	11.41
150	12	F	2017 05 04	2004 11 19	12 7 15	12.46
151	15	F	2017 05 04	2002 12 03	15 7 1	14.43
152	12	M	2017 05 04	2005 03 04	12 2 0	12.16
153	11	M	2017 05 08	2006 02 16	11 2 21	11.25
154	15	F	2017 05 12	2001 07 06	15 10 6	15.86
155	12	M	2017 08 03	2005 03 17	12 4 16	12.41
156	14	M	2017 05 13	2003 01 07	14 8 6	14.36
157	13	F	2017 05 19	2003 08 15	13 7 4	13.77
158	12	M	2017 05 20	2005 06 06	12 11 14	12.91
159	11	M	2017 05 22	2006 03 26	11 1 26	11.16
160	14	F	2017 05 23	2003 03 13	14 2 10	14.21
161	11	M	2017 06 08	2005 10 06	11 8 2	11.6
162	11	F	2017 06 09	2006 02 16	11 3 23	11.32
163	11	M	2017 06 09	2006 06 06	11 0 3	11
164	15	M	2017 06 12	2001 12 1	15 6 11	15.05
165	15	M	2017 06 12	2002 02 06	15 4 6	15.33
166	14	F	2017 06 14	2002 08 08	14 10 6	14.86
167	15	F	2017 06 15	2002 04 17	15 3 18	15.17
168	15	F	2017 06 15	2001 12 04	15 6 11	15.54
169	13	M	2017 06 15	2002 02 06	13 4 9	13.33
170	14	F	2017 06 16	2002 09 09	14 9 7	14.78
171	13	M	2017 06 24	20004 01 20	13 5 4	13.41
172	13	M	2017 06 24	2003 10 13	13 8 11	13.66
173	14	M	2017 06 24	2003 04 21	14 2 3	14.16
174	11	M	2017 06 28	2006 05 24	11 1 4	11.08
175	12	F	2017 07 01	2004 10 20	12 9 11	12.7
176	15	M	2017 07 01	2002 08 12	15 10 19	15.91
177	14	M	2017 07 04	2002 12 09	14 6 25	14.58
178	15	M	2017 07 04	2001 09 01	15 10 2	15.83
179	11	F	2017 07 05	2006 03 15	11 3 20	11.32
180	14	M	2017 07 05	2002 0 01	14 10 4	14.83
181	12	F	2017 07 06	2005 02 03	12 5 15	12.43
182	15	M	2017 07 07	2001 09 24	15 9 13	15.75
183	13	F	2017 07 08	2004 04 17	13 2 13	13.23
184	14	F	2017 07 11	2003 05 08	14 2 3	14.19
185	12	F	2017 07 14	2005 03 19	12 3 25	12.33
186	13	M	2017 07 14	2004 05 07	13 2 7	13.16
187	11	M	2017 07 16	2005 08 24	11 10 22	11.91
188	14	F	2017 07 19	2003 03 16	14 4 3	14.35
189	14	M	2017 07 21	2003 03 13	14 4 8	14.33
190	15	F	2017 07 24	2001 12 19	15 7 5	15.61
191	12	M	2017 07 26	2005 04 16	12 3 10	12.25
192	14	M	2017 07 26	2003 05 20	14 2 6	14.16
193	11	F	2017 07 31	2005 09 19	11 10 12	11.87
194	12	F	2017 07 31	2005 05 20	12 2 11	12.21
195	15	M	2017 08 01	2001 12 11	15 7 20	15.66
196	12	M	2017 08 03	2005 06 23	12 2 10	12.16
197	13	M	2017 08 26	2004 04 03	13 4 23	13.41
198	15	M	2017 08 28	2002 06 19	15 2 9	15.16
199	12	F	2017 09 05	2004 09 24	12 11 11	12.96
200	12	F	2017 09 06	2005 06 12	12 2 24	12.24
201	13	M	2017 09 06	2004 07 25	13 2 11	13.16
202	14	F	2017 09 09	2003 07 14	14 1 25	14.78
203	14	M	2017 09 20	2003 04 16	14 5 4	14.41
204	14	F	2017 12 20	2003 06 12	12 6 8	14.53

Master sheet for calculated chronological, dental and skeletal ages of 204 children of 7-16 age group

Code no	Age	Sex	CA	DA	SA
1	7	F	7.2	7.16	7.1
2	7	F	7.88	7.24	7.1
3	9	M	9.83	9.41	9
4	8	M	8.25	7.95	9
5	8	F	8.74	8.49	10
6	8	M	8.33	8.74	8
7	8	F	8.63	8.4	8.1
8	8	F	8.55	8.28	7.1
9	9	F	8.93	8.74	10
10	9	F	9.81	10.03	10
11	8	F	8.18	7.8	7.1
12	9	F	9.16	9.41	6.1
13	7	F	7.14	6.7	6.1
14	7	M	7.41	7.11	7
15	9	F	9.77	10.03	10
16	8	F	8.21	8.49	8.1
17	9	F	9.26	9.41	10
18	7	F	7.83	8.01	7
19	10	M	10.50	10.81	11
20	9	F	9.55	9.41	10
21	8	M	8.33	7.96	9
22	9	M	9.83	10.06	10
23	7	M	7.25	7.29	7
24	7	M	7.5	7.38	7
25	9	F	9.79	10.03	8.1
26	7	F	7.21	6.65	6.1
27	7	F	7.27	6.57	7
28	10	F	10.21	8.4	10
29	11	F	11.87	13.84	13.6
30	10	M	10.66	10.93	11
31	10	M	10.75	12.35	11.6
32	10	F	10.83	10.56	13.6
33	10	M	10.58	10.64	11
34	10	M	10.41	10.03	11
35	10	F	10.41	8.4	10
36	10	F	10.34	8.4	10
37	9	M	9.16	8.26	9
38	7	M	7.91	7.81	7
39	8	M	8.08	7.41	8
40	7	M	7.33	7.41	8
41	7	F	7.23	6.65	7.1
42	9	M	9.83	10.24	9
43	10	M	10.75	10.24	11.6
44	8	M	8.58	8.36	7
45	7	F	7.18	6.7	7
46	8	M	8.58	9.57	8
47	8	M	8.66	8.3	9
48	10	F	10.6	10.84	10
49	10	M	10.92	11.36	10
50	7	M	7.41	6.77	7
51	8	F	8.86	8.74	10
52	9	F	9.2	8.97	8.1
53	7	M	7.58	7.95	7
54	10	F	10.33	9.07	10
55	10	F	10.26	10.12	11
56	10	F	10.22	10.02	10
57	9	F	9.22	7.38	8.1
58	9	M	9.41	8.7	10
59	7	M	7.58	7.38	8
60	7	F	7.13	7.27	7
61	9	M	9.91	8.84	10
62	9	M	9.08	8.74	8
63	7	M	7.25	7.8	8
64	7	F	7.44	7.04	7.1

65	8	F	8.65	8.35	8.1
66	7	F	7.66	7.39	8.1
67	10	M	10.16	10.12	10
68	8	F	8.35	8.68	8.1
69	9	F	9.95	10.03	10
70	7	M	7.08	6.68	6
71	8	M	8.83	8.28	8
72	10	M	10.25	10.93	9
73	10	F	10.38	10.03	10
74	10	M	10.33	10.12	11
75	9	M	9.16	8.64	9
76	7	F	7.41	7.21	7.1
77	9	F	9.36	9.41	8.1
78	9	F	9.5	8.74	8.1
79	8	M	8.41	9.61	8
80	8	F	8.15	7.94	7.1
81	8	M	8.25	8.02	7
82	9	M	9.83	10.12	10
83	8	F	8.89	8.82	8.1
84	10	F	10.85	9.07	10
85	7	M	7.91	7.75	6
86	9	M	9.41	9.37	9
87	10	M	10.25	10.06	11.6
88	10	F	10.28	10.03	11
89	10	M	8	8.38	10
90	9	M	9.91	8.54	9
91	9	M	9.33	9.06	9
92	7	F	7.24	6.48	5.9
93	12	M	12.08	10.93	12.6
94	7	F	7.16	7.16	7.1
95	11	F	11.75	12.68	13
96	12	M	12.33	11.95	11.6
97	11	F	11.6	11.79	13
98	11	F	11.3	11.18	12
99	11	M	11.75	10.93	11.6
100	12	F	12.02	11.26	13
101	15	F	15.19	15.79	16
102	15	F	15.36	12.88	16
103	12	M	12.16	10.24	11.6
104	13	M	13.75	11.28	12.6
105	11	M	11.75	12.83	11.6
106	11	M	11.33	11.33	11
107	14	F	13.93	11.48	13.6
108	11	M	11.25	10.19	11
109	13	F	13.59	15.79	13.6
110	13	M	13.75	14.34	16
111	13	F	13.42	12.6	13.6
112	13	M	13.83	12.84	13.6
113	14	F	14.67	13.84	16
114	12	M	12.33	12.16	12.6
115	15	M	15.16	13.59	16
116	15	F	15.45	12.88	15
117	13	F	13.7	13.84	14
118	14	M	14.5	14.7	16
119	13	F	13.24	12.27	13.6
120	14	M	14.33	14.7	15.6
121	11	M	11.23	10.98	10
122	15	F	15.75	15.79	17
123	15	F	15.94	15.79	16
124	15	F	15.39	13.84	16
125	14	F	14.81	13.84	14
126	14	F	14.83	12.27	16
127	13	M	13.16	10.93	11
128	15	M	15.91	16.03	16
129	15	M	15.25	14.7	15
130	13	F	13.25	11.99	13
131	13	F	13.18	11.99	13
132	12	M	12.58	12.38	13.6
133	14	M	14.08	14.34	15
134	15	M	15.25	13.8	15
135	12	M	12.16	11.76	13

136	11	F	11.68	12.27	13.6
137	13	F	13.32	12.88	13
138	11	F	11.88	13.84	13
139	12	M	12.58	14.34	13.6
140	11	M	11.91	8.9	12.6
141	14	M	14.16	14.34	15
142	11	F	11.61	10.67	11
143	13	F	13.62	13.84	13.6
144	12	F	12.56	11.99	13
145	12	F	12.15	10.03	10
146	14	F	14.66	15.55	16
147	13	M	13.33	13.59	13.6
148	15	F	15.26	13.84	16
149	11	M	11.41	10.81	11.6
150	12	F	12.46	13.84	13.6
151	15	F	14.43	15.79	16
152	12	M	12.16	9.57	11.6
153	11	M	11.25	10.04	10
154	15	F	15.86	15.79	16
155	12	M	12.41	11.33	11.6
156	14	M	14.36	14.34	16
157	13	F	13.77	13.84	13.6
158	12	M	12.91	13.24	12.6
159	11	M	11.16	10.93	11.6
160	14	F	14.21	13.84	14
161	11	M	11.6	11.81	10
162	11	F	11.32	11.15	10
163	11	M	11	10.93	11.6
164	15	M	15.05	16.03	14
165	15	M	15.33	12.35	15
166	14	F	14.86	15.79	16
167	15	F	15.17	15.79	16
168	15	F	15.54	15.79	17
169	13	M	13.33	14.34	13.6
170	14	F	14.78	12.27	15
171	13	M	13.41	13.59	14
172	13	M	13.66	13.59	14
173	14	M	14.16	14.34	15
174	11	M	11.08	10.04	10
175	12	F	12.7	12.27	14
176	15	M	15.91	16.03	16
177	14	M	14.58	14.34	14
178	15	M	15.83	16.03	16
179	11	F	11.32	11.18	11
180	14	M	14.83	14.34	15
181	12	F	12.43	12.88	13
182	15	M	15.75	16.03	16
183	13	F	13.23	12.27	13
184	14	F	14.19	13.03	15
185	12	F	12.33	11.48	13.6
186	13	M	13.16	14.7	13
187	11	M	11.91	11.81	12.6
188	14	F	14.35	13.84	14
189	14	M	14.33	13.53	14
190	15	F	15.61	15.79	17
191	12	M	12.25	11.55	12.6
192	14	M	14.16	14.34	15
193	11	F	11.87	10.98	11
194	12	F	12.21	11.18	13
195	15	M	15.66	16.03	16
196	12	M	12.16	10.93	12.6
197	13	M	13.41	13.53	14
198	15	M	15.16	14.34	15
199	12	F	12.96	12.88	13.6
200	12	F	12.24	10.67	14
201	13	M	13.16	10.99	13
202	14	F	14.78	12.88	14
203	14	M	14.41	14.34	15
204	14	F	14.53	12.27	13.6

Master sheet for inter and intraexaminer reproducibility for 20 randomly selected children

		Examiner 1		Examiner 1 (after 4 weeks)		Examiner 2		Examiner 2 (after 4 weeks)	
Sr no.	Code no.	DA	SA	DA	SA	DA	SA	DA	SA
1	12	9.41	6.1	9.41	6.1	9.07	6.1	9.07	6
2	61	8.84	10	9	10	9	10	9.06	10
3	58	8.7	10	8.7	10	7.83	10	8.51	10
4	159	10.93	11.6	10.93	11.6	10.93	12.6	11.31	12.6
5	32	10.56	13.6	10.56	13.6	10.56	13.6	10.56	11
6	112	12.84	13.6	12.84	13.6	12.38	14	12.84	13.6
7	28	8.4	10	8.01	10	8.4	10	8.01	10
8	54	9.07	10	9.07	10	9.07	10	9.07	10
9	99	10.93	11.6	10.93	11.6	10.81	12.6	10.93	12.6
10	103	10.24	11.6	10.24	11.6	9.57	12.6	10.24	11.6
11	105	12.83	11.6	12.83	12.6	12.78	12.6	12.38	12.6
12	51	8.74	10	8.74	10	8.4	10	8.4	10
13	108	10.19	11	10.24	11.6	11.9	11.6	10.24	11.6
14	53	7.95	7	7.95	7	6.69	6	8	6
15	119	12.27	13.6	13.84	13.6	13.84	13.6	13.84	13.6
16	44	8.36	7	8.14	7	8.14	7	7.44	7
17	6	8.74	8	8.74	8	8.74	8	8.74	8
18	112	15.79	17	15.79	16	15.79	16	15.79	16
19	121	10.98	10	10.98	10	11.99	11	11.99	11
20	46	9.57	8	9.57	8	9.57	8	9.41	8