DENTAL AGE DETERMINATION IN SOUTH AUSTRALIAN CHILDREN

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Dental Surgery

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July 1999

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ABSTRACT

Age determination has great importance in diverse fields when there is inadequate or inaccurate record of date of birth. This study applies the universally used "Demirjian system" to determine whether the dental maturity standards and scores based on French-Canadian children can be reliably applied to South Australian children. The sample includes a small group of medically compromised children to determine any significant differences in their estimated dental age, when compared to the rest of the sample. The skeletal ages of a subset were assessed using the Greulich and Pyle method and compared to their estimated dental ages. Cases demonstrating extreme variations between chronological, dental and skeletal ages were examined in detail, exploring the probable reasons for such differences and reinforcing that caution must be applied, particularly when using such data in forensic situations.

When Demirjian's standards were applied to the 7-12.99 age-group children, accuracy was found to be low, with mean differences between dental age and chronological age being 0.1 years (S.D.=1.1) and 0.3 (S.D.=1.3) years for males and females respectively, which were statistically significant ($p < 0.05$). Across the whole sample, nearly 60% of the children, (57.8 % males and 59.8 % females) exhibited greater than 0.5 years difference between estimated age and chronological age. When the skeletal ages calculated using the Greulich and Pyle Atlas method (1959) were compared with the chronological age, the accuracy was also found to be very low, with mean differences between skeletal and chronological age being -0.9 years (S.D.=1.3) and -0.07 (S.D.=1.5) in males and females respectively, indicating a significant pattern of underestimation of chronological age in males and a less

significant pattern of underestimation in females. 82% of males and 63% of females showed greater than 0.5 years difference between the estimated skeletal age and chronological age. 59% of the medically compromised children had overestimated ages with 67% of males and 57% of females showing a greater than 0.5 years difference between the estimated dental age and chronological age.

These results indicate that both Demirjian's method for dental age estimation and the Greulich and Pyle method for skeletal age estimation have low accuracy when used for a group of South Australian children, especially in forensic situations. It demonstrates the need to develop maturity standards within the Australian population taking into account the various factors that can affect the pattern of growth in children.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, being available for loan and photocopying, if accepted for the award of the degree.

Soni Stephen
July, 1999

For Papa, Mummy and my brother Rony,

for their love, support and sacrifices

to ensure my happiness and success.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and gratitude to my supervisors Dr Kenneth Brown and Dr Jane Taylor and for their supervision, guidance, support, patience and encouragement during the course of this project.

Many thanks to Mr Fearnley Szuster for his valuable time and help in the planning and interpretation of the statistical tests and results and Wendy Schwertd for the technical assistance.

Sincere thanks to Mrs Elaine Formenti for all the help she has given me during this project.

I also wish to thank my clinical supervisor Dr Margaret Evans for her wonderful support and encouragement all through my course.

Last but not the least, I wish to remember my mentor, late Dr Kevin R. Allen who guided me and paved the path for where and what I am today.

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CHAPTER 1

INTRODUCTION

Age determination is the process of establishing chronological, dental or skeletal age of a living or deceased person. Accurate age determination has great importance in diverse fields such as forensic science, paediatric dentistry, orthodontics, physical anthropology, endocrinology and nutrition. Legally, it is required in relation to matters of criminal maturity and consent and is also extremely valuable in establishing the identity of unidentified bodies. Large scale immigration, including refugee flows from developing nations to developed countries, also leads to circumstances where accurate age determination may be needed.

Many developing nations do not have a reliable system for recording birth details and hence, many children do not have accurate age data. In cases where there are inadequate or inaccurate records of date of birth, age determination techniques may need to be employed to assess an individual's age. The lack of accurate birth data for many of these children who migrate has put the medical and dental profession under pressure to find a method as precise as possible for determination of age (Staaf, Mornstad and Welander, 1991).

In dentistry, age determination is relevant to the timing of various paediatric dental and orthodontic treatment procedures. A paediatric dentist treats children during their primary and mixed dentition periods. Accurate assessment of the age of a child during these periods is important to ascertain any abnormalities associated with eruption sequences and the orthodontic status of the child.

Growth is characterised by considerable variation in the rate of progress of different systems towards the attainment of physiological maturity. There is no precise timetable for any physiological event in the human body. Similar developmental processes occur at different times in different individuals. This led to the development of the concept of physiological age, which is defined in terms of stages of development of certain structures. The various physiological age parameters are skeletal age, dental age, and age of attainment of various secondary sex characteristics. The chronological age of a child alone may have very little or even no place in assessing the maturational state of the child. Therefore, when it is necessary to determine the maturity of a child, parameters like dental age and skeletal age also have to be considered.

1.1 Age determination methods

Over the years, many methods based on dental and skeletal maturity and age changes in the body tissues have been developed to determine the age of an individual. Age determination based on external characteristics of the person, such as facial changes, have also been carried out. There are many facial changes which occur with age, like the round cheeks of a young person disappearing at about the age of 30. Also around the age of 30 years, wrinkles may appear at the corners of the eye; the nasolabial fold often deepens at about the age of 35; deep folds at the back of the head appear after 60 years. At about the same time, there is pronounced growth of hair in the external auditory canal in males.

These changes, however, do not have much value in accurate age determination especially in a forensic situation. Following death, the soft tissues change very quickly, particularly in cases where the body has been in water for some time. In addition, with cosmetic surgery becoming increasingly common, many of the age related changes of skin could be cleverly masked. In such cases, the skeletal remains, including the teeth, hold more clues to the identity of the person than any remaining soft tissues. Examination of internal organs of unknown bodies may reveal some useful information. A pronounced arteriosclerosis or atrophy of the heart may indicate advanced age, but these changes can also occur in young individuals. The nternal structure of bone, such as trabecular pattern is also quite useful for age determination. In elderly people the various joints show age changes, including considerable wear. Osteoporosis can be correlated with advancing age. Fragility of bone, particularly of the vertebrae is a characteristic sign of old age.

Investigations of the bone may give some information about age. During childhood, cranial developments can be seen clinically and also with aid of radiographs. The sutures in the cranium close and the fontanelles decrease in size and disappear after completion of bone formation. Estimation of skeletal age using hand-wrist films has also been utilised in determination of age. According to Johanson (1971), the methods of estimating age using bone may give valuable information but the variations are so great that the results have to be combined with other findings to reach a better conclusion. In some cases, important parts of the body including the skeleton may have disappeared. The teeth are the least destructible of all body tissues and are therefore of particular value for age determinations, especially since there are a great number of changes in the hard tissues of the teeth, the enamel, dentine and cementum which can be investigated. The limitation of all these changes is that they show great variation in the age at which they occur.

1.2 Concept of dental age

Teeth have been used as an indicator of age for a very long time. In the last century in United Kingdom, the law presumed that children below the age of seven years did not have the capacity to commit a crime. Evidence that a child had not reached that age was often very important to avoid punishment of the child. Thomsen (1836)- a forensic medical expert at that time stated that "if the third molar hath not protruded, there can be no hesitation in affirming that the culprit has not passed his seventh year". By "the third molar" he meant the first permanent molar erupting around the age of 6-7 years of age posterior to the two deciduous molars (Cited by Johanson, 1971). Not long before this period, children used to be hanged for committing trivial crimes. Registration of births was not a common practice then and hence, there was great difficulty in producing evidence of age (Miles, 1963).

It is also only logical to assume that even before the above mentioned situation teeth had been used to estimate age in children. The pattern of eruption of teeth is quite evident and generally consistent and was unlikely to have escaped the notice of people in earlier times.

Another need for the assessment of age in children in history arose in connection with the Factory Act of 1833 in United Kingdom, which forbade the employment of children under the age of nine years and restricted the working hours of children between nine and thirteen years of age to not more than nine hours per day. The need for cheap labour for the mill owners, combined with the willingness of many parents to exploit the earning capacity of their children, led to total evasion of the act. It was almost impossible to enforce the act because the only evidence of age demanded was that the child should be of "ordinary strength and appearance of a child at nine years of age".

Saunders (1837), a distinguished dentist of the time, laid before the British parliament a pamphlet pointing out the value of dentition in the assessment of age. This was presented as result of a study into the state of the dentition in 1000 children. He argued that with the aid of his tables and a little industrious application, relatively untrained people could conduct the assessment of age for factory purposes (Cited by Johanson, 1971).

Social progress has changed our reasons for the importance of age assessment, but the ultimate aim of researchers in this field still remains to devise simple, accurate and non-constructive methods that can be used by relatively untrained people. The present day emphasis of age assessment is to be as accurate as possible and to have a uniform method applicable to various regions.

Chronological age alone is not sufficient for assessing the stage of development of growing children. Developmental ages, like dental age, skeletal age and onset of secondary sexual characteristics give more information on the growth status of children. These are estimated from the degree of maturation of different tissue systems.

Nystrom *et al.* (1986) suggested that tooth development is a useful measure of maturity because it represents a series of recognisable events that occur in the same sequence from an initial event to a constant end point.

Kullman (1995) stated that the dental methods for age estimations are considered more reliable than most other methods by the majority of researchers and are among the most commonly used means to determine age.

A pilot study conducted by Joshi *et al.* (1996), which compared the methods of Moorrees, Fanning and Hunt (1963) and Demirjian (1973) in estimating the age of South Australian children, revealed that the latter method was more applicable in South Australian children. Their conclusion that both methods had limited application in forensic situations in their present form suggests that new standards would have to be established for the Australian population.

1.3 Aims and objectives

Only a limited number of studies on dental age determination have been done on Australian populations. As mentioned earlier, estimation of dental age is a very important part of forensic dentistry as well as in cases of inadequate or unreliable birth records. This study attempts to assess the reliability of using the maturity scores compiled by Demirjian *et al.* (1976) from a French-Canadian population sample in determining the age of a sample of South Australian children between 7.0 and 12.9 years of age.

Aims of the study:

1. To assess the dental age of a group of South Australian children (7-12 years) using Demirjian's dental maturity scores and determine the reliability and accuracy of the tables in South Australian children.

2. To assess the skeletal age in the same sample using the Greulich and Pyle method and compare the accuracy of estimated skeletal age with the estimated dental age when determining chronological age.

3. To determine whether it is possible to improve the accuracy of age estimation by combined use of dental and skeletal criteria.

4. To determine whether there are any differences when Demirjian's tables are used in determining age in a group of medically compromised children when compared with the ages obtained in normal children with no known medical conditions.

5. To examine cases demonstrating marked difference between dental, skeletal and chronological age.

CHAPTER 2

LITERATURE REVIEW

2.1 Determination of dental age

A variety of methods to determine age from the teeth and jaws have been developed over the years. These methods are based on assessment of development stages of tooth, tooth eruption, changes in dentition due to various extrinsic factors using radiographic and microscopic views and chemical analyses of dental tissues.

2.1.1 Determination of dental age based on developmental stages

The developmental status of a child is usually assessed in relation to physical events that take place during the progress of growth (for example, skeletal ossification stages, attainment of peak velocity, or the pubescent changes in the body). Although growth events occur in a reasonably constant sequence, the ages at which they are reached vary considerably among children. Indicators of developmental age are therefore more informative than chronological age particularly for clinical application (Grave and Brown, 1976).

Lewis and Garn (1960) stated that dental maturity has often been considered a good indicator of chronological age and, has been regarded as superior to other methods for evaluation of an individual's somatic maturity such as methods based on the bones of the hand.

Dental age may be estimated by comparing the dental development status of a person of unknown age with published dental development surveys. By doing this, a likely chronological age for that individual can be calculated. This result may make a valuable contribution to a forensic identification or any other situation where a confirmation of the likely age of the individual is necessary.

The pre-mineralisation and mineralisation stages in dental development are already well established. The incremental pattern of mineralisation is subject to periodic disturbances, which affect the developing teeth in a unique way. Birth, diseases, drug-intake, dietary changes and the uptake of certain chemical elements can all cause changes in the incremental pattern. These changes can be detected and in some instances, be retrospectively linked to a specific time or event during the individual's life (Ciapparelli, 1992).

Dental development data are usually based on:

1. histological premineralization sequences
2. histological mineralization sequences
3. incremental patterns of enamel and dentine formation
4. emergence of teeth into the oral cavity
5. gross mineralization sequences observed by :
    a. radiographic means
    b. direct observation of dissected developing teeth in situ or individually

2.1.1.1 Dental age based on developmental features of teeth and jaws

In the early 1930's underdevelopment of the jaws and irregularities of the teeth were frequently associated with early surgical treatment of complete congenital clefts of the upper jaw and lip. The etiology of underdevelopment and irregularities in these cases could not be evaluated without a thorough knowledge of the normal, as well as abnormal structures that must be considered in the surgical correction of congenital clefts. In order to ascertain exact data of the minute structure of the maxilla in early infancy, Logan and Kronfeld (1933) conducted a study in Chicago. They observed the jaw sections of thirty infants and children up to fifteen years of age, who had died from prolonged debilitating illnesses. Even though this study was originally undertaken for a small group of cleft repair surgeons, it revealed a vast amount of data regarding the time of calcification of various teeth and position of deciduous and permanent tooth germs during the early years of life. These data were of great benefit to the general dental practitioner, orthodontist, paediatric dentist and the oral surgeon, but no information about the range of variations or of differences between sexes could be obtained from such a small number of subjects. Also, since many of the subjects had suffered from prolonged debilitating illnesses, the chronology of tooth development could have been affected.

Schour and Massler (1940) conducted one of the earliest documented studies regarding the chronology of tooth development. They based their data on the observations of Logan and Kronfeld (1933) on sections of the jaws of infants and children up to 15 years of age. Many of the children were debilitated from the age of five months in utero up to fifteen years of age. The development of teeth was traced chronologically according to the successive development periods that characterize the growing individual so that the development of the dentition and the individual as a whole could be correlated. They published an illustrated development chart for deciduous and permanent teeth. The charts are easy to use for direct comparison with radiographs, but the data is limited to ages below fifteen years because there is no data recorded for stages of growth of the third molars between fifteen and twenty-one years. The major criticisms of this study are that the chart does not have separate surveys for males and females and the range about the mean ages from 2 years to 15 years is put at ± 6 months and is, thus, too narrow for the timing of physiological events such as eruption or root resorption, which take place over a much longer period of time. The accuracy of the charts can also be questioned because many of the subjects were medically debilitated and the sample size was too small (Miles, 1963). However, Ciapparelli (1995) suggested that in spite of the shortcomings, these surveys do have a useful role to play in forensic investigations. The yearly stages of development depicted are accurate and it is very much debatable whether more sophisticated methods yield more accurate mean data. Allowances should be made for the narrow variation and the fact that males and females are not dealt with separately.

Gray and Lamons (1959) conducted a survey of skeletal and dental development in 61 children and found that their results agreed with the Schour and Massler chart, provided the age ranges were assumed to include the standard deviation.

Nolla (1960) assessed the age of immature dentitions from radiographs based on a serial study of fifty children. Points were awarded to each tooth on a scale ranging from one point when the crypt only was seen and calcification had not commenced, to ten points when the root apex was just completed. The sum of the points of the whole dentition gave the age assessment. It was observed that the girls were always advanced in all teeth at all stages. The root completion of the mandibular first molar, in particular, occurred at 11 years and six months for boys and 10 years for girls.

Fourteen stages of mineralization for developing single and multi-rooted permanent teeth were defined by Moorrees, Fanning and Hunt (1963) following their study on development of permanent maxillary incisor and all permanent mandibular teeth. The results were expressed as the mean age of attainment for each of the fourteen stages for the developing teeth studied, ± 2 standard deviations. The crown formation stages showed less variation when compared to the root formation stages. This is crucial when accuracy is of prime importance. The chart provided more information on the individual stages of development for each tooth and gave separate charts for each sex. The earliest age in the survey is six months and the data included development of the third molar. Other points of interest that emerged from this study are:

1. differences in the crown formation stages between the sexes are minimal;
2. sexual differences in the development become obvious during root formation, where females develop ahead of males and
3. greatest sexual dimorphism is expressed in eruption of the mandibular canine, females being up to 11 months in advance of males with this particular tooth.

Haavikko (1970) identified 12 radiographic stages of tooth formation, six of them relating to the crown and six of them to the root. For each tooth and developmental stage, a median age and its dispersion were given. The corresponding ages for all permanent teeth were summed and divided by the number of teeth, giving a mean age. In a later modification, Haavikko (1974) used a set of only four teeth. One set of teeth was used for individuals below 10 years of age and another for individuals above this age.

The stages of crown and root development in three primary and six permanent teeth in a group of American children were studied by Fanning and Brown (1971). Revised standards of tooth formation by developmental stages using indicators likely to be most useful to the clinician were presented. Serial oblique jaw radiographs of 151 males and 139 females were used for assessment of stages of development of deciduous mandibular canines and molars, permanent mandibular canines, premolars and molars. Twenty stages of crown and root formation were studied and the standards established were in close agreement with those of the earlier studies. They also claimed that, until comparative standards were available, the values derived for North American children should provide valid standards for dental maturation in Australians.

Demirjian, Goldstein and Tanner (1973) formulated a new method of dental maturity estimation, or dental age assessment, by reference to the radiological appearances of the seven teeth on the left side of the mandible. The maturity scoring system was based on 2928 panoramic radiographs of 3 to 17 year old children of French-Canadian background. The authors stated that although this method was probably universal in application, the conversion to dental age was dependent on the population considered.

Demirjian and Goldstein (1976) presented an updated seven-teeth system in by extending the number of stages assessed and looking at a greater age range. They also presented a new four-teeth system, which eliminated the need for rating all seven teeth. Thus, in children where one or more teeth were missing the new system could be used. When comparing the old and the new seven teeth system, the standard deviation of difference between the two systems, up to the age of thirteen, was not more than three months of the average change in maturity per year. After this age, the relative value of standard deviation increased which is a reflection of the increasing indeterminancy associated with assigning a chronological age to almost mature individuals. When compared, the new seven-teeth and the four-teeth system showed a different pattern. The standard deviation showed a slow increase to about age nine and a more rapid increase thereafter. The standard deviations were equivalent up to ten months with average change in maturity per year as far as thirteen years of age. The comparison between the four teeth systems showed a rapid decrease in the standard deviation up to six years of age followed by a slower decrease to about eleven years of age. It was therefore concluded that the systems did not measure precisely the same underlying quantity and relatively large differences could occur when shifting from the four teeth to the seven teeth system.

Gustafson and Koch (1974) determined the dental development from panoramic radiographs in terms of three developmental stages of tooth formation and clinical emergence of any of the primary and permanent teeth (excluding third molars) in the right lower and left upper jaws. The stage of development of each tooth included was marked off on a card on which the reference values of the dental indicators, combined for the sexes, were given. Thereafter, the dental age was estimated by using a ruler to weigh together the plotted stages. The dental age was read on the y-axis of the card, on which 'even' ages in years are marked. The method was based on reference material collected from a number of studies from different parts of the world.

A new method for the evaluation of dental age in healthy children, using the curve of the total number of erupted permanent teeth was presented by Filipsson (1975). The method was based on the observation that the curves of the total number of teeth erupted are parallel and similar in shape in different individuals, provided that logarithms are used for both age and number of erupted teeth. The chronological age for a specific reference point on the eruption curve was determined graphically in individual subjects. At this stage, each child had reached the same degree of dental maturity. A group of 133 healthy boys and 137 healthy girls were examined annually for seven years for the purpose of this study. The mean age at the reference point of the tooth eruption curve was 8.75 years for the boys and 8.44 years for the girls.

Demirjian (1980) suggested that the concept of "dental age" is simpler to visualize when compared to either chronological age or to other developmental ages and should be replaced by a scale of maturity (Demirjian, 1973), between "immaturity" and "complete maturity". This can be expressed by figures between 0 and 100 and could later on, be transformed and presented in terms of age, if needed.

A new, simplified method for analysing dental age was formulated by Gat *et al.* (1984). They determined six stages of development of the permanent dentition from OPGs obtained from 196 Norwegian children between the ages of 4.5 and 13.5 years. Each stage was assigned a numerical value to permit statistical analysis. The numerical values of different stages were scored and charted separately for boys and girls. A comparison of the left and right sides of the jaws was also undertaken. The high correlation coefficient in the study indicated that the method is well suited for repeat and comparative examinations by different observers.

Hagg and Matsson (1985) conducted a study to investigate the accuracy and precision of three different methods for the estimation of chronological age based on tooth formation; namely Liliequist and Lundberg (1971), Demirjian *et al.* (1973) and Gustafson and Koch (1974). To test the accuracy of each method, the mean difference and degree of linear correlation between estimated and true chronological age was determined in 300 Swedish children between the ages of 3.5 and 12.5 years. The data was arranged in subgroups according to sex and age. To test the precision for each method, the inter-examiner variation was studied in terms of the mean difference between estimated age obtained from independent readings of 60 OPGs of the teeth by the two examiners. The intra-examiner variation was studied by calculating the mean difference between two independent readings of the same 60 radiographs by the same examiner. A high accuracy was found when the method proposed by Demirjian *et al.* was applied to 3.5 to 6.5 year old children. However, this method showed a low accuracy in the older age groups. The accuracy of the method devised by Liliequist and Lundberg (1971) was found to be low in all age groups and age determination using this method resulted in systematic underestimation of age. The accuracy of the method described by Gustafson and Koch (1974) was high when applied to boys, but low in girls. The precision was found to be high for methods of Demirjian *et al.* (1973) and Liliequist and Lundberg (1971), but somewhat lower for the Gustafson and Koch (1974) method. The authors concluded that the estimation of age is preferably done during early childhood. Of the methods tested, the one proposed by Demirjian *et al.* (1973) was the most reliable at these ages due to its comparatively high accuracy and precision.

Disadvantages of the Demirjian system in a forensic setting were discussed by Ciapparelli (1992). Two disadvantages were highlighted, namely that the system required mandibular teeth and that the developmental stages of third molars were not included. In skeletal remains the mandible often disarticulates and is lost and thus unavailable for assessment. However, he recommended the use of this system in preference to the system proposed by Moorrees, Fanning and Hunt (1963).

Liversidge (1999) compared the dental maturation of 18th and 19th century British children using Demirjian's method and reported that the differences were not significant. This suggested similar maturation over 200 years, however many of the young children born approximately 200 years ago were found to be dentally delayed. This could have been due to illnesses to which they succumbed. They also pointed out one of the disadvantages of the Demirjian's method which is its lower scale limit and concluded that the method may not be suitable for younger children.

Mornstad, Staaf and Welander (1994) estimated age with the aid of tooth development by a method based on objective measurements. The structures measured were crown height, apex width and root length. With the aid of a multiple regression model, a linear relationship between some of these distances and age were shown. The distances that were best correlated with age differed according to sex and age. The authors found that this method had a 95% confidence interval (C.I.) of + or -2 years around the estimated age. It therefore seems to be more accurate than earlier methods. The individual variation in tooth development is of the same order of magnitude and hence, a better estimation cannot be done in children 6 to 14 years of age.

Loevy and Goldberg (1999) in an attempt to evaluate the predictability of dental maturation patterns in non-French Canadians boys using the maturation curves developed by Demirjian and Goldstein (1976) studied 79 radiographs of Caucasian Americans and reported that there is considerable risk when using this method for treatment planning prior to the age of 8 years. The risk was found to be the highest when the children were less than 6 years of age due to growth prediction uncertainties.

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2.1.1.1.1 Studies based on tooth eruption

Many attempts have been made to determine the "dental age" of a child based on the number of teeth present in the mouth at each chronological age. Frequent examination is essential in determining the time of emergence of individual teeth. Variations in the sequence of tooth emergence in both dentitions add to the difficulties of establishing a dental age. Filipsson (1975) and Moorrees and Kent (1978) suggested that a count of total number of teeth present in the mouth is useful for evaluating dental development in populations with low incidence of caries as the impact of caries on eruption is minor and hence, the validity of age assessment based on tooth emergence is higher.

Cattell (1928) was the first to conduct such a study and assign a dental maturity age according to the number of emerged teeth in the mouth. Later authors (Voors and Metselaar, 1958, Moorrees *et al.*, 1963 and Mc Gregor *et al.*, 1968) have also worked in the same direction. Thoma (1944) mentioned that tooth eruption is neither spontaneous nor is the tooth stationary after it has erupted.

Brauer and Bahador (1942) compared the calcification process to emergence, for both sets of teeth in 415 children. They concluded that calcification age and emergence age do not necessarily correspond to chronological age. These conclusions were corroborated by Garn *et al.* (1960), who found that tooth calcifications and eruption processes are independent of each other.

Smith (1945) used the degree of eruption of teeth when estimating age within the younger age group and the degree of calcification of the skeleton in older age groups. The degree of eruption of a tooth gave a fairly accurate age correlation in the younger age group by the standards of those days.

Demisch and Wartmann (1956) compared the calcification of the third molar and bone age in children. Independent studies by Hotz (1959) and Green (1961) concluded that a high correlation existed between dental and chronological age, but not between dental age and skeletal age. Large variations in skeletal age were observed in both studies. Green (1961) was of the opinion that dental age estimation is more reliable than skeletal age.

Miles (1963) commented that in the literature on chronology of tooth eruption, there seems to be no authoritative statements as to how long it usually takes a tooth to reach occlusion once it has begun to emerge through the gum. He suggested that even though such information is of little interest to many, it might be of great importance from a forensic perspective. His personal observations and inquiry suggested that the time taken for the final stage of eruption is highly variable; in the case of deciduous teeth, it may be six weeks or more and for permanent teeth even when ample space is available, it may be six months or more.

Hagg and Taranger (1985) conducted a longitudinal study of the timing of tooth emergence in 212 Swedish children from birth to 18 years. They examined tooth emergence at the ages of 1, 3, 6, 9, 12 and 18 months and then annually from two years to eighteen years. The validity of their values for dental age established in this study was evaluated by counting the number of emerged permanent teeth as estimated from radiographs of another sample of Swedish children aged between 6.5 and 12.5 years. They found that the mean differences between chronological age and dental age based on the counts of the first 28 permanent teeth was 1.1 months in girls and 0.7 months in boys. In both sexes, the mean differences between dental and chronological age was positive in the younger group and negative in the older group. A non-significant sex difference in the emergence of the deciduous teeth was also observed. Following the results obtained in this study, the authors commented that the assessment of dental development and dental age by means of tooth counts is a convenient and simple method, although it can only be applied at ages when emergence can be expected. It is especially useful in cross-sectional evaluations, as no serial data are required. However, Demirjian (1980) highlighted a few limitations. There is a high probability of inaccuracies for an individual child, for whom low birth weight, local pathological conditions, supernumerary teeth, the early loss of deciduous teeth and some general pathological conditions should be considered. Besides, there is little information available during periods when there is no variation in the number of teeth. He also added that teeth, being less prone to environmental changes, could be regarded as the ideal instrument for chronological age determination.

2.1.1.1.2 Studies based on third molar development

The third molar is generally not included in the charts or tables used for dental age assessment. Its morphology and clinical presentation make it the most variable of the permanent teeth. As third molars have great variation in their eruption times it is advisable to use the development of their roots, which is supposed to be less influenced by different factors. Based on this, Johanson (1971) studied the developmental pattern of a large number of third molars using intra oral radiographs and orthopantograms of 155 patients. He studied the development of the roots in particular and found that the roots of third molars began to develop after 14 years of age and was fully completed by the 20th year. It was suggested that age determination based on the root development of third molars could be considered as a complement to forensic medicine findings between 14 to 20 years of age.

It is the only developing tooth after the age of 14 years and hence assumes great forensic significance.

Harris and Nortje (1984) and van Heerden (1985) all used a five-stage system of root development in their studies of root development of the third molar. Their findings indicated insignificant differences in third molar development between the four quadrants and no sexual differences.

Ciapparelli (1985) found an almost constant variation of about ± 1 year for both root and crown formation stages. He, therefore, suggested that it could not be assumed that variation during development of this tooth is greater than that of other developing teeth.

Successful estimations of age were demonstrated based on the full eruption of third molars with well-closed apices by Thomas *et al.* (1987). However, Thorson and Hagg (1991) reported that both accuracy and precision was low when the third molar was used for estimating the dental age.

Kullman *et al.* (1992) studied the radiological development of the root of the mandibular third molar and explored its usefulness in age estimation. They also studied differences in scoring between two independent examiners. The study revealed minor differences between sexes in the time sequence of mineralisation. The method gave a low precision in the estimated ages. A standard deviation of about 1 to 2 years was found around the mean age of the different developmental stages. A significant difference was also found between the estimates of the two observers. They also suggested the use of an additional age indicator like skeletal age from a hand radiograph along with dental age to increase the precision and accuracy in the age estimation.

In another study by Kullman *et al.* (1995) the formed part of the root of the lower third molar as seen in an OPG was digitized and the data directly stored in a computer for statistical analysis. They reported that although there were some statistical advantages for this method, the precision of age estimation was slightly inferior to the standard method.

2.1.2 Studies on dental age determination based on changes in tooth structure

Other workers have investigated various alternative ways to determine age from teeth. After eruption into the oral cavity, teeth continuously undergo changes throughout life, which affect all dental and periodontal tissues. These changes are produced by the process of ageing and by physiologic use. The physiologic use may be less than normal when atrophic changes occur or it may be increased, producing abnormal wear and traumatic injuries. These alterations generally do not interfere with function, but often they are exaggerated or accompanied by complications. Various age changes occur in teeth and some of these changes are obvious to the naked eye while others have to be seen under a microscope.

Lacassagne, a professor at the Institute of Forensic Medicine in Lyon in 1889, was one of the first to use changes in the fully formed teeth of adults for age determinations. He successfully estimated the age and identified a body by using changes in bone, teeth and hair as proof for identity (Johanson, 1971). His techniques were little used until Bodecker (1925) showed that certain morphological changes in the teeth could be related to age.

Age changes occurring in dental tissues were also observed and recorded by Thoma (1944). He observed enamel attrition, sclerosis of dentine, denticles in the pulp, deposition of cementum, continuous eruption of teeth and alterations in the periodontal structures. From his work, it can be inferred that the enamel of the tooth shows no definitive evidence of a changed histological structure with increased age of the patient, though there is some evidence that it becomes more calcified, especially on the surface. The dentine shows changes which, according to Beust (1931,1934; cited by Thoma, 1944), are brought about by maturation of the teeth. When ground sections were stained and photographed, it demonstrated sclerosed dentine, which was believed to be produced by hypercalcification of the matrix and deposits in the lumen of the dentinal canals. Young dentine, not so affected, will take the stain, while sclerosed dentine will not because its tubules are obliterated by transparent or opaque deposits and therefore, impermeable to fluids. Since the roots of the tooth are affected as well as the crown, it was inferred that the sclerosis is not a reaction to outside stimuli alone. The sclerosed tissue generally alternates with permeable dentine that gives rise to a peculiar fan-shaped effect caused by distribution of the differentiated dentine. This property of dentin may be used for attempting age determination of an individual.

Gustafson (1950) devised a method of determining the age of an individual by examining the microscopic preparations of the teeth and evaluating the age changes. This method was devised due to the need for positive forensic identification, when the subjects have undergone changes so extensive that external characteristics yield no information and the teeth are often the only means of identification. It was observed that certain changes due to age are visible even on the whole tooth, such as changes in transparency at the root apex. From teeth of individuals in the lower age group, it is possible to estimate directly and with a fair amount of accuracy the age of the person. In older individuals, the changes caused by mastication are observed in the form of attrition. Macroscopic examination is not sufficiently reliable when estimating the age of older individuals and hence investigation on ground sections is required. For the purpose of studying dental formation, different developmental stages have been defined by several authors. These stages have usually been marked by recognizable tooth shapes, from the beginning of calcification through to the final mature form. Useful stages must be easily recognized and a tooth generally passes through the same stages in every individual.

Pillai and Bhaskar (1974) conducted a study in India on 83 teeth using Gustafson's method. They found this method useful for age estimation in an Indian population and found the method useful in assessing age even from a single tooth. No sex differences were noted in the various age groups in the study. They also commented that the parameter of secondary dentine formation was unreliable but not as much as was root resorption. The diet did not seem to influence the age changes in and around teeth.

It is well known that dentine and cementum are deposited in layers with advancement of age. Free and Sauer (1966) suggested that changes in quantities of mineral salts deposited or differential growth rates of cemental tissues may be responsible for this phenomenon resulting in cementum lines which can be equated with age. Stott, Sis and Levy (1982) in their study concluded that countable cemental rings were present in human teeth and that the rings counted from a photograph gave a close estimate of the actual age of the individual. Numerous other studies into age determination using cementum have been carried out and is thought to be a moderately reliable method of assessing age (Naylor *et* *al.*, 1985, Condon *et al.*, 1986, Stein and Corcoran, 1994 and Solheim, 1990). The major drawback is that the method is unsuitable in living subjects because it can be employed only on extracted teeth.

Studies into determining age based on translucency of dentine have been conducted by Altini and Fleming (1983), Lopez, Morales and Luna (1993) and Lorentsen and Solheim (1989).

Kvaal and Solheim (1994) derived a formula for age calculation based on measurement of teeth. They studied age-related changes in 452 extracted, unsectioned incisors, canines and premolars. They suggested that the formulae derived from their study might be used for dental age estimations in forensic and archaeological cases, where teeth are loose or can be extracted and where it is important that the teeth are not sectioned.

2.1.3 Studies based on chemical analyses of dental tissues

Various workers have carried out many physical and chemical tests including specific gravity, variation in amount of mineral with increase in age, hardness of dentin, nitrogen and phosphate content of teeth, colour etc. The increasing mineralization of the bones with increasing age can be analysed by different methods. However, the large variation in mineralization is too great and hence interferes with reliable determination of age by various methods.

Many chemical methods have been tried by various workers to show increases in mineralization of teeth with age. Gerlach (1931) determined the calcium content in different areas of the dentine and related his findings to age. His results demonstrated that the calcium content of the crown was greater than that of the root in young individuals. The difference was observed to be smaller in older individuals than in younger ones. He also found that the mean calcium content increased with age.

Sutor (1937) used specific gravity to relate tooth age to the degree of mineralization and found a direct relation between mineralization and age.

May (1952) attempted to determine the variation in the amount of mineral in teeth with increasing age and found that there was an increase although it was not very significant. Forster and Happel (1959) used the same method but found no correlation between the increase in mineral content and age of a tooth. They concluded that the method could not be used for forensic purposes.

The nitrogen content of teeth was investigated by Bhussry and Emmel (1955) and they claimed that it increased with age and could be correlated with an increase in the amount and intensity of a pigment. This explained the differences in colour between the teeth of young and old individuals.

Dalitz (1962) tried to correlate the hardness of dentine with age using areas of dentine which were not affected by external pathological defects, pulpal changes or root surface changes. The sclerosed dentine at the apex was also avoided. No correlation between age and hardness of the dentine was found and it was suggested that such methods would not assist in age determination from teeth.

Many workers like Masters and Bada (1980), Ohtani and Yamamoto (1987), Ogino and Ogino (1988), Ritz, Schultz and Schwarzer (1990) and Mornstad, Pfeiffer and Teivens (1994) have carried out extensive investigations into the racemization method of determining age from teeth. The amino acid racemization method needs sophisticated scientific equipment and several days of laboratory work. Helfman (1976) commented that it was not a field technique and mentioned the possibility of wrong results following onset of early racemization due to intense heat in certain cases.

2.2 Differences in dental development between sexes

During the years of growth and development, girls are advanced over boys in many respects. They are earlier on an average, in appearance of ossification centres, in epiphyseal union and appearance of secondary sexual characteristics. While the direction of sexual dimorphism in deciduous teeth may be somewhat questionable, the fact that girls tend to be earlier in eruption of the permanent teeth is not (Meredith, 1946).

Hurme (1949) reported that male and female white children of European ancestry had an average difference of 0.45 year (or nearly 5 %) with a maximum of 0.93 year (9%) for the eruption time of the mandibular canine tooth.

Even though it was understood that there were differences in the eruption of teeth between sexes, whether comparable or equivalent sex differences exist in tooth calcification was open to question. The work of Logan and Kronfield (1933) did not make any distinction between sexes while Broadbent's (1941) work on radiographic standards grouped male and female data.

Hunt and Gleiser (1955) showed how use could be made of the fact that while there is little difference in chronology of tooth development between sexes, skeletal maturation occurred about one year earlier in the female than in the male. If the dental and bone ages correspond closely, the subject is probably male; if the bone age is advanced in comparison with dental age, it is probably a female. The authors correctly sexed 73% of a sample of two-year-old children and 81% of a sample of eight-year-old children.

While other radiographic investigations on the mandibular first molar by Gleiser and Hunt (1955) and on the mandibular third molar by Demisch and Wartmann (1956) suggested advancement of girls over boys, generalizations could not be made from their studies. Garn *et al.* (1959) suggested that it could be entirely possible that dental advancement of girls over boys was largely limited to eruption, so that the permanent teeth of girls emerge with a lesser degree of calcification. They investigated the sex differences in tooth calcification and eruption in 225 children using serial oblique-jaw radiographs taken over a period of 18 years. The teeth studied were the permanent mandibular molars and premolars with five distinct stages of calcification and eruption observed. The results showed that, in general, girls tend to be more advanced than boys in the mean ages at which each of the five distinct stages of calcification and eruption were attained. These data confirmed the trend suggested by Gleiser and Hunt and emphasized the need for quantitative sex-specific norms for tooth calcification.

Liliquest and Lundberg (1971) conducted a study, firstly to investigate the reliability of the method used by Schmid and Moll (1960) for determining skeletal ages, secondly to devise a means of determining tooth age with indication of numeric values, and thirdly to correlate these two methods. They also investigated whether there was any difference in the skeletal ages of boys and girls obtained by the Schmid and Moll method and to dental age according to the new method. They devised a means of determining the tooth age with indication of numeric values using the teeth in one half of the lower jaw. The developmental stages of a tooth were divided into eight phases with numeric values assigned to the stages. They concluded that tooth age may be obtained by the values of the teeth in one half of the lower jaw and the sum of these values was well adapted for comparison between groups. They also noted significant differences between boys and girls and suggested that special standards should be made for the both. The correlation between skeletal and tooth age determined by the methods were very good.

The sexual differences in dental calcification on a large scale within an ethnically homogeneous population were studied by Demirjian and Levesque (1980). Panoramic radiographs of 5,437 French-Canadian children ranging from 2.5 to 19 years were evaluated according to Demirjian's method (1976). The maturity of each mandibular tooth was evaluated individually. For each stage of each tooth, the developmental curves of boys and girls were compared. A common pattern was found for each tooth, namely the chronological similarity between boys and girls in the early stages of development and the advancement of girls over boys for the later stages. Up to the age of five or six, no differences were found in the timing of the dental development between boys and girls, in contrast to the older ages where the girls were always more developed than the boys. When the emergence curve was plotted with development curves, a close relation was established between the stage of formation of all teeth and their emergence.

2.3 Ethnic differences in dental development

Different populations mature at different rates and hence some populations exhibit tooth formations and eruption at an early age compared to others. Sundick (1977) observed these differences and attributed them to genetic and nutritional factors. It was also suggested that different populations followed different tooth formation and eruption sequences and individuals within the same population showed variations in these sequences. He suggested the presence of secular trends in most maturational events. This has high significance in forensic odontology.

The dental maturity in Finnish children was assessed in a semi-longitudinal study by Nystrom *et al.* (1986). This study was undertaken to construct dental maturity curves for Finnish children and also to compare their maturity with that of the French-Canadian sample used by Demirjian and Goldstein (1976). Seven hundred and thirty eight OPGs were obtained from 248 healthy Finnish children between 2.5 and 16.5 years of age and overall dental maturity was estimated based on the development of seven left mandibular permanent teeth. The results of the study showed Finnish children to be more advanced in dental maturation than the French-Canadian sample. In boys, the advancement was seen at the age of 5 to 10 years and in girls at the age of 4 to 12 years. They concluded that differences in overall maturity exist among white populations. Maturity standards should, therefore, be based on studies made in the same population for which they are going to be used.

The reliability and validity of three commonly used dental age assessment methods were tested on Swedish children aged 5.5 to 14.5 years by Staaf, Mornstad and Welander (1991). They found that by using Demirjian's method (1976) the age in both sexes were overestimated by 10 months. The method devised by Haavikko (1974) produced a systematic underestimation of about 4-6 months. The method devised by Liliquest and Lundberg showed an overestimation of about 7 months for boys, but a correct estimate for girls. The authors concluded that the charts made from Scandinavian populations gave a good precision while the Canadian standards systematically gave an overestimated age of about 6 -10 months when used on Swedish children.

Mornstad *et al.* (1995) confirmed the above conclusion in a study conducted to examine the validity of the four methods for dental age determination in Swedish children. The radiographs were examined by paediatric dentists, radiologists and forensic odontologists and the results showed a satisfactory precision when the method was based on Scandinavian population. Demirjian's method was shown to consistently overestimate the dental age when used on the Swedish children.

Davis and Hagg (1994) assessed the accuracy and precision of the Demirjian system (1976) in estimating the chronological age of Chinese boys and girls. Although the precision was found to be high, the accuracy was low. The mean difference between the dental age and the true age of the Chinese children was 11 and 7 months for boys and girls respectively. The 95% confidence interval was about ± 15 months in both sexes. The results indicated that Demirjian's method could not be used to accurately estimate the chronological age of Chinese children of this age group. The possible explanation for the low accuracy of the

Demirjian system when applied in children of different racial origin could be due to ethnic difference in maturational standards (Demirjian, 1986). They also compared tooth emergence and when the eruption of seven permanent mandibular teeth were compared between French-Canadian standards, Swedish standards (Hagg and Taranger, 1986) and Chinese standards (Lee *et al.*, 1965) no marked differences were seen. They believed that there were likely to be specific ethnic differences in tooth formation, hence the overestimation of dental age on the basis of tooth formation observed is less likely to be due to ethnic differences but rather to the method of estimation devised.

Hagg and Matsson (1985) observed a similar pattern for two other methods (Liliequist and Lundberg, 1971, Gustafson and Koch, 1974), based on tooth formation devised for estimation of dental age when applied in Swedish children. They concluded that methods based on dental formation may not to bc suitable for estimation of dental age above the age of 5-6 years, neither on an individual nor on a population basis due to the consistent overestimation of dental age, independent of the system used for assessment.

Farah, Knott and Booth (1995) conducted a study aimed at assessing the dental age of children in Perth, Western Australia by using the Demirjian's method (1976). They applied the 'four teeth system' by Demirjian and Goldstein and compared the data obtained with results obtained from other studies. The results showed that Perth females were more dentally mature than males from ages 7.0 to 15.0 years. They concluded from their overall results that the method proposed by Demirjian (1976) was accurate and reliable for dental age determination in the Perth population and also could be used for forensic purposes.

Nykanen *et al.* (1998) reported a study that examined the validity of Demirjian's standards (1976) for dental age estimation when applied to 261 Norwegian children. They observed that the Norwegian children were advanced in dental maturity compared to the French-Canadian reference sample. The mean differences between dental and chronological ages in males ranged from 1.5 to 4.0 months and varied in different age groups. In females the differences increased with age. The variability in individual dental ages was marked and increased with age. They suggested that considering the individual variations in dental maturity, other indicators of biologic maturity should supplement estimation of chronological age in individual children.

Koshy and Tandon (1998) examined the applicability of Demirjian's method in estimating the age in a group of South Indian children. An overestimation of 3.04 and 2.82 years was found in males and females respectively. They concluded that the method was not suitable for age determination in South Indian children and suggested that individual assessment parameters need to be put forward because of wide ethnic differences.

2.4 Dental age determination in medically compromised children

The forensic dentist is obliged to provide precise age data for an individual when requested by police or other agencies. When estimating age for forensic purposes all available resource materials must be carefully evaluated including the possible factors that may cause variation. Only after all data are carefully evaluated can error in age estimations be reduced (BiggerStaaf, 1977). This indicates the importance of giving consideration to various factors that can influence or reduce the accuracy in dental age determination including medically compromised children.

Myllarniemi *et al.* (1978) reported that in children suffering from hypopituitarism, the dental ages were retarded, but to a lesser degree when compared to the skeletal ages. They also noticed that when the growth hormone therapy was discontinued, the lag in dental age increased with similar findings with skeletal age.

In an attempt to examine the influence of factors like birth weight, post natal size and birth order on dental eruption, Ounsted, Moar and Scott (1987) studied three groups of children who were small, average or large for their gestational ages at birth. The children were examined immediately after birth and thereafter at the ages of 2, 6,12, 18 months and 2 and 3 years. During these examinations their emerged teeth were also counted. All three factors appeared to have a direct influence on the number of erupted teeth at any given age.

Townsend and Hammel (1988) outlined the process of dental development and reviewed the evidence that dental emergence is relatively independent of nutritional and environmental influences. They commented that eruption of deciduous teeth was a good indicator of age.

Loevy and Aduss (1988) studied the relation between chronological age and the development of permanent teeth in patients with cleft lip and palate using the Demirjian's method of age determination. They reported that no significant differences were found between the dental ages and the chronological ages in both boys and girls in general.

However, interestingly, a significant difference was seen in boys with a unilateral cleft lip and palate.

In another study, using Demirjian's method to examine tooth development in children with cleft conditions, Poyry, Nystrom and Ranta (1989) reported a mean delay of six months in the 3-9 years age groups which decreased to two months in the 8-14 years age group. They also noted that the delay was longer in children with cleft palate than in children with only cleft lip.

Roberts *et al.* (1985) studied children with precocious puberty depending on the type of etiology, for example, McCune-Albright syndrome, familial male, congenital adrenal hyperplasia, central nervous system lesions and idiopathic precocious puberty. They reported that dental development was significantly retarded relative to their chronological age in patients with idiopathic precocious puberty while no significant abnormal dental development was detected in the other kinds of precocious puberty.

Dahllof *et al.* (1989) studied the effects of chemotherapy on dental maturity in children with haematological malignancies. They observed no significant differences between the chronological and dental ages and also in the number of erupted permanent teeth when compared to healthy controls. They concluded from their results that chemotherapy given to children with haematological malignancies did not interfere with dental maturity or eruption of permanent teeth.

Seow and Hertzberg (1995) studied dental development in children with cleidocranial dysplasia. They reported these children experienced a delay in dental development of approximately three years compared to normal children. They also reported that the root lengths of the mandibular first permanent molar were significantly longer than those of normal children.

Midtbo and Halse (1992) investigated the skeletal and dental maturity and dental eruption in young patients with Turner's syndrome and reported that while the dental maturity was accelerated the skeletal maturity showed increasing retardation with age. They found that the clinical eruption did not differ significantly in these patients.

Genetic influences on dental development have been reported by various authors (Potter *et al.,* 1976, Sharma *et al.,* 1985, Corruccini and Sharma, 1995). Pelsmaekers *et al.* (1997) studied the genetic and environmental influence on dental maturation in twins and suggested a presence of genetic influence. They found that the variations found in dental age were best explained by additive genetic influences and by environmental factors common in twins. They emphasized the importance of the influence of common environmental factors in the formation of teeth.

Kaloust *et al.* (1997) investigated the dental development in children with Apert syndrome and reported that most children with the syndrome had a dental age lower than their chronological age. Their results showed a mean developmental delay of 0.96 years with a trend of increasing delay with increased age.

2.5 Inter- and intra-observer variation in dental age determination

Dental age determination is largely a subjective exercise. There should be some indication of the expected inter-observer variation and its extent. It is also beneficial to calibrate by applying the ageing criteria chosen to radiographs of children of known age, thereby gauging the likely margin of overestimation or underestimation of age.

Borrman *et al.* (1995) in a study which was one of the first of its kind, investigated inter-examiner variation in assessment of age-related factors in teeth. They reported significant differences between observers for all types of measurements. The study revealed systematic differences among observers as well as differences in interpreting the definitions of the scores for different parameters. They suggested that age estimation using statistical analysis is dependent on the individual observer and his/her experience and that too much emphasis should not be placed upon estimated dental age. They also referred to the importance of these findings from a forensic point of view.

Kullman *et al.* (1996) compared inter- and intra-observer variation in age estimation when using subjective and objective methods. They reported significant systematic differences between observers when using subjective methods while the objective method using a digitizer showed good precision within and between observers. They concluded that the overall observer agreement was best using the objective methods on several teeth although there were some significant differences when only one tooth was involved. They suggested that the subjective evaluation could be improved by prior calibration.

Reventid, Mornstad and Teivens (1996) studied the intra- and inter- examiner variations in ages estimated by four dental age determination methods namely, Liliequist and Lundberg (1971), Demirjian *et al.* (1973), Gustafson and Koch (1974) and Haavikko (1974). They reported that different examiners could differ considerably from each other when rating the same radiograph and hence a wide range of estimated ages should be expected when multiple examiners are involved.

Roche *et al.* (1970) in a study conducted to assess some factors influencing the replicability of assessments of skeletal maturity using Greulich-Pyle method reported that there was statistically significant increase in replicability in inter-observer differences from those based on single assessments to those based on a mean of paired assessments. In estimates of increments, both the intra-observer and inter-observer differences showed no real variations in replicability between those based on assessments by the same single observer and those by different single observers. They also noted that the quality of roentgenographic exposure or positioning did not alter the level of replicability.

2.6 Concept of skeletal age

Skeletal age is a very important indicator of maturity of an individual. In disturbances of growth and puberty and in endocrine diseases, skeletal age and body-height are of great importance both for diagnosis and prognosis with respect to puberty and final height. The assessment of skeletal age is thus employed in paediatric endocrinology, orthopaedics, neurology and orthodontics. Skeletal age is also used as an indicator in hormone treatment of children with growth disorders.

The bones present in the hand and wrist are good indicators of skeletal development. The regularity in development of the bones of the hand and wrist is evident both before and after birth. In the embryo it manifests itself in the fixed order in which the mesenchyme of the carpals become transformed into cartilage.

2.6.1 Skeletal age assessment

Guerich and Pyle (1959) stated that the establishment of school health programs and routine health examinations of children requested by parents created a need for more information about the normal growth and development of infants and children that would be comparable to what was known at that time about the diagnosis and treatment of the illnesses which they had. This created a need for a method that would provide more precise information about the developmental status of a child than what could be inferred from height, weight and age alone. They also discussed the many difficulties posed by height and weight tables to determine the developmental status of children. Significant differences in nutritional level and the existence of early maturing and late maturing strains in a population and ethic and genetic diversity, all played a role in creating difficulties for those who attempted to assess the developmental status of children. This led to the search for some dependable indicator of maturity which would, within reasonable limits, be independent of bodily size (Greulich and Pyle, 1959).

The developmental status of the skeleton, as disclosed by hand and wrist radiographs, appears to meet the need. The advantages of using the hand and wrist radiographs, as described by Greulich and Pyle are many:

1. The changes associated with progressive maturity are readily visible in the radiograph.

2. The changes occur in an orderly sequence.
3. They cover the entire period from birth to early adulthood.
4. They permit the direct comparison of children without regard to genetic or other differences in bodily size.
5. The maturative changes in the skeleton are intimately related to those of the reproductive system, which in turn are directly responsible for most of the externally discernable changes on which the estimation of general bodily maturity is usually based on.

A single radiograph of a child's hand provides the following useful information:

1. It affords an objective measure of the amount of progress that the child has made toward attaining physical maturity.
2. It makes it possible to distinguish the poorly from the adequately mineralized skeleton.
3. It reveals imbalances in skeletal development.
4. It discloses scars of interrupted growth that provide a record of past illnesses and other misadventures.
5. If hand radiographs are repeated on the same child after a period of months, a record of skeletal status at two points in time can be obtained, from which it is possible to determine the rate at which skeletal development is proceeding (Greulich and Pyle, 1959).

The radiographic study of the hand and wrist is the most useful single procedure that is available for determining developmental status. However, this is only one aspect of growth and development. Therefore, in any intensive study on the health of the child, the hand film should be supplemented by significant physical measurement and other data (Greulich and

Pyle, 1959). A hand-wrist radiograph may be utilised by the forensic dentist to assess the skeletal age of children of similar genetic constitutions and similar socio-economic circumstances. These radiographs provide detailed information about the growth progress of the individual towards maturity. They permit the assessment of the maturational rates for the individual shafted (long) and non-shafted (round or irregular) bones.

Each bone develops along a timetable unique to the individual. The initial appearance of each bone's ossification centre(s) reflects the regularity and orderliness of the developing skeletal system. Apparently, the genetic control of the sequential developmental changes was established far back in the evolutionary history of mankind and continues to operate throughout the periods of prenatal and postnatal growth and development. The constant unfolding of the human skeletal features in the developing hand and wrist makes the hand-wrist film an excellent instrument for observing the contained maturity indicator images. The appearance of specific individual bone growth patterns correlates well with the initiation of certain secondary sex characteristics during puberty and late adolescence. Thus, the relative developmental precocity of the female compared with the male is observed readily in hand-wrist maturity indicators.

Most children grow and develop at different rates because of genetic differences even when adequately nourished, however, there are early and late maturing children. The observed differences for the skeletal features in the early maturer will be distinctly advanced compared with those in average and late maturers. Also, there are racial differences in skeletal developmental rates among different populations. Skeletal age assessments using standard hand-wrist film assume that:

1. there are ossifying features and articular facets in growing bones that are the same for both sexes;
2. the ossification processes occur more rapidly in females than males, therefore two standards are required for the direct reading of skeletal age and
3. there are chronological intervals between transitional features of growing bones which are predictable and relatable to other observable biological events, for example, pre-pubertal growth spurt and menarche.

In spite of various limitations, the chronological age of the average growing child correlates well with the biological progress of skeletal age. The skeletal maturation of the distal ends of the radius and ulna, carpals, metacarpals and proximal, middle and distal phalanges can be assessed individually or collectively.

2.6.1.1 Skeletal age assessment using hand-wrist radiographs

The skeletal development of the hand and wrist by means of radiographs was first investigated by Pryor (1907). He was also the first to point out the skeletal precocity of females as compared with males and reported cases in which ossification of carpals occurred in an atypical order. A new method of determining the skeletal age based on the appearance of the joint surfaces, the size relationships and the shape of the bones in the metaphyseal-epiphyseal regions and other centres of ossification in the hand and wrist radiograph was developed by Todd (1937).

A study conducted by Mackay (1952) on the development of skeletal maturation of the hand in African children demonstrated the same order of ossification as reported by Pryor.

Skeletal developmental studies in Japan by Sutow and his associates (1953) reported a similar order of ossification in 6 to 19 year old children.

The sequence of chondrification as described by Senior (1929) was extensively investigated by O'Rahilly, Gray and Gardner (1957). A comparable regularity in the order of chondrification of other skeletal elements of the hand and wrist as well as the order of appearance of their primary centres of ossification was observed. Among the children who were in good health, considerable regularity was observed in the order in which carpals and epiphyses begin to ossify, in the sequence of individual series of changes in shape which each of them undergo as they develop, including the order in which the epiphyses fuse to their shafts. Greulich and Pyle (1959) reported that irregularities in initial ossification seem to occur more frequently in the carpals than in the metacarpals or phalangeal epiphyses, but considerable regularity was seen even among the carpals. The sequence of ossification of all carpals except the scaphoid (navicular) were constant and the same for both sexes. The sequence of ossification observed was: capitate, hamate, triquetral, lunate, trapezium (greater multangular), trapezoid (lesser multangular) and pisiform. In boys, the scaphoid centre appeared before that of the trapezium. In girls, the scaphoid either closely preceded or followed the trapezoid.

The International Agreement for Unification of Anthropometric Measurements to be made on living subjects, drawn up at the Monaco and Geneva Conferences of Physical Anthropologists in 1906 and 1912 respectively, specified that measurements be made of the left rather than the right side of the body and of left extremities. This agreement, together with the fact that the number of right-handed persons in most populations is much larger than the number of left-handed persons resulting in the left hand less likely to be maimed or otherwise injured, influenced the early workers in their decision to use radiographs of the left hand rather than the right for their studies.

Studies have shown that there is very little difference between the degree of development of the two hands of an individual. Driezen (1957) compared right and left hand films of 450 children in Alabama. The differences between the skeletal ages of the two hands exceeded three months only in 13% of the children and it was more than six months in only 1.5% of them. Their study suggested that the divergences in the overall skeletal maturation of the two hands were so minor as to be negligible in the evaluation of skeletal status from x-rays.

Greulich and Pyle (1959) developed a well-known and widely accepted method of measuring the skeletal maturity of children by using hand-wrist x-rays. Their atlas consists of a series of typical radiographs of children at 30 points along the maturity scale. Separate standards were established for boys and girls and the chronological age of the children whose radiographs were used in the series did not vary more than 2% from the age at which their examinations were done.

Another widely accepted and tested but more time consuming method of assessing bone age was developed by Tanner, Whitehouse and Healy (1962) which was revised by Tanner *et al.* (1975). They suggested three methods of scoring maturity of individual bones to determine the skeletal ages namely the RUS (radius, ulna, short bones), carpal method and the TW2 method (1975), where both were combined. The RUS score rated the radius, ulna, metacarpals of digits 1, 3 and 5, proximal phalanges of digits 1, 3 and 5, middle phalanges of digits 1, 3 and 5 and distal phalanges of digits 1, 3 and 5.

The carpal bone method scored the capitate, hamate, triquetral, lunate, scaphoid, trapezium and trapezoid. The disadvantage of using the carpal bones was that only 97% of the carpal score was reached by 13 years of age in boys and 11 years of age in girls.

In the Tanner-Whitehouse (1962) method, all the growth centres were scored. Each growth centre was given a maturity rating on a scale of 8 (A to H), except for the radius which was given a scale of 9 (A to I). A numerical score was then allotted to each centre to allow biologic variability. The total derived gave the overall maturity rating. Boys and girls obtained different scores for the same stage since the radiological appearance of all the bones did not indicate the same maturity in both sexes. Each was compared to the atlas standards, consisting of radiographs and descriptions. Only the individual growth centres were pictured. This method gives maximum flexibility so that different features of the system can be used for different purposes as necessary. The RUS score is more effective in the prediction of adult height than either the carpal score or the Tanner-Whitehouse bone score method.

Yarbrough *et al.* (1973) devised a simple method of counting the number of ossified hand-wrist centres. 1447 radiographs of Gautemalan boys and 2,310 radiographs of American boys were used in developing the method. It was demonstrated that this simple method could provide considerable information about the actual centres ossified and hence could be used to estimate the stage in the sequence of onset of ossification attained by a particular boy. When compared with the methods of Greulich and Pyle (1959) and Tanner *et al.* (1962), there was a favourable result in regard to the time required for an assessment but the method was found useful only in the range of birth to about 7 years.

In an attempt to determine whether skeletal assessments using a three finger method (first, second and third finger) was as reliable as those using the whole hand-wrist, Leite, O'Reilly and Close (1987) studied radiographs of 19 males between 10 and 16 years of age and 20 females between 12 and 18 years of age. The maturity of sesamoid and epiphyseal-diaphyseal stages of ossification were evaluated. The results indicated that the three-finger method never deviated from the hand-wrist by more than 2.89 months with a minimum of 0.32 months in males. The maximum deviation in females was 4.45 months with a minimum of 1.55 months. It was noted that by using only three fingers it could be incorporated into a cephalometric radiograph, avoiding the need for extra radiographs.

In order to reduce the amount of time consumed for the scoring process following the Tanner-Whitehouse method (1962), Hill and Pysnent (1994) developed a fully automated bone ageing system. The Royal Orthopaedic Hospital Skeletal Ageing System is an automated system capable of examining a radiographic image and classifying the features specified in the Tanner-Whitehouse (TW2) skeletal maturity assessment method (1962). The system calculates bone age from the same population data. The authors found that there was no inter-observer error using the system. The time taken was found to be 4 minutes when compared to the 20 minutes otherwise taken when an experienced person did the scoring.

Roche, Chumela and Thissen (1988) suggested the FELS method for assessing hand wrist radiographs. This method is based on 98 maturity indicators for all ages combined. The recorded grades are entered into a computer that provides the skeletal age and standard error of the estimate of each radiograph. This method is supposed to be more sensitive since a higher number of maturity indicators are used. This method also provides standard errors.

Fishman (1982) developed a new system for evaluation of skeletal maturity from hand-wrist radiographs. His system uses only four stages of bone maturation found on six anatomical sites along with eleven discrete adolescent skeletal maturational indicators (SMI's) covering the entire period of adolescent development found in these sites. He claimed that the method has been found to be generally valid in both clinical and research situations.

Among the many methods proposed for assessing the skeletal maturity from hand-wrist radiographs, only those of Greulich and Pyle, and Tanner Whitehouse and Healy are used commonly and applicable through the whole range of maturity (Roche, Davila and Eyman, 1971).

Some investigators use the Greulich and Pyle Atlas to assess the skeletal maturity of hand and wrist without making bone specific assessments while others use the slower version in which each bone or selected bones are assessed. (Roche *et a.l* 1971, Roche and Davila, 1976)

2.6.1.1.1 Tanner-Whitehouse (TW2) method of assessing hand-wrist radiographs

The left hand is used and its correct positioning is of great importance since the appearance of certain bones will be different if the x-ray tube is not centred correctly and the hand and thumb not placed correctly.

Twenty bones are assessed in the following order:

Radius, ulna, metacarpals 1, 3, 5

Proximal phalanges 1, 3, 5

Middle phalanges 3, 5

Distal phalanges 1, 3, 5

Carpals

The Tanner-Whitehouse method assumes a fixed sequence of stages of maturity indicators for each bone. It has often been suggested that the carpal bones give different information about the maturity process than do long bones. Hence, Tanner and Whitehouse derived three separate scoring systems. One concerns the radius, ulna and finger bones (RUS), another the carpals only and a third, both combined. They introduced a set of biological weights where the digits 2 and 4 are given a weight of zero (they are not examined). This system of weights defines the score for the 13 bones comprising the RUS score. For the carpal score, equal weights are used for each of the seven bones. In the TW2, a 20 bone score is used (half of RUS + half of the carpal weights). The total maturity score for an individual is obtained by simple addition.

The TW2 method provides maximum flexibility so that different features of the system can be used for different purposes as necessary. The RUS score is more effective in prediction of the adult height than either the carpal score or the TW2 20 bone score.

2.6.1.1.2 Greulich and Pyle Atlas method

The Greulich and Pyle Atlas consists of a series of typical radiographs of children at 30 points along the maturity scale. The subject's film is compared to a standard of the same sex and nearest chronological age. The film is then compared with adjacent standards, both older and younger than the one that is of nearest chronological age. The most closely resembling standard is selected and individual bones and epiphyses are compared individually in a sequence, beginning with distal ends of the radius and ulna, proceeding next to the carpals, metacarpals and the phalanges.

2.6.1.1.3 Reliability studies using the Tanner-Whitehouse method

Waldman *et al.* (1977) reported the skeletal maturity during the first five years of life of 492 Chinese children in a longitudinal study. Hand wrist radiographs taken half yearly were asscssed by the Tanner-Whitehouse method. It was observed that the skeletal age was in advance of chronological ages in both sexes, but significantly more so in females especially between 18 months and three years. The various socio-economic situations and their relationship to skeletal maturity were also considered

2.6.1.1.4 Reliability studies using the Greulich-Pyle method

Interest in improving the assessment of skeletal maturity led to two types of investigations. The aim of some (Tanner *et al.*, 1962, 1972, Murray *et al.*, 1971, Yarbrough *et al.*, 1973) have been to develop alternatives to the well known method of Greulich and Pyle (1959). Other studies by Roche and Johnson (1969), Roche and French (1970) Roche *et al.* (1970) and Johnson *et al.*,(1973) have been concerned with improving the interpretations of Greulich-Pyle assessments and providing new data concerning their reliability.

Roche (1970) analysed skeletal maturation rates for the ages 3 to 13 years using the bone specific assessments of Greulich and Pyle (1959) on serial radiographs of 40 children. He observed that the mean rates of skeletal maturation resembling those of the population from which the atlas standards were derived were the same. The rank order correlation between the sexes in communality indices tended to be higher in girls than in boys and were relatively low for the radius, ulna and carpals.

In a cross sectional study of 4500 Chinese pre-school children living in Hong Kong, Chang *et al.* (1967) and Low (1972) observed that although skeletal maturation (Greulich and Pyle method) in females was significantly faster than in males initially, there was a progressive retardation in both sexes during the second year of life especially in children from lower socio-economic group.

Roche and Davila (1976) determined the reliability of skeletal maturity assessments of hand-wrist radiographs using the Greulich-Pyle method. Their study suggested that the carpals should be excluded when the hand-wrist is being assessed and that either single ages should be given to groups of bones e.g. metacarpals or the bones of hand-wrist should be assessed in a random order.

The skeletal age of 1100 normal Danish children was assessed by Mathiasen (1973) in order to examine the biological scatter and difference from that of the American sample used in the Greulich-Pyle Atlas. A biological normal distribution of skeletal age around chronological age, with a standard deviation of about one year was observed. When compared with the atlas standards, the males were found to be retarded by an average of 9.8 months and females by an average of 5 months.

2.6.1.1.5 Comparison between the two methods

Various studies have been conducted comparing the two main methods of assessing the skeletal age using hand-wrist radiographs, namely Greulich and Pyle method (1959) and the Tanner-Whitehouse method (1962).

Comparing the two methods, Buckler (1977) stated that the bone age's using the Tanner-Whitehouse method were younger than those obtained using the Greulich and Pyle method. This was attributed to the fact that the American children from whom the Greulich and Pyle standards were derived, came from a higher socio-economical group than did the British children of the Tanner-Whitehousc standards. Moreover, they were also obtained from an earlier chronological starting point.

In a study comparing seven different methods used to assess skeletal age, Roche and Johnson (1969) assessed the hand-wrist development of 169 Melbourne children using serial radiographs. When extreme values were excluded, including those obtained from carpals or other selected bones, methods employing arithmetic means of all bone skeletal ages yielded similar means in the age range studied in each sex. No significant differences were observed between the means derived from the averages of skeletal ages of the most and least mature bones and those obtained from all bone skeletal ages. The results suggested that the exclusion of skeletal ages of carpal bones or the use of selected skeletal ages could lead to quicker assessments without changes in means and variability.

Biggerstaff (1977) mentioned that the film matching technique using the Greulich and Pyle radiographic atlas is commonly used by most observers and the collective features of all bones permit a reasonable assessment of skeletal age in an individual.

Milner, Levick and Kay (1986) compared the Greulich and Pyle and Tanner-Whitehouse methods. They studied the hand and wrist radiographs of 66 boys and 58 girls and found a linear relationship between the two methods for the boys but not for the girls. They suggested that the atlas matching method has a valuable place in non-specialist hospitals concerned with immediate diagnosis rather than with the long term care of growth problems.

Acheson *et al.* (1966) contrasted the two methods to assess their reliability and found that the magnitude of systematic error was independent of the sex of the child. They found that, according to the Tanner-Whitehouse method, the average reading of all assessors was nearly one skeletal year higher than the same averages using the Greulich-Pyle Atlas. It was also noted that there was no relationship between the rank order of the reading of both assessors by the two methods. The Greulich-Pyle Atlas gave rise to significantly less systematic error (bias) than the TW2 method. However, the bias associated with the TW2 method was considerably reduced if the skeletal age of the carpals was excluded from the total assessment.

Roche, Davila and Eyman (1971) compared Greulich and Pyle method with the Tanner-Whitehouse method and reported that the skeletal ages obtained by the former were close to the chronological age and would be suitable for most clinical and research purposes.

Wenzel, Droschl and Melsen (1984) assessed the skeletal maturity in Austrian children using the Greulich and Pyle method and the TW2 method. They observed that assessment using the Greulich and Pyle method showed dependence on age groups as well as sex with the major deviations at and after puberty, especially in boys. TW2 bone ages were not dependent on age groups or sex. They suggested that the TW2 method should be preferred, especially at the time around puberty.

Catellanos *et al.* (1996) stated that the Greulich and Pyle method enables differentiation of a series of transitional features that will be identical for any population. The atlas includes a set of standards for the male case and a different set for females. This is because the ossification process takes place more slowly in males than in females as first observed by Pryor (1923).

The reproductibility of the Tanner-Whitehouse system (1962) was assessed by Medicus *et al.* (1971). Standardised hand wrist radiographs of 300 children aged 4 to 18 years, evenly distributed according to sex and maturity were studied. The study demonstrated that the definitions of the stages were sufficiently clear to enable consistent ratings and good inter-observer agreement. The authors, however, concluded that comparison of bone age assessment using this method requires thorough familiarity with the rating process and an experienced observer more than other methods.

King *et al.* (1994) in an audit of the Tanner-Whitehouse method versus the Greulich-Pyle method analysed the reproducibility of bone ages by the two methods. They reported that the Greulich-Pyle method took less time to perform than the TW 2 method, and provided results of similar reproductibility and they stressed that there was no clinically significant difference.

2.7 Differences in skeletal maturity between sexes

The sexual dimorphism in the hand and wrist ossification of 94 males and 111 females from ages 3 to 18 years was investigated by Thompson, Popovich and Luks (1973) in a longitudinal study. The bones of the wrist, phalanges and third finger metacarpal were rated according to the criteria of Greulich and Pyle. Several sex dependent patterns were observed in the maturation of the hand and wrist. The bones of the wrist had more distinct sex dependent patterns than those of the third finger. Some bones were more difficult to rate in one sex than the other. The middle finger in males was significantly more difficult to accurately rate than the ulna, when compared to females. In most bones, the variation of the first appearance of the difficult stages was larger in males. The presence of a phase difference in some bones due to the earlier maturation in girls was also observed.

The accuracy of the Greulich and Pyle Atlas method was also tested among the primary school children in Western Australia. Blanksby *et al.* (1975) conducted a skeletal survey for assessing the levels of skeletal growth and development of 50 boys and girls. The results revealed that while the method was satisfactory for assessing skeletal ages in boys it progressively overestimated the level of development of the girls as their ages advanced.

Chen, Jee, Mohamed (1990) assessed the bone age of Malaysian children aged 12 to 28 months using the Greulich and Pyle Atlas. The bone age was then compared to the chronological age. 83.4% of the cases for males and 94.8% of the cases for females matched within the ± 6 month discrepancy range. The authors stated that the atlas could be used with a good degree of confidence for practical purposes.

The applicability of the Greulich and Pyle skeletal age standards were reassessed by Loder *et al.* (1993). The ages of subjects were evenly distributed between 0 to 18 years of age in a "blinded review". They were divided into four age groups after the difference between the median bone age and the child's chronological age for each radiograph was calculated. Varying correlation was seen, and the authors concluded that the atlas was not applicable to all the children of today especially in the case of black girls.

Baughan, Demirjian and Levesque (1979) gave the skeletal maturity standards for French-Canadian children of school age between the ages of 6 and 17 years. The hand-wrist radiographs of 4084 Montreal children were evaluated according to the Tanner-Whitehouse skeletal maturity system (1962). The study showed that there was a slight delay of the French-Canadian children when compared to the British standards. However, when measured on the separate RUS and carpal weighed systems, the French-Canadians showed a large advance by the former and a delay by the latter. The opposing direction of these differences suggested that the skeletal maturity could not be treated as a unitary concept.

Harris *et al.* (1980) compared different methods of predicting a child's adult height. The results indicated that the method of skeletal age assessment were more critical to accurate height prediction than the choice of other prediction methods. This was because of inter-population differences in the rate and pattern of progress toward maturity and thus indicated the need to compare the children under examination to the most appropriate standards available.

2.8 Ethnic differences in skeletal maturity

Various methods of assessing the age have been compared and contrasted, but ethnic differences between populations necessitate individual assessment parameters for a particular group, as a uniform standard cannot be maintained for age determination in different populations.

Lee (1971) studied the hand wrist radiographs of 571 Chinese boys and girls, 2 months to 17 years old. The radiographs were assessed centre by centre according to the Greulich-Pyle Atlas. The author concluded that the less retarded hand epiphyses of the distal rows had a precocious ossification timing, while the more retarded centres of the proximal rows around the wrist had delayed ossification timing relative to the American white children in the Greulich-Pyle study.

Ontell *et al.* (1996) in a study conducted to examine the applicability of the Greulich-Pyle standards to children of different ethnic groups in the United States observed that the mean differences between bone age and chronological age were found to vary by ethnicity, sex and age group.

2.9 Relationship between dental and skeletal ages

Various studies have been done for many years to establish correlation between dental and skeletal ages. Robinow *et al.* (1942) used factor analysis to establish correlation between the emergence of primary teeth and the appearance of ossification centres, height, and the onset of walking. No correlation was found between these parameters and he concluded that dental development is a relatively independent growth process.

Sutow *et al.* (1954) investigated the correlation between the number of permanent teeth in the mouth and skeletal development in Japanese children. It was observed that the children with more teeth in the mouth were also the most skeletally advanced.

Greulich and Pyle (1959) found a close relationship between skeletal maturation and reproductive systems and were able to predict the occurrence of menarche to within three months, several years before the event. Root formation and bone formation are both connective tissue responses and hence a close correlation could be expected. Since bone age bears a close relationship to the maturation of the reproductive system, it could have a similar close relationship with root calcification. This leads one to believe that root formation may be as good a maturation indicator as bone age is (Lauterstein, 1961). In a cross sectional study in dental development and skeletal age, he reported a high degree of relationship between bone age and root age and root age and eruption time of permanent teeth.

In a longitudinal study, Lamons and Gray (1958) concluded that there is greater correlation between dental eruption and chronological age, than between dental eruption and skeletal age. In another longitudinal study by Meredith (1959), a low degree of correlation was found between eruption of the canine and the first and second mandibular molars and the age of maximum rate of circumpubertal height growth.

Garn *et al.* (1962) studied the calcification and emergence patterns of third molar in relation to bone age and chronological age. Due to its inconsistent development, a low correlation between the development of the third molar and menarche and skeletal development was seen.

Steel (1965) investigated the relationships between dental and physiological maturation in a group of two-year-old children. He did not detect any direct interdependence between dental and skeletal maturation. These results were confirmed by Gyulavari (1966) in his study of low birth weight of Hungarian children. He was of the view that skeletal and dental development are independent and stressed the need to establish dental standards for each population. Bjork and Helm (1967) also failed to find any significant correlation between dental age and skeletal age, height, or age at menarche.

Chertkow and Fatti (1979) investigated the relationship between the stages of mineralization of various teeth and the early radiographic evidence of calcification of the ulnar sesamoid of the first metacarpophalangeal joint among South African Caucasoid boys and girls. They observed that the calcification of the adductor sesamoid was closely related to the completion of root mineralization of the mandibular canine prior to apical closure. No significant sex differences were seen and while the correlation among other teeth were low, it was suggested that the root completion of the mandibular canine prior to apical closure might be used as a maturity indicator. They cautioned that racial variations may exist and should be considered when assessing racial groups.

Demirjian *et al.* (1985) evaluated the interrelationships among measures of somatic, skeletal, dental and sexual maturity. The menarche, peak height velocity (PHV), 75% skeletal maturity, appearance of the ulnar sesamoid and 90% dental development were taken as the measures of girls of ages 6 to 15 years. The age at which French-Canadian girls attained 90% of their dental development showed no significant relationship with the other maturity indicators. The results imply that the mechanisms controlling dental development are independent of those controlling somatic and/or sexual maturity.

Mappes *et al.* (1992) in a study conducted to examine the regional variation in the tempos of tooth mineralization and hand-wrist ossification suggested that the results confirmed the essential independence of the development of the dental and osseous tissue systems. Coutinho *et al.* (1993) suggested that given the well-established relation between skeletal and somatic maturity, stages of calcification of the mandibular canine might be used as a first level diagnostic tool to estimate the timing of pubertal growth spurt. The ease of recognizing dental developmental stages, together with the availability of intraoral or panoramic radiographs in most orthodontic or paediatric dental practices are practical reasons for attempting to assess a person's physiologic maturity without resorting to multiple hand-wrist radiographs.

The accuracy of two dental and one skeletal age estimation methods were tested by Kullman (1995) in 12 to 19 year old Swedish adolescents. The first dental method tested was traditional with a subjective assessment of the root development stage. The second was a new method with a metric measurement of formed root length. An additional independent indicator of chronological age was employed, namely the skeletal maturity according to the atlas method of Greulich and Pyle (1958). All methods gave an overestimation of chronological age, with the highest overestimation being more than one year for the two dental methods. The skeletal age assessment could be used as a predictor up to 18 years of age.

As Demirjian said, the evidence so far indicates that the skeletal system as well as height and onset of puberty develop largely independently of the dental system. Various studies have been done and are still planned to test the existing methods and to develop new methods to accurately estimate the skeletal and dental ages in various populations. The efforts so far have resulted in various findings and variations and it is important to keep in mind the fact that the present population of the world is constantly changing. The earlier studies were all done in homogenous populations localised to specific regions. The current trends of migration and mixing of ethnicity makes it very difficult for the modern investigator to determine standards of growth and development. However, it is still very important to consider the differences in growth and development between various populations while determining the age of an individual.

CHAPTER 3

MATERIALS AND METHODS

This study was carried out in the Forensic Odontology Unit, The University of Adelaide, South Australia. The main aim of the study was to test the reliability of 'Demirjian's method' of dental age determination in a group of South Australian children. The skeletal ages of a subset of the sample were also assessed using the Greulich and Pyle Atlas method for age estimation.

3.1 Sample selection and distribution

The data used in this study were obtained from radiographs of a random sample of 400 South Australian children between the ages of 7.0 - 12.9 years of age. The sample consisted of 211 males and 189 females. Twenty-nine of the selected subjects had a known medical condition and were patients at the Women and Children's Hospital in Adelaide. Radiographs belonging to the subjects with a known medical condition were inter-dispersed with the whole sample. The radiographs were obtained from the records of children who attended various school dental clinics under the care of the South Australian Dental Service, Orthodontic and Paediatric Dentistry Clinic at The University of Adelaide, the Dental Department at Women's and Children's Hospital and a specialist Paediatric Dentistry practice in Adelaide.

Subjects with any congenitally missing or extracted mandibular permanent teeth except the third molar were excluded from the sample. All radiographs except the ones that were obtained from the Women's and Children's Hospital were of children with no known significant medical condition.

Orthopantomographs (OPG) were used for assessing the dental age while the skeletal ages were assessed using hand-wrist radiographs (Figures 3.1 and 3.2). Only subjects with good quality radiographs were selected for the study. All necessary dental and skeletal structures were easily distinguishable on the radiographs.

The date of birth of each subject was obtained from the clinical records and the chronological ages were calculated based on the date the radiographs were taken. Only cases where the hand-wrist radiograph was taken on the same day or within 7 days of the orthopantomograph were included for skeletal age assessment. In cases where the hand-wrist radiograph was obtained on a different day than the OPG, the chronological age was calculated based on the date the OPG was obtained.

3.2 Coding

The personal details on all the radiographs were thoroughly masked and numerically coded by two non-investigators. The numerical codes were assigned at random and the key was known by only one non-investigator. The investigator was not aware of the name, sex, chronological age or medical status of the child whose radiograph was being assessed. The codes were revealed only after all the radiographs were scored as the chronological ages and sex of the subjects were necessary for analysing the results.

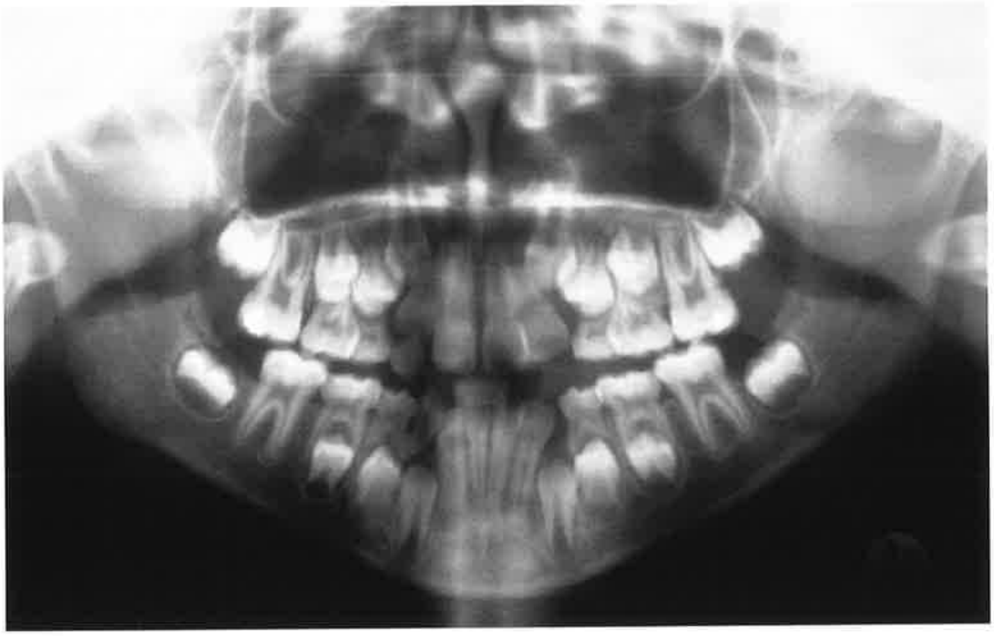


Figure 3.1 Orthopantomograph.

Figure 3.2 Hand - wrist radiograph.

3.3 Methods

The sample was arranged into six age groups according to chronological age and sex (Table 4.1). For the purposes of statistical analysis and ease of calculation all the chronological ages were converted to years and months where months were noted as fraction of a year. For example: 9 years and 9 months when converted would be 9.75 years.

The data obtained were further grouped as follows:

- Chronological age (CA)
- Estimated dental age (EDA)
- Estimated skeletal age (ESA)
- Dental maturity score (DMS)
- Normal samples
- Medically compromised samples

3.3.1 Dental age assessment

The dental age was estimated from OPGs using the written and pictorial criteria described by Demirjian *et al.* (1973, 1976). Demirjian *et al.* identified and described eight stages of development, from calcification of the tip of the cusp to the closure of the apex, designated by a 0 for no calcification, and letters A to H, corresponding to the eight stages (Figure 3.3). Letters rather than numbers were selected so as not to leave the false impression that each stage is equidistant from the other.

Assigning the ratings (Demirjian *et al.* 1976)

1. The mandibular permanent teeth are rated in the following order: 2nd molar, 1st molar, 2nd bicuspid, 1st bicuspid, canine, lateral incisor, central incisor.
2. All teeth are rated on a scale A to H. The rating is assigned by following carefully the written criteria for each stage and by comparing the tooth with diagrams and radiographs given in Figure 3.3. The illustrations are only to be used as an aid, not as the sole source of comparison. For each stage, there are one, two, or three written criteria marked a, b, and c. If only one criterion is given, this must be met for the stage to be taken as reached; if two criteria are given, then it is sufficient if one of them is met for the stage to be recorded as reached; if three criteria are given, the first two of them must be met for the stage to be considered reached. At each stage, in addition to the criteria for that stage, the criteria for the previous stage must be satisfied. In borderline cases, the earlier stage is always assigned.
3. There are no absolute measurements to be taken. A pair of dividers is sufficient to compare the relative length (crown/root). To determine apex closure stages, no magnifying glass is necessary. The ratings should be made with the naked eye.
4. The crown height is defined as being the maximum distance between the highest tip of the cusps and the cemento-enamel junction. When the buccal and lingual cusps are not at the same level, the midpoint between them is considered as the highest point.

Dental formation stages

If there is no sign of calcification, the rating 0 is given. The crypt formation is not taken into consideration. Each stage is then given a numerical score, according to the mathematical technique by Tanner *et al.* (1975) and Healy and Goldstein (1976), the sum of which provides an estimate of an individual's dental maturity on a scale from 0-100.

Stage description (A-H)

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 cemento-enamel junction.

(b) The superior border of the pulp chamber in uniradicular teeth has a definite curved form, being concave towards the cervical region. The projection of the pulp horns, if present, gives an outline like an umbrella top. In molars, the pulp chamber has a trapezoidal form.

(c) Beginning of 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 in 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 semilunar 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 semilunar 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. (a) The walls of the root canals are now parallel (distal root in molars).

(b) The apical ends of the root canals are 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.

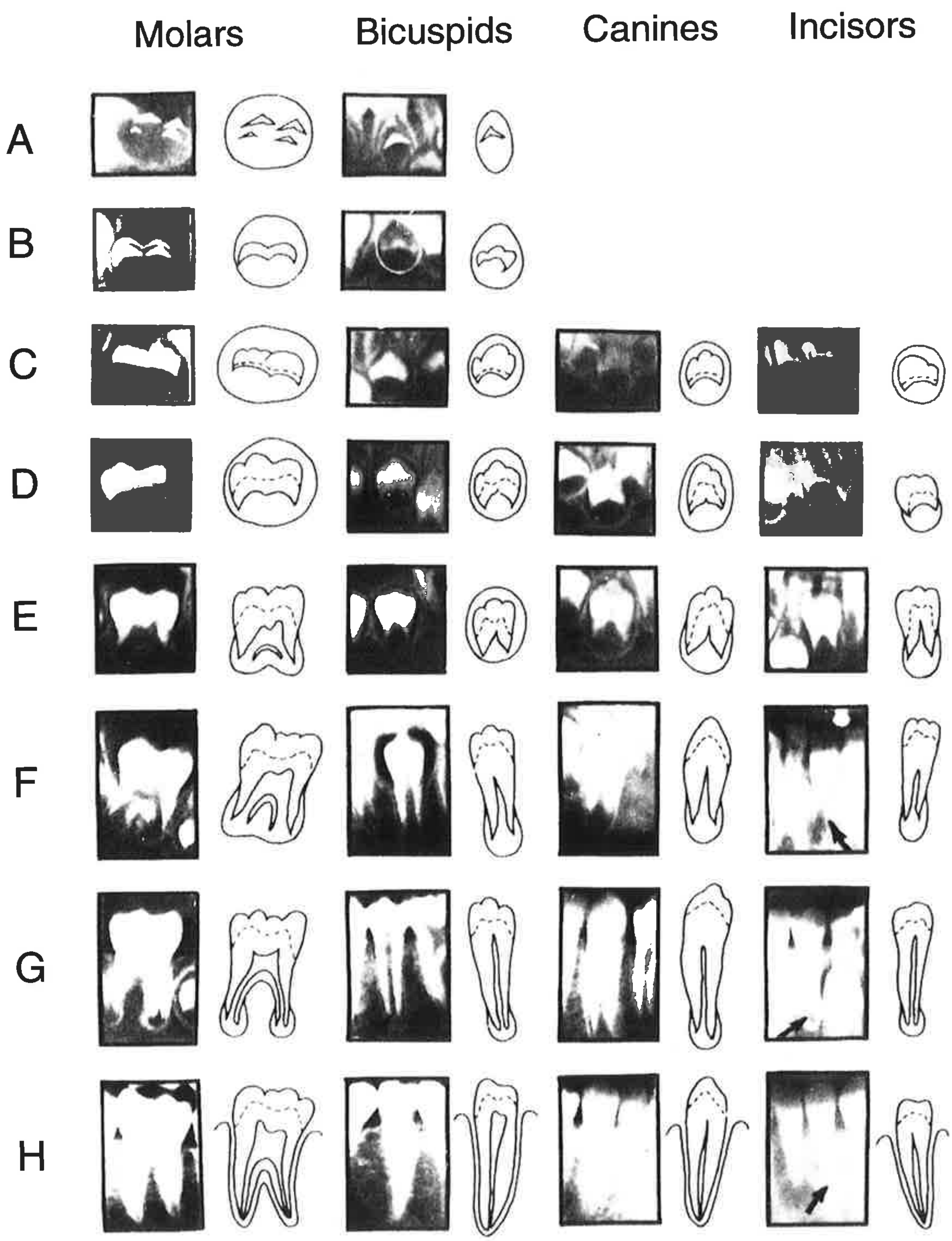


Figure 3.3 Pictorial description of developmental stages.

Using the scoring system:

1. Each tooth was rated according to the stage of development.
2. Each tooth rating was converted into a score using the appropriate (male or female) tables (Table 3.1) with self-weighted scores for dental stages in boys and girls.
3. The stages for each sample and maturity score were entered into a table (Table 3.3).
4. The scores for all seven teeth are added together to give the maturity score.
5. The maturity scores were plotted on the centile charts (boys and girls as appropriate) where the age of the child was known.
6. The maturity score was converted directly into a dental age either by reading off the horizontal scale the age at which the 50th centile attained that maturity score value (Figure 3.4).

Table 3.1 Self weighted scores for dental stages:7 teeth (mandibular left side) - Males

	STAGES								
TOOTH	0	A	B	C	D	E	F	G	H
M 2	0.0	1.7	3.1	5.4	8.6	11.4	12.4	12.8	13.6
M 1				0.0	5.3	7.5	10.3	13.9	16.8
PM 2	0.0	1.5	2.7	5.2	8.0	10.8	12.0	12.5	13.2
PM 1		0.0	4.0	6.3	9.4	13.2	14.9	15.5	16.1
C				0.0	4.0	7.8	10.1	11.4	12.0
I 2				0.0	2.8	5.4	7.7	10.5	13.2
I 1				0.0	4.3	6.3	8.2	11.2	15.1

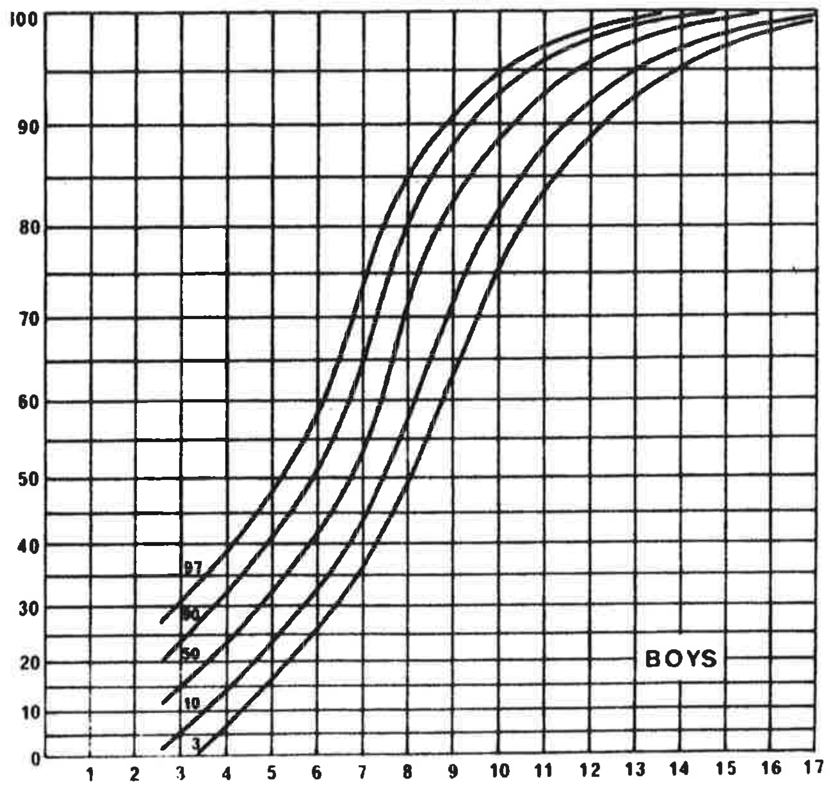
Table 3.2 Self weighted scores for dental stages:7 teeth (mandibular left side) – Females

	STAGES								
TOOTH	0	A	B	C	D	E	F	G	H
M 2	0.0	1.8	3.1	5.4	9.0	11.7	12.8	13.2	13.8
M 1				0.0	3.5	5.6	8.4	12.5	15.4
PM 2	0.0	1.7	2.9	5.4	8.6	11.1	12.3	12.8	13.3
PM 1		0.0	3.1	5.2	8.8	12.6	14.3	14.9	15.5
C				0.0	3.7	7.3	10.0	11.8	12.5
I 2				0.0	2.8	5.3	8.1	11.2	13.8
I 1				0.0	4.4	6.3	8.5	12.0	15.8

Table 3.3 Dental maturity scoring sheets

Code xxx	STAGES								
TOOTH	A	B	C	D	E	F	G	H	**Score**
M 2					✔				11.4
M 1								✔	16.8
PM 2						✔			12.0
PM 1						✔			14.9
C							✔		11.4
I 2								✔	13.2
I 1								✔	15.1
Total									**94.8**

Code xxx	STAGES								
TOOTH	A	B	C	D	E	F	G	H	**Score**
M 2				✔					9.0
M 1							✔		12.5
PM 2			✔						5.4
PM 1					✔				12.6
C						✔			10.0
I 2							✔		11.2
I 1								✔	15.8
Total									**76.5**



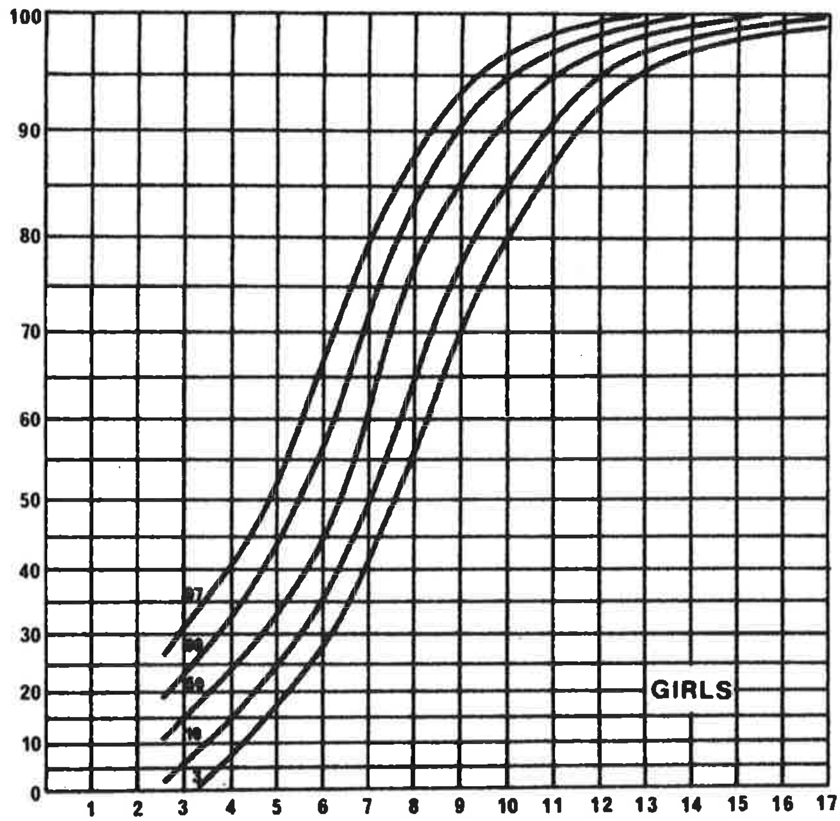


Figure 3.4 50th percentile graphs for males and females.

3.3.2 Skeletal age assessment

The skeletal ages of subjects in the sample, where a hand-wrist radiograph was available, were estimated using the Greulich and Pyle Atlas method (1959). All the hand-wrist radiographs available were of the left hand. (Figure 3.2)

Greulich and Pyle (1959) compiled a Radiographic Atlas of Skeletal Development of the Hand and Wrist. The atlas included radiographic images of hand and wrist bones for skeletal age standards in the new born to skeletal age of 19 years in males and newborn to 18 years in females. The size of the individual bones as they appear in the standards given in the atlas is the same as in the original hand-films from which the plates were made.

3.3.2.1 Assessing hand-wrist radiographs using the Greulich and Pyle Atlas method (1959)

The film was first compared with the standard of the same sex and nearest chronological age in the atlas. Then the film was compared with adjacent standards, both older and younger than the one that was of the nearest chronological age. The standard which superficially appeared to resemble it most closely was selected, after which a more detailed comparison of the individual bones and epiphyses were made. The bones were checked in a regular order to prevent the overlooking features that are important in making the assessment. A suggested way to begin was to start at the distal ends of the radius and ulna, proceeding next to the carpals, then to metacarpals and then to phalanges. As an added insurance against missing some of their significant developmental features, it was suggested that the carpals too, be studied in a regular sequence - preferably in the order in which they usually appear: capitate, hamate, triquetral, lunate, scaphoid, trapezium, trapezoid, pisiform.

The adductor and flexor sesamoids of the thumb appear in that order, usually several years after the pisiform has begun to ossify.

If an individual bone in the film to be assessed was found to be in the same stage of development as the corresponding bone in the standard selected for detailed comparison, it was given the skeletal age that had been assigned to that bone in that standard. If it appeared to be either less advanced or more advanced than its counterpart in that standard, it was compared with the same bone in adjacent standards. The proper skeletal age assigned to it was that which was given in the standard to the corresponding bone that showed the same degree of development. If none was found that corresponded exactly in the developmental status with the bone to be assessed, its skeletal age was estimated from that of those which it most closely resembled. The developmental status of all bones of the hand to be assessed occasionally corresponds exactly to that of a hand standard in the atlas. In such situations, the skeletal age of that standard was the skeletal age assigned to the child's hand. If, however, its developmental status did not correspond exactly to that of any one standard but was, rather, intermediate between those of two adjacent standards, the age assigned to the film was the one corresponding intermediate between the ages of the two standards that it most closely resembled.

After the skeletal ages were estimated using the method described, the radiographs were decoded and the chronological ages of the subjects were revealed. It should however be noted that before the films were compared with the atlas standards, the sex of the subject was revealed to the investigator so that the comparison could be made with the appropriate sex standards in the atlas.

3.4 Intra- observer differences

The developmental stages of twenty randomly selected and coded radiographs were scored by the investigator using Demirjian's standards. These observations were adopted as a standard for comparison. The investigator then scored the same set of radiographs three times on three different days in an attempt to avoid familiarisation. A total of four hundred and twenty developmental stages (7 stages per radiograph for 20 samples $\times$ 3 sets) were scored on three different days. The observations were then compared with the standard in an attempt to find out the rate of intra-observer variations in identifying the developmental stages. It was observed that 368 stages out of the 420 stages scored were matching in the three sets of observations and thus an overall agreement of 87.6% (368 / 420) was obtained. This accuracy was considered acceptable for the purpose of this study.

3.5 Statistical analysis

The obtained data were statistically analysed to understand the relationship between the ages. The data were entered into an American Standard Code for Informatics Interchange (ASCII) file and were analysed using the SPSS for UNIX package. The mean ages were compared using paired t-tests and the mean differences, standard deviations and significance were calculated. The associations between the ages were analysed and the degree of association between the ages established by calculating the correlation coefficient using Pearson's correlation method. Scatter diagrams were also generated to demonstrate the correlation between the ages. The estimated dental and skeletal ages in age groups were also cross tabulated against the chronological age groups to observe the accuracy of matches in age groups. The ranges of over and underestimation of dental and skeletal age from chronological age in the whole sample and individual age groups were also plotted and analysed.

CHAPTER 4

OBSERVATIONS AND RESULTS

This study was undertaken to assess the accuracy and reliability of the 'Demirjian method' of dental age assessment when applied in a group of South Australian children. When the sample comprised of 400 subjects (211 males and 189 females) was grouped into its respective chronological age groups, the following pattern of distribution was observed:

4.1 Distribution of sample

When grouped into the six age groups, fifty-nine (34 males and 25 females) were between 7.00 and 7.99 years of age, 73 (37 males and 36 females) between 8.00 and 8.99 years of age and 78 (40 males and 38 females) were in the 9.00 to 9.99 years age group. Seventy-nine (42 males and 37 females) belonged to the 10.00 to 10.99 years age group, 58 (30 males and 28 females) to the 11.00 to 11.99 years group and fifty-three (28 males and 25 females) in the 12.00 to 12.99 year age group (Table 4.1, Figures 4.1 and 4.2).

Table 4.1 Distribution of sample by chronological age

AGE	MALES	FEMALES	**TOTAL**
7.00 - 7.99	34	25	**59**
8.00 - 8.99	37	36	**73**
9.00 - 9.99	40	38	**78**
10.00 - 10.99	42	37	**79**
11.00 - 11.99	30	28	**58**
12.00 - 12.99	28	25	**53**
TOTAL	**211**	**189**	**400**

Figure 4.1 Distribution of the sample

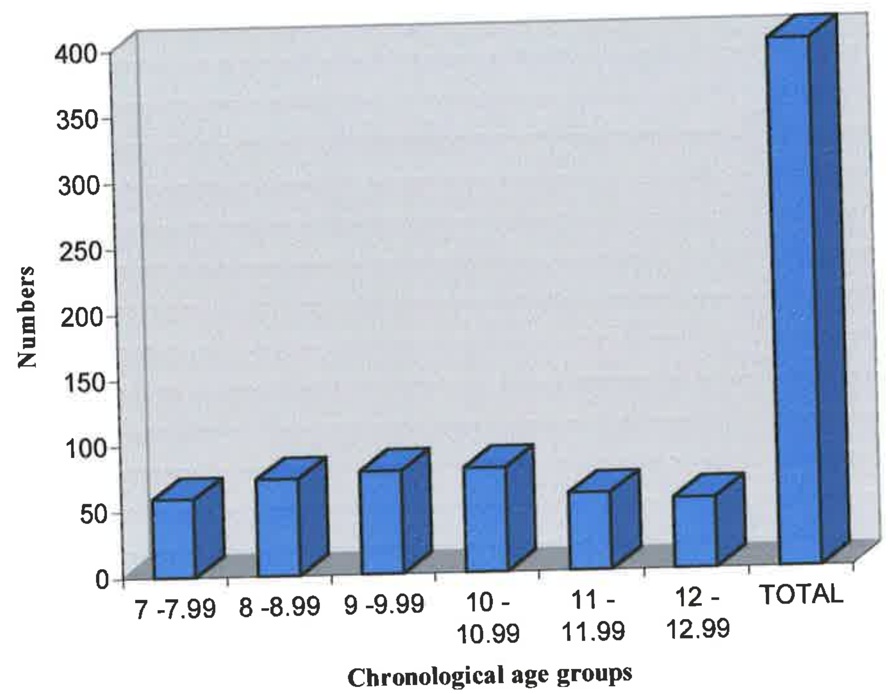
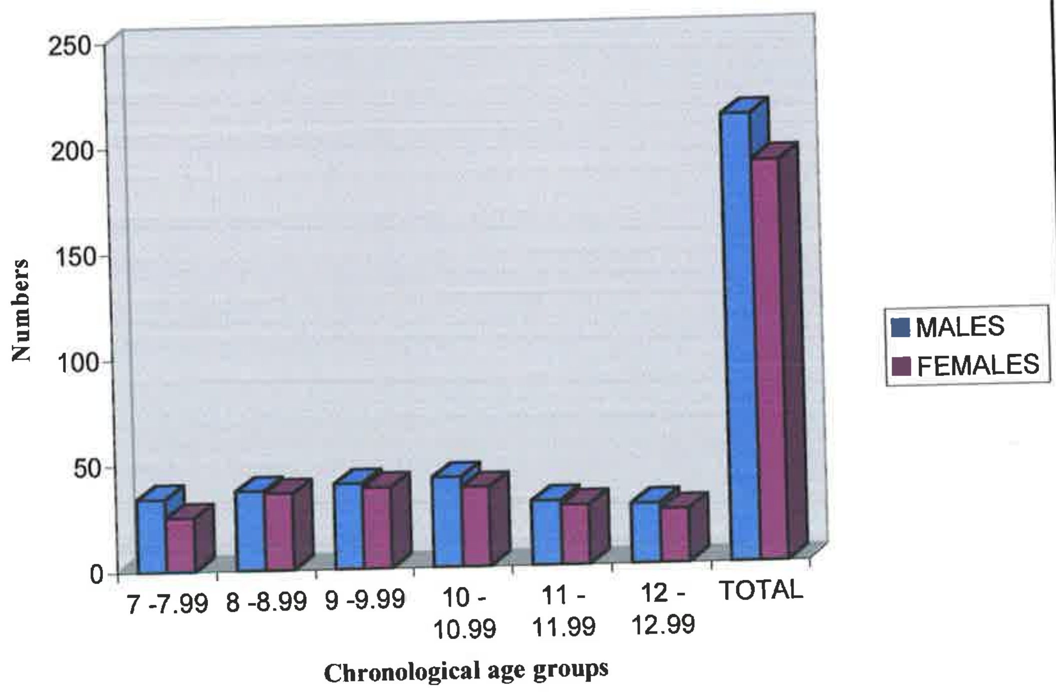


Figure 4.2 Distribution of the sample - Male : Female



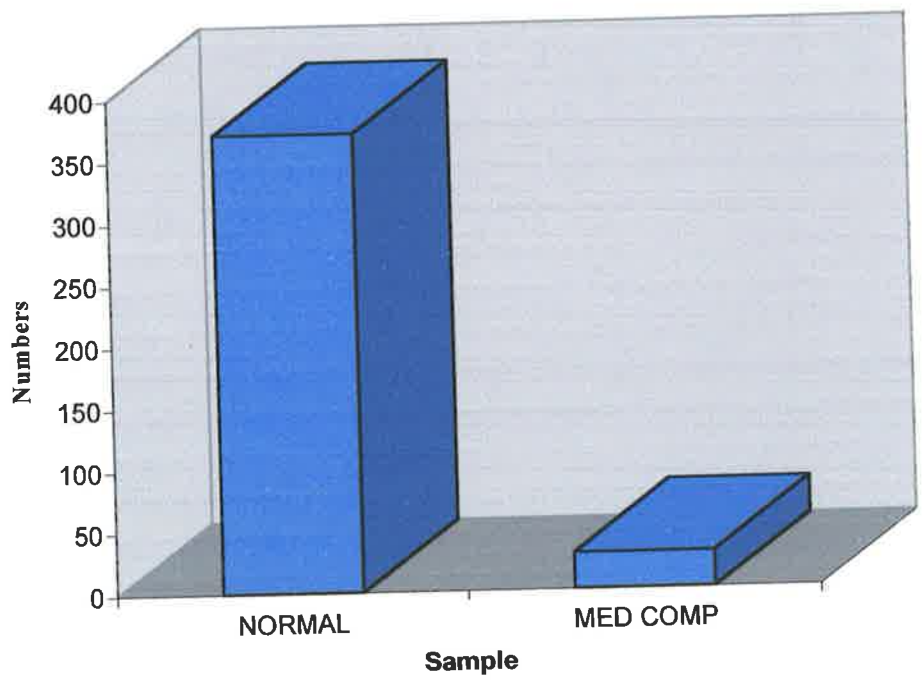
4.1.1 Medically compromised group

Twenty-nine (15 males and 14 females) out of the 400 were medically compromised but were not grouped according to their medical conditions (Table 4.2, Figure 4.3).

Table 4.2 Normal by medically compromised

	Normal	Medically compromised
Males	196	15
Females	175	14
Total	371	**29**

Figure 4.3 Distribution of medically compromised children in the sample



The 400 OPGs were studied and maturity scores were assigned to each sample. The maturity scores obtained were converted into estimated dental ages (EDA) using the standards and conversion graph given by Demirjian (1976). The data were then tabulated according to the various headings mentioned earlier. The estimated ages were then subjected to various statistical tests to compare them with their chronological ages. The tests involved frequency estimation, paired t-tests and correlation coefficients between age groups.

4.2 Chronological age

The lowest chronological age was 7.00 years and the highest was 12.91 years. The mean chronological age in the whole sample was 9.84 years. The lowest chronological age in males was 7.00 years and the highest was 12.91 years. The lowest age in females was 7.50 years and highest 12.83 years. The mean chronological age was 9.83 years in males and 9.84 years in females.

4.3 Maturity scores

The maturity scores of the 211 males and 189 females were converted to estimated dental age (EDA) using Demirjian's conversion graph (Demirjian 1976). In males, the highest maturity score obtained was 100.00 and the lowest was 61.30. In females, the maximum and the minimum maturity score calculated were 99.50 and 66.30 respectively (Figures 4.4 and 4.5).

Figure 4.4 Maturity scores

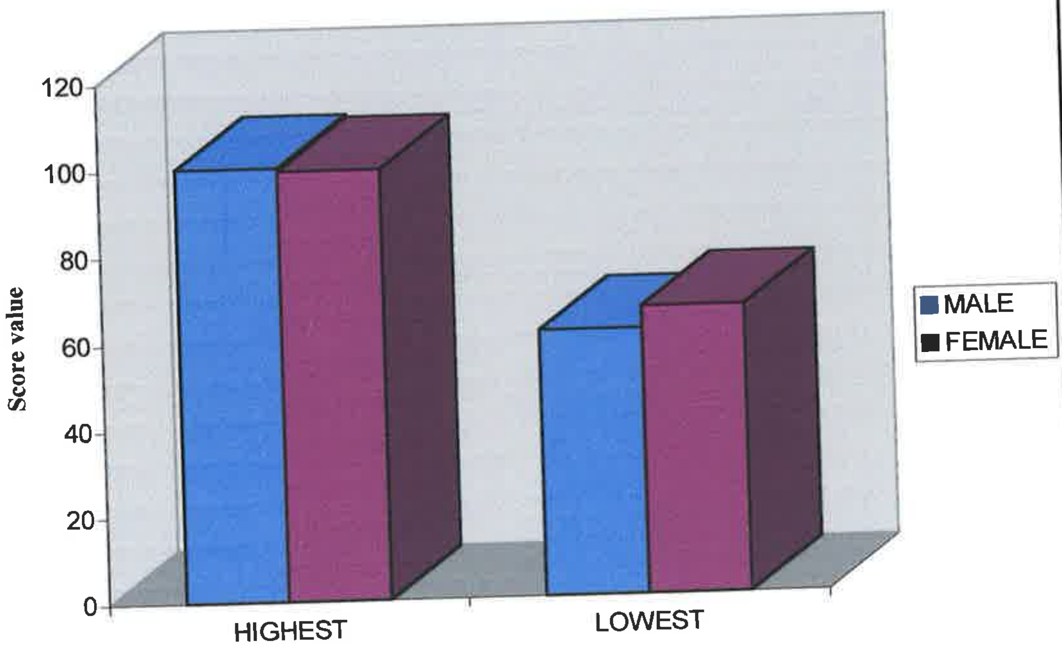
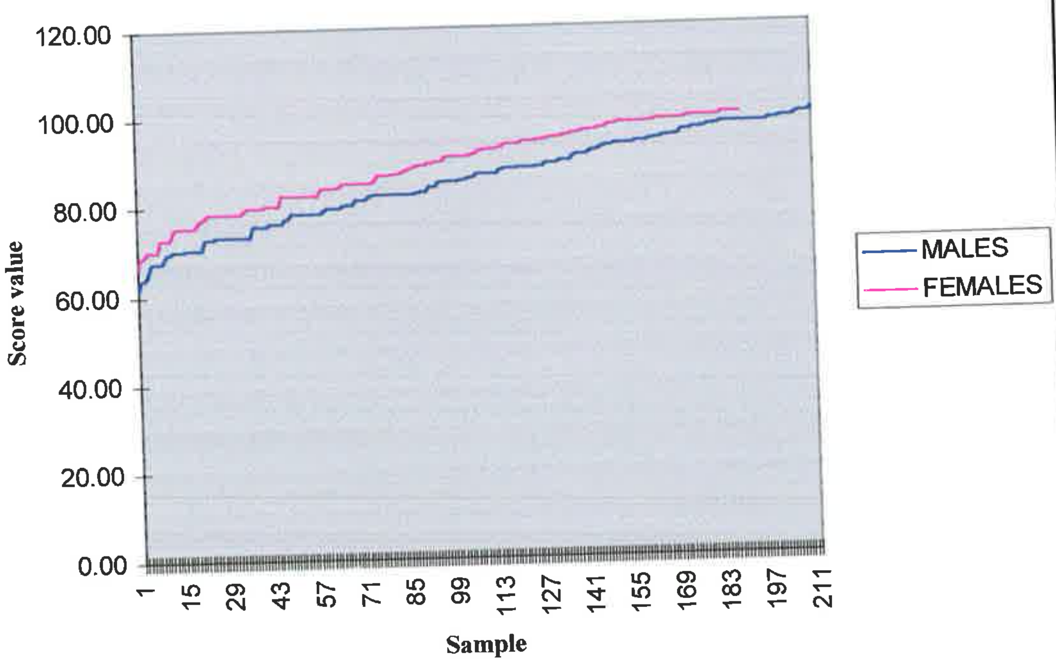


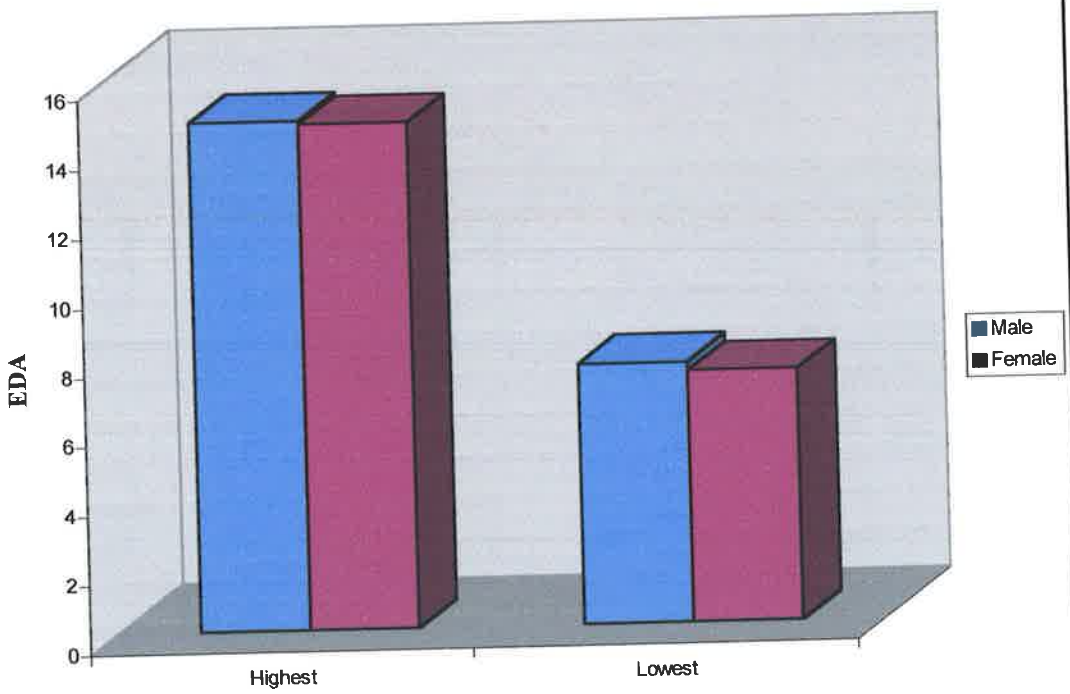
Figure 4.5 Comparison of maturity levels - males : females



4.4 Estimated dental age

The maturity scores were converted into estimated dental ages for all 400 samples. The highest EDA in the whole sample was 14.70 years and the lowest was 7.25 years. The highest EDA in males was 14.70 and the lowest was 7.50. In females the highest EDA was 14.60 and the lowest 7.25 years (Figure 4.6).

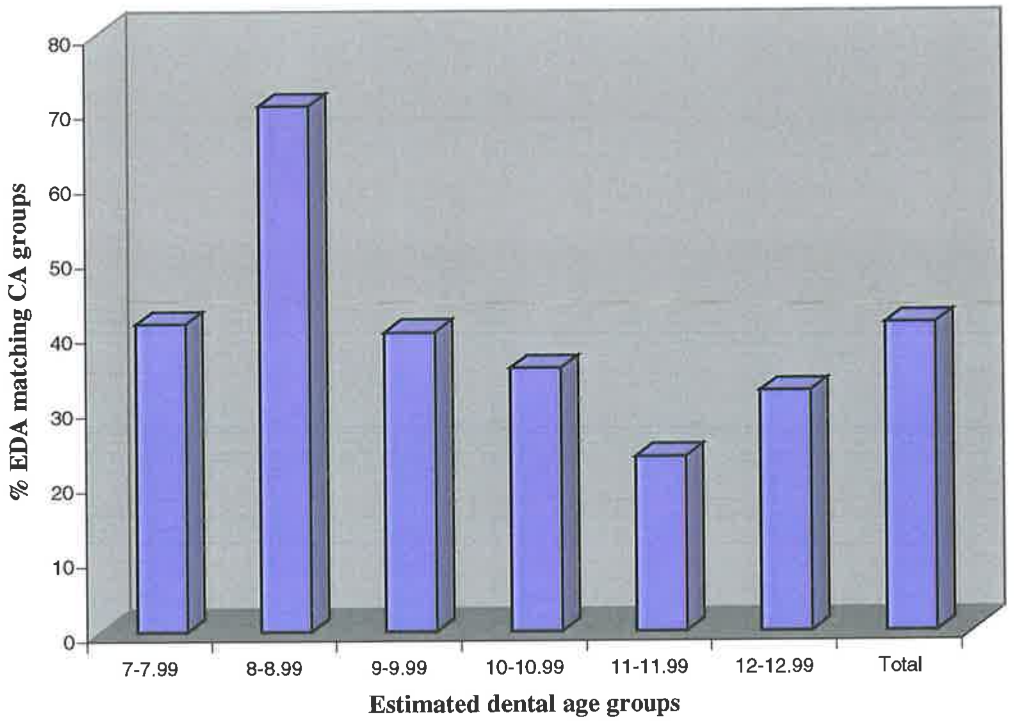
Figure 4.6 Estimated dental age



4.4.1 Comparison of estimated dental age and chronological age in males

When the estimated dental age and chronological age in males were compared, the percentage of EDAs falling into the corresponding CA group was observed to be highest (70.3%) in the 8.0-8.99 year old group and lowest (23.3%) in the 11.00-11.99 year old group. Overall, 87 out of 211, i.e. 41.23% fell in the corresponding CA groups (Table 4.3 and Figure 4.7).

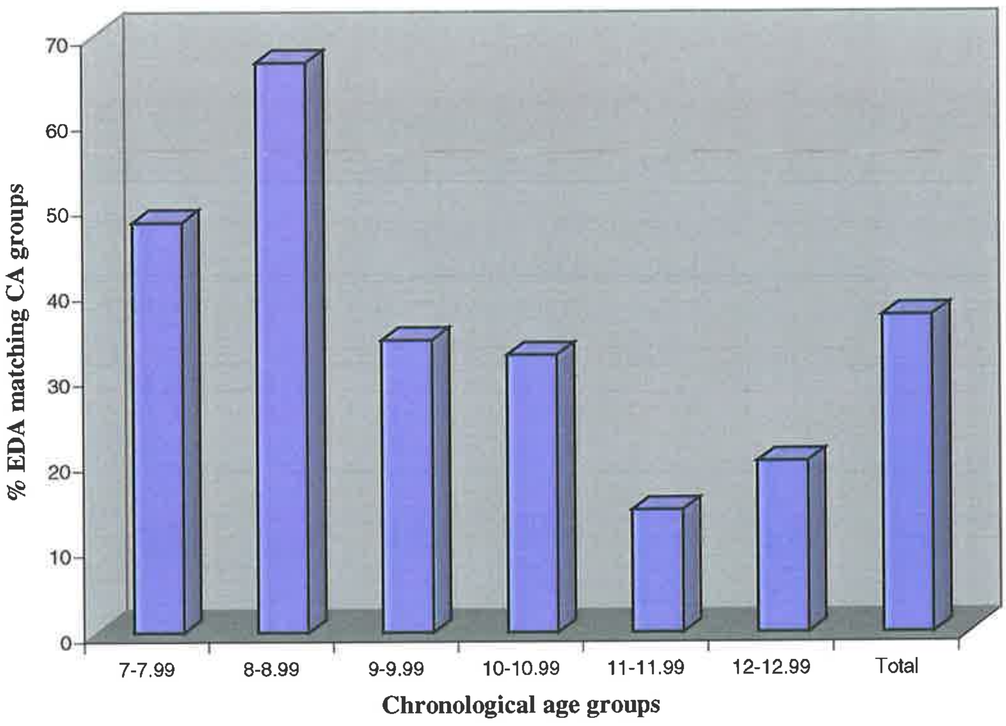
Figure 4.7 Comparison of EDA and CA in males



4.4.2 Comparison of estimated dental age and chronological age in females

When the estimated dental age and chronological age in females were compared, the percentage of EDAs falling into the corresponding CA group was observed to be highest (66.7%) in the 8.0-8.99 year old group and lowest (14.3%) in 11.00–11.99 year old group. Overall, only 70 out of 189 i.e. 37% fell into the corresponding CA groups (Table 4.4 and Figure 4.8).

Figure 4.8 Comparison of EDA and CA in females



4.4.3 Comparison of estimated dental age and chronological age in the whole group.

When the estimated dental age and chronological age for the whole sample were compared, it was observed that the percentage of EDAs falling in the corresponding CA group was highest (68.5%) in the 8.00-8.99 year old group while lowest (18.9%) in the 11.00-11.99 year old group. Overall, 157 out of 400 i.e. 39.3% fell into the corresponding CA groups (Table 4.5 and Figure 4.9).

Figure 4.9 Comparison of EDA and CA - whole group

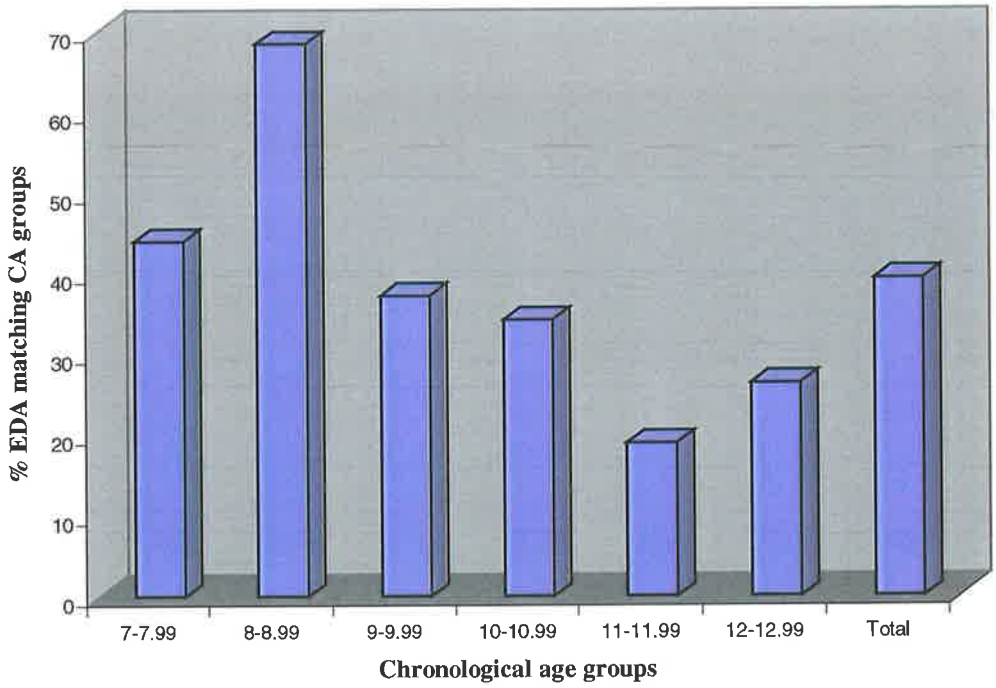


Table 4.3 Estimated dental age to chronological age - males

CHRON AGE	ESTIMATED DENTAL AGE								
	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	14	18	1	0	0	1	0	0	34
8 - 8.99	5	26	6	0	0	0	0	0	37
9 - 9.99	1	17	16	4	2	0	0	0	40
10 - 10.99	1	2	13	15	5	5	1	0	42
11 - 11.99	0	3	3	4	7	10	1	2	30
12 - 12.99	0	0	0	15	4	9	7	4	28
TOTAL	21	66	39	27	18	25	9	6	211

Table 4.4 Estimated dental age to chronological age - females

CHRON AGE	ESTIMATED DENTAL AGE								
	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	12	10	3	0	0	0	0	0	25
8 - 8.99	6	24	3	2	0	0	1	0	36
9 - 9.99	1	15	13	7	2	0	0	0	38
10 - 10.99	0	5	7	12	4	5	3	1	37
11 - 11.99	0	0	4	4	4	5	9	2	28
12 - 12.99	0	0	2	5	2	5	6	5	25
TOTAL	19	54	32	30	12	15	19	8	189

Table 4.5 Estimated dental age to chronological age - whole sample

CHRON AGE	ESTIMATED DENTAL AGE								
	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	26	28	4	0	0	1	0	0	59
8 - 8.99	11	50	9	2	0	0	1	0	73
9 - 9.99	2	32	29	11	4	0	0	0	78
10 - 10.99	1	7	20	27	9	10	4	1	79
11 - 11.99	0	3	7	8	11	15	10	4	58
12 - 12.99	0	0	2	9	6	14	13	9	53
TOTAL	40	120	71	57	30	40	28	14	400

4.4.4 Comparing mean differences between estimated dental age and chronological age in males

The mean estimated dental age and the mean chronological age in males were 9.98 and 9.84 years respectively. The difference between mean EDA and CA was found to be 0.15 years (S.D. = 1.1). This was a statistically significant difference ($p < 0.05$) (Table 4.6) although hovering on the border line. The mean differences between the ages in males varied in the different age groups from -0.30 years to 0.85 years (Table 4.7).

Table 4.6 Paired t-tests: EDA - CA (males)

Number of pairs	Mean differences	Standard Deviation	p value
211	0.15	1.1	0.049

Table 4.7 Mean differences between EDA and CA age groups (males)

Age group	Mean difference(yrs)	Standard deviation	Total number
7.00 -7.99	0.85	.95	34
8.00 - 8.99	0.02	.60	37
9.00 - 9.99	-0.30	0.75	40
10.00 - 10.99	0.03	1.16	42
11.00 - 11.99	0.20	1.43	30
12.00 - 12.99	0.14	1.20	28

4.4.5 Comparing mean differences between estimated dental age and chronological age in females

The mean estimated dental age and the chronological age in females were 10.12 and 9. 84 years respectively. The difference between mean EDA and CA was found to be 0.3 years (S.D. = 1.3). This was a statistically significant difference ($p < 0.05$) (Table 4.8). The mean differences between the ages in females varied in the different age groups from -0.08 years to 0.65 years (Table 4.9).

Table 4.8 Paired t-tests : EDA-CA (females)

Number of pairs	Mean differences	Standard Deviation	p value
189	0.3	1.3	.003

Table 4.9 Mean differences between EDA and CA in age groups (females)

Age group	Mean difference	Standard deviation	Total number
7.00 -7.99	0.63	0.65	25
8.00 - 8.99	0.18	1.00	36
9.00 - 9.99	-0.08	0.92	38
10.00 - 10.99	0.34	1.60	37
11.00 - 11.99	0.65	1.60	28
12.00 - 12.99	0.10	1.70	25

4.4.6 Comparing mean differences between estimated dental age and chronological age in the whole group.

The mean estimated dental age and the chronological age in the whole sample were 10.05 and 9.84 years respectively. The difference between mean EDA and CA was found to be 0.2 years (S.D. = 1.2). This was a statistically significant difference ($p < 0.05$) (Table 4.10). The mean differences between the ages varied in the different age groups from -0.2 years to 0.75 years (Table 4.11).

Table 4.10 Paired t-tests : EDA-CA (whole group)

Number of pairs	Mean differences	Standard Deviation	p value
400	0.2	1.2	.000

Table 4.11 Mean differences between EDA and CA in age groups (whole group)

Age group	Mean difference	Standard deviation	Total number
7.00 -7.99	0.75	0.84	59
8.00 - 8.99	0.10	0.80	73
9.00 - 9.99	-0.2	0.84	78
10.00 - 10.99	0.2	1.40	79
11.00 - 11.99	0.41	1.50	58
12.00 - 12.99	0.14	1.42	53

4.5 Estimated skeletal age

The skeletal ages of a subset consisting of 85 subjects (50 males and 35 females) were estimated by comparing their hand-wrist radiographs to standards given in the Radiographic Atlas of Skeletal Development of Hand and Wrist by Greulich and Pyle. The highest ESA in the subset was 14.00 years and the lowest 6.00 years.

The estimated skeletal ages were compared with the chronological ages in males, females and the whole group. The ages were cross-tabulated using Chi-squares tests and the mean ages compared using paired t-tests.

4.5.1 Comparison of estimated skeletal age and chronological age in males

When the estimated skeletal age (ESA) and chronological age (CA) in males were compared, the percentage of ESA's falling into the corresponding CA group was observed to be highest (27.3%) in the 12.00-12.99 year old group. There were no matches in the 8-8.99 and 11-11.99 age groups. Overall, 6 out of 50 i.e. 12% fell in the corresponding CA groups. (Figure 4.10, Table 4.12).

4.5.2 Comparison between estimated skeletal age (ESA) and chronological age (CA) in females

When the estimated skeletal age and chronological age in females were compared, it was observed that the percentage of ESAs falling into the corresponding CA was highest (100%) in the 11.00-11.99 year old group. There was no match in the 9-9.99 year old group. Overall, 14 out of 35 i.e. 40% fell in the corresponding CA groups (Figure 4.11, Table 4.13).

Figure 4.10 Comparison of ESA to CA in Males

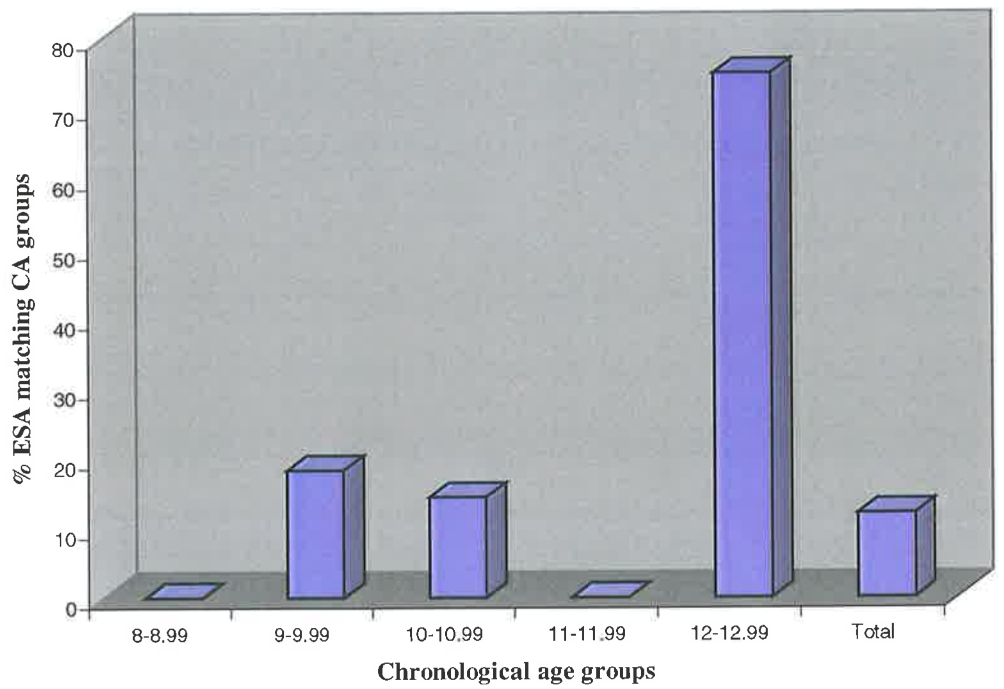
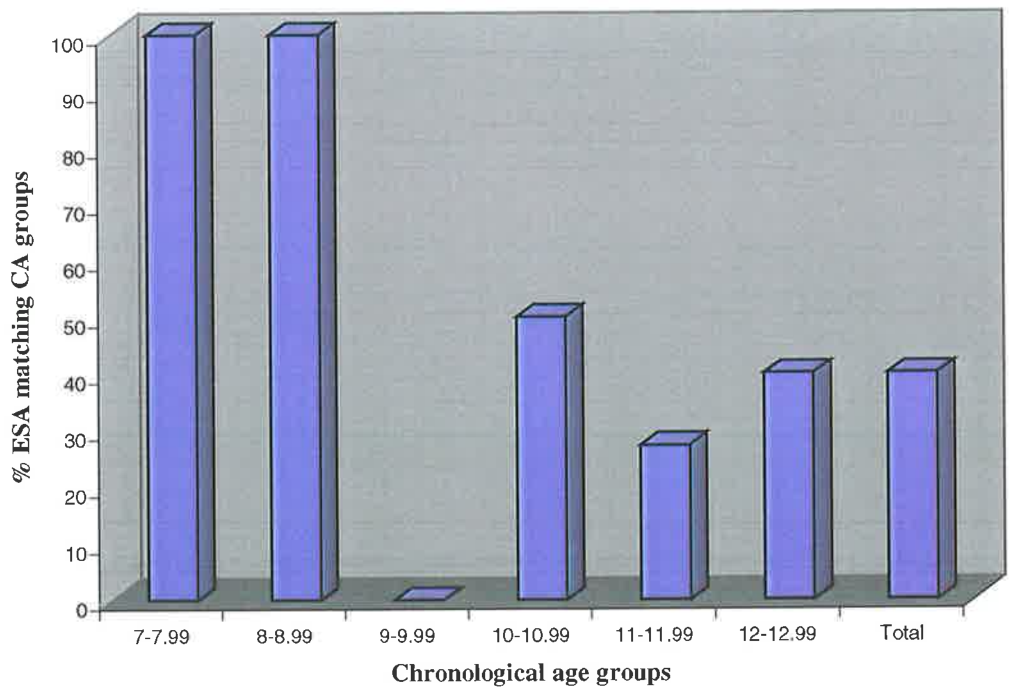


Figure 4.11 Comparison of ESA to CA in females



4.5.3 Comparison between estimated skeletal age and chronological age in the whole group

When the estimated skeletal age and chronological age in the whole sample were compared, it was observed that the percentage of ESAs falling into the corresponding CA was highest (100%) in the 7-7.99 year old group and lowest (11.1%) in the 9-9.99 year old group. Overall, 20 out of 85 subjects i.e. 23.5% fell in the corresponding CA groups (Figure 4.12, Table 4.14).

Figure 4.12 Comparison of ESA to CA in whole group

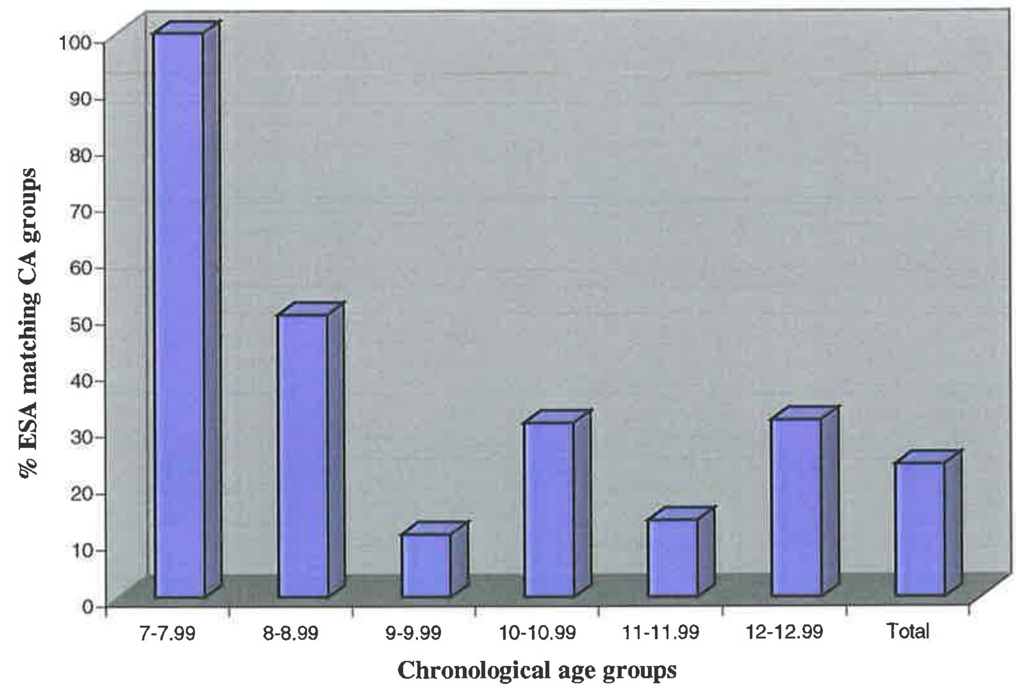


Table 4.12 Estimated skeletal age and chronological age - males

CHRON AGE	ESTIMATED SKELETAL AGE								
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	0	0	0	0	0	0	0	0	0
8 - 8.99	1	0	0	0	0	0	0	0	0	1
9 - 9.99	1	3	4	2	3	2	0	0	0	15
10 - 10.99	0	1	1	5	1	4	0	0	0	12
11 - 11.99	1	0	2	4	2	0	1	0	1	11
12 - 12.99	0	0	0	0	1	4	3	0	0	11
TOTAL	3	4	7	11	7	10	4	3	1	50

Table 4.13 Estimated skeletal age and chronological age - females

CHRON AGE	ESTIMATED SKELETAL AGE								
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	1	0	0	0	0	0	0	0	1
8 - 8.99	0	0	1	0	0	0	0	0	0	1
9 - 9.99	0	1	1	0	0	0	1	0	0	3
10 - 10.99	0	0	1	1	7	1	4	0	0	14
11 - 11.99	0	0	1	0	5	3	1	1	0	11
12 - 12.99	0	0	0	0	0	0	2	3	0	5
TOTAL	0	2	4	1	12	4	8	4	0	35

Table 4.14 Estimated skeletal age and chronological age - whole sample

CHRON AGE	ESTIMATED SKELETAL AGE								
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12 - 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	1	0	0	0	0	0	0	0	1
8 - 8.99	1	0	1	0	0	0	0	0	0	2
9 - 9.99	1	4	5	2	3	2	1	0	0	18
10 - 10.99	0	1	2	6	8	5	4	0	0	26
11 - 11.99	1	0	3	4	7	3	2	1	1	22
12 - 12.99	0	0	0	0	1	4	5	6	0	16
TOTAL	3	6	11	12	19	14	12	7	1	85

4.5.4 Comparing mean differences between estimated skeletal age and chronological age in males

The mean estimated skeletal age and chronological age in males were 9.87 and 10.78 years respectively. The mean difference between ESA and CA was found to be -0.9 years (S.D. = 1.5) (Table 4.15). This was a statistically significant difference ($p < 0.05$). The mean differences between the ages in males varied in different age groups from -2.08 years to -0.31 years (Table 4.16).

Table 4.15 Paired t-tests : ESA-CA (males)

Number of pairs	Mean differences	Standard Deviation	p value
50	-0.9	1.5	.000

Table 4.16 Mean differences between ESA and CA in age groups (males)

Age group	Mean difference	Standard deviation	Total number
8.00 - 8.99	-2.08	-	1
9.00 - 9.99	-0.81	1.80	15
10.00 - 10.99	-0.75	1.15	12
11.00 - 11.99	-1.70	1.90	11
12.00 - 12.99	-0.31	0.90	11

4.5.5 Comparing mean differences between estimated skeletal age and chronological age in females

The mean estimated skeletal age and chronological age in females were 10.73 and 10.81 years respectively. The mean difference between ESA and CA was found to be -0.08 years (S.D. = 1.2) (Table 4.17). This was not statistically significant (p= 0.724). The mean differences between the age in females varied in different age groups from -0.50 years to 0.15 years (Table 4.18).

Table 4.17 Paired t-tests : ESA-CA (females)

Number of pairs	Mean differences	Standard Deviation	p value
35	-0.08	1.2	.724

Table 4.18 Mean differences between ESA and CA in age groups (females)

Age group	Mean difference	Standard deviation	Total number
7.00 – 7.99	-0.41	-	17
8.00 - 8.99	-0.31	-	1
9.00 - 9.99	0.13	2.80	3
10.00 - 10.99	0.15	1.24	14
11.00 - 11.99	-0.50	1.23	11
12.00 - 12.99	-0.20	0.41	5

4.5.6 Comparing mean differences between estimated skeletal age and chronological age in the whole group

The mean estimated skeletal age and chronological age in the whole sample were 10.22 and 10.79 years respectively. The mean difference between ESA and CA was found to be -0.57 years (S.D. = 1.4) (Table 4.19). This was a statistically significant difference ($p < 0.05$). The mean differences between the age in the whole group varied in different age groups from -1.20 years to 0.15 years (Table 4.20).

Table 4.19 Paired t-tests : ESA-CA (whole group)

Number of pairs	Mean differences	Standard Deviation	p value
85	-0.57	1.4	.001

Table 4.20 Mean differences between ESA and CA in age groups (whole group)

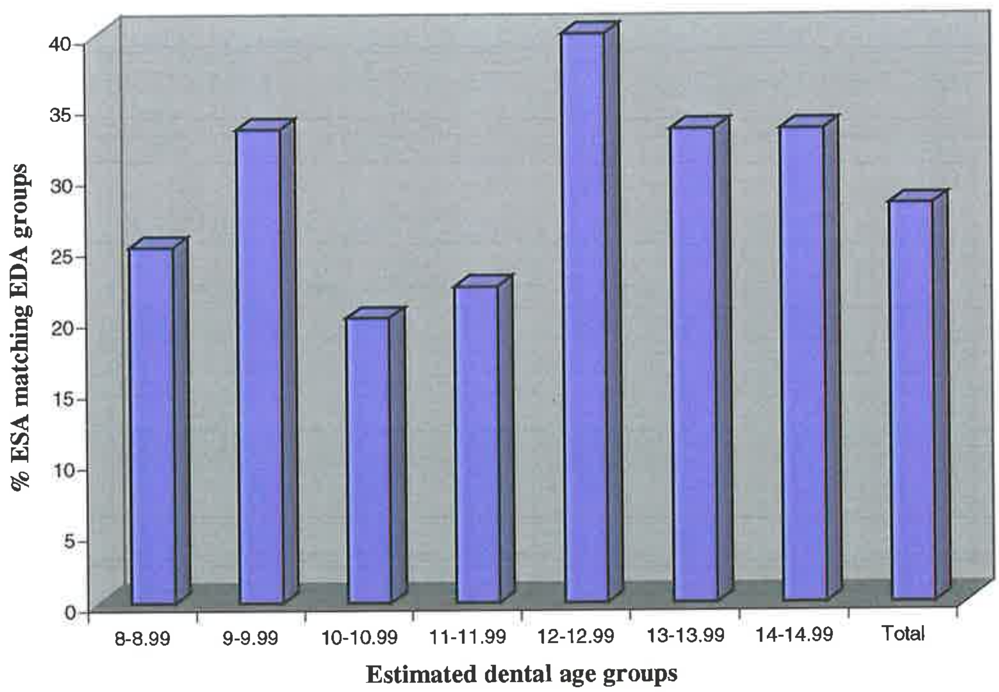
Age group	Mean difference	Standard deviation	Total number
7.00 – 8.99	-0.14	-	1
8.00 - 8.99	-1.20	1.25	2
9.00 - 9.99	-0.65	1.90	18
10.00 - 10.99	-0.30	1.30	26
11.00 - 11.99	-1.10	1.70	22
12.00 - 12.99	-0.15	0.80	16

The estimated skeletal ages were compared with estimated dental ages in males, females and the whole group. The ages were cross tabulated and the mean ages differences compared using paired t-tests.

4.6.1 Comparison between estimated skeletal age and estimated dental age in males

When the estimated skeletal age and estimated dental age in males were compared, it was observed that the 14 out of 50 i.e. 28% percentage of ESAs in males fell into the corresponding EDA group. The highest percentage of matches (40%) was seen in the 12.00-12.99 year ESA groups and lowest (20%) in the 10-10.99 year old ESA group (Figure 4.13, Table 4.21).

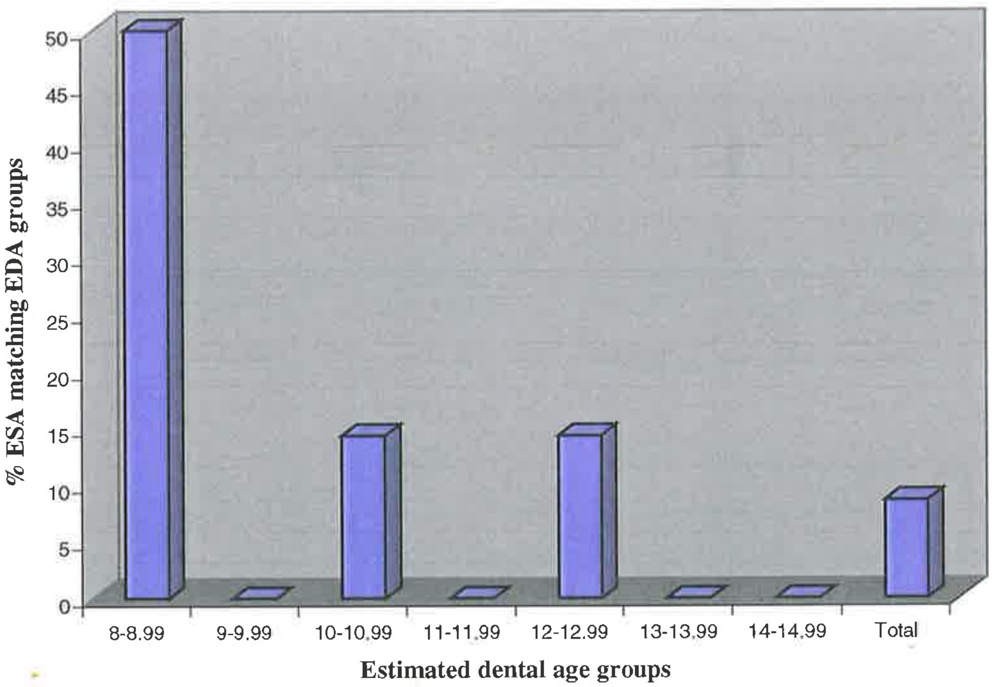
Figure 4.13 Comparison of ESA and EDA in males



4.6.2 Comparison between estimated skeletal age and estimated dental age in females

When the estimated skeletal age and estimated dental age in females were compared, it was observed that only 5 out of 35 i.e. 14.3% matched with the corresponding EDA group. The highest percentage of matches 50% were found in the 8.00 -8.99 year old ESA groups and no matches in the 9,11, 13 and 14 year old ESA groups (Figure 4.14, Table 4.22).

Figure 4.14 Comparison of ESA and EDA in females



4.6.3 Comparison between estimated skeletal age and estimated dental age in the whole subset

When the estimated skeletal age and estimated dental age in the whole skeletal age subset were compared, it was observed that only 17 out 85 subjects, i.e. 20%, had matching estimated EDAs. The highest percentage of matches (30%) were found in the 8.00- 8.99 year old ESA group and lowest (11.1%) in the 13-13.99 year old group (Figure 4.18, Table 4.23).

Figure 4.15 Comparison of ESA and EDA in whole subset

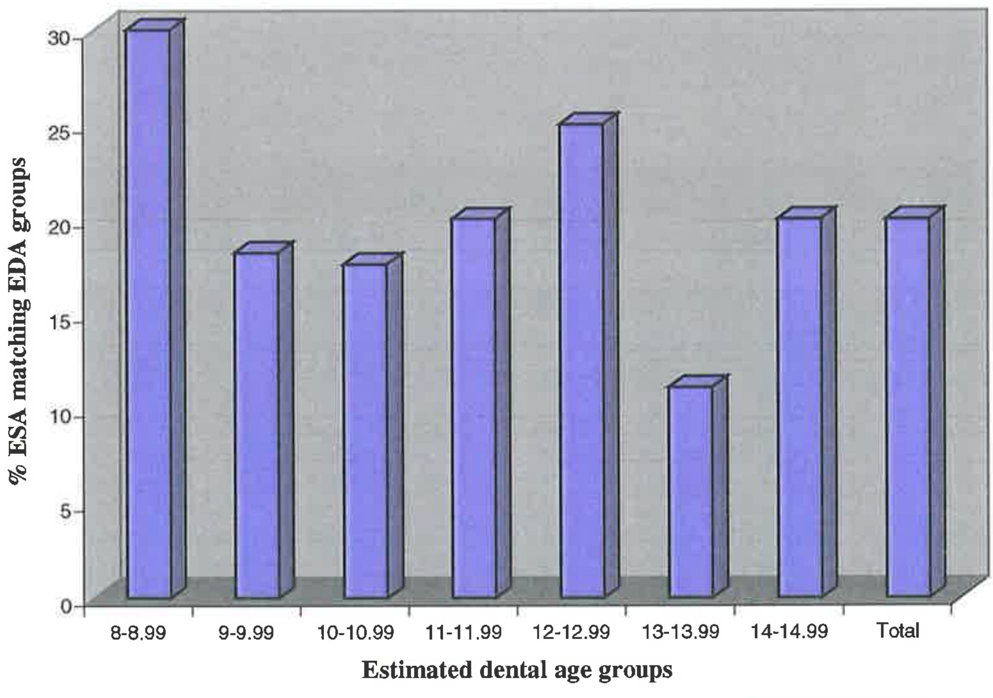


Table 4.21 Estimated skeletal age and estimated dental age- males

DENTAL AGE	ESTIMATED SKELETAL AGE									
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12- 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	0	0	0	0	0	0	0	0	0
8 - 8.99	1	1	2	2	2	0	0	0	0	8
9 - 9.99	0	1	3	4	2	2	0	0	0	12
10 - 10.99	1	0	1	3	2	3	0	0	0	10
11 - 11.99	1	1	1	2	1	2	1	0	0	9
12 - 12.99	0	1	0	0	0	1	2	1	0	5
13 - 13.99	0	0	0	0	0	1	1	1	0	3
14 - 14.99	0	0	0	0	0	1	0	1	1	3
TOTAL	3	4	7	11	7	10	4	3	1	50

Table 4.22 Estimated skeletal age and estimated dental age- females

DENTAL AGE	ESTIMATED SKELETAL AGE									
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12- 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	0	0	0	0	0	0	0	0	0
8 - 8.99	0	0	1	0	0	0	1	0	0	2
9 - 9.99	0	1	1	0	4	1	3	0	0	10
10 - 10.99	0	1	1	1	1	1	1	1	0	7
11 - 11.99	0	0	0	0	1	0	0	0	0	1
12 - 12.99	0	0	1	0	4	0	1	1	0	7
13 - 13.99	0	0	0	0	2	2	2	0	0	6
14 - 14.99	0	0	0	0	0	0	0	2	0	2
TOTAL	0	2	4	1	12	4	8	4	0	35

Table 4.23 Estimated skeletal age and estimated dental age- whole group

DENTAL AGE	ESTIMATED SKELETAL AGE									
	6 - 6.99	7 - 7.99	8 - 8.99	9 - 9.99	10 - 10.99	11- 11.99	12- 12.99	13 - 13.99	14 - 14.99	TOTAL
7 -7.99	0	0	0	0	0	0	0	0	0	0
8 - 8.99	1	1	3	2	2	0	1	0	0	10
9 - 9.99	0	2	4	4	6	3	3	0	0	22
10 - 10.99	1	1	2	4	3	4	1	1	0	17
11 - 11.99	1	1	1	2	2	2	1	0	0	10
12 - 12.99	0	1	1	0	4	1	3	2	0	12
13 - 13.99	0	0	0	0	2	3	3	1	0	9
14 - 14.99	0	0	0	0	0	1	0	3	1	5
TOTAL	3	6	11	12	19	14	12	7	1	85

4.6.4 Mean differences between estimated skeletal age and estimated dental age in males

The means of estimated skeletal age and estimated dental age in males were 9.87 years and 10.69 years respectively. The mean differences between ESA and EDA was found to be -0.81 (S.D.= 1.6) (Table 4.24). This was a statistically significant difference ($p< 0.05$).

Table 4.24 Paired t-tests : ESA-EDA (males)

Number of pairs	Mean differences	Standard Deviation	p value
50	-0.81	1.6	.001

4.6.5 Mean differences between estimated skeletal age and estimated dental age in females

The means of estimated skeletal age and estimated dental age in females were 10.73 years and 11.29 years respectively. The mean differences between ESA and EDA was found to be 0.56 years (S.D.= 2.0) (Table 4.25). This was not statistically significant ($p=0.107$).

Table 4.25 Paired t-tests : ESA-EDA (females)

Number of pairs	Mean differences	Standard Deviation	p value
35	-.56	2.0	.107

4.6.6 Mean differences between estimated skeletal age and estimated dental age in the whole subset

The means of estimated skeletal age and estimated dental age in the whole group were 10.22 years and 10.93 years respectively. The mean differences between ESA and EDA was found to be -0.7 years (S.D.= 1.8) (Table 4.26). This was a statistically significant difference ($p < 0.05$).

Table 4.26 Paired t-tests : ESA-EDA (whole sample)

Number of pairs	Mean differences	Standard Deviation	p value
85	-0.7	1.8	.000

4.6 Range of differences between estimated dental age and chronological age

The range of differences between the estimated dental ages and chronological ages in males, females and the whole group was analysed. The percentage of subjects whose estimated dental age varied only up to ± 0.5 years from their chronological ages were also calculated.

4.7.1 Range of differences between estimated dental age and chronological age in males

When the range of differences between estimated dental ages and chronological ages in males alone were analysed, it was found that 117 (55.4 %) out of 211 males had overestimated dental ages while 92 males (43.6%) had underestimated dental ages. Only 2 males had no differences between estimated dental age and their chronological ages, but when the exact matches were extended to include differences less than 0.07 years (less than a month), then the number of matches rose to 11 males (5.2%). When analysing the number of males whose estimated dental ages differed only up to ± 0.5 years (6 months) from their chronological age, it was observed that 89 (42.2%) of the 211 males fell within this range while 122 (57.8%) fell outside this range (Figure 4.16).

4.7.2 Range of differences between estimated dental age and chronological age in females

When the range of differences between estimated dental ages and chronological ages in females alone were analysed, it was found that 100 (52.9%) out of the 189 females had overestimated dental ages while 87 (46%) had underestimated dental ages. Only 2 females had no differences between estimated dental age and their chronological age, but when the exact matches were extended to include differences less than 0.07 years (less than a month), then the number of matches rose to 10 (5.3%) females. When analysing the number of females whose estimated dental ages differed only up to ± 0.5 years (6 months) from their chronological age, it was observed that only 78 (41.3%) of 189 females fell within this range while 122 (64.6%) fell outside this range (Figure 4.17).

4.7.3 Range of differences between estimated dental age and chronological age in the whole group

When the range of differences between estimated dental age and chronological age of the whole group was analysed, it was observed that the dental ages in 217 subjects (54.3%) were overestimated, ranging from 0.02 years to 5.50 years while 179 (44.7%) had their ages underestimated ranging from -0.03 to-3.58 years. Only 4 subjects (1%) had matching dental and chronological ages in the whole group, but when the exact matches were extended to include differences less than 0.07 years (less than a month), then the number of matches rose to 21 (5.3%).

When analysing the number of subjects whose estimated dental ages differed within a range of ± 0.5 years (6 months) from their chronological age in the whole group, it was observed that only 167 (41.8%) of the subjects, fell within this range. The remaining 233 (58.2%) differed by more than ± 0.5 years from their chronological ages (Figure 4.18).

Figure 4.16 Difference estimations between EDA and CA in males

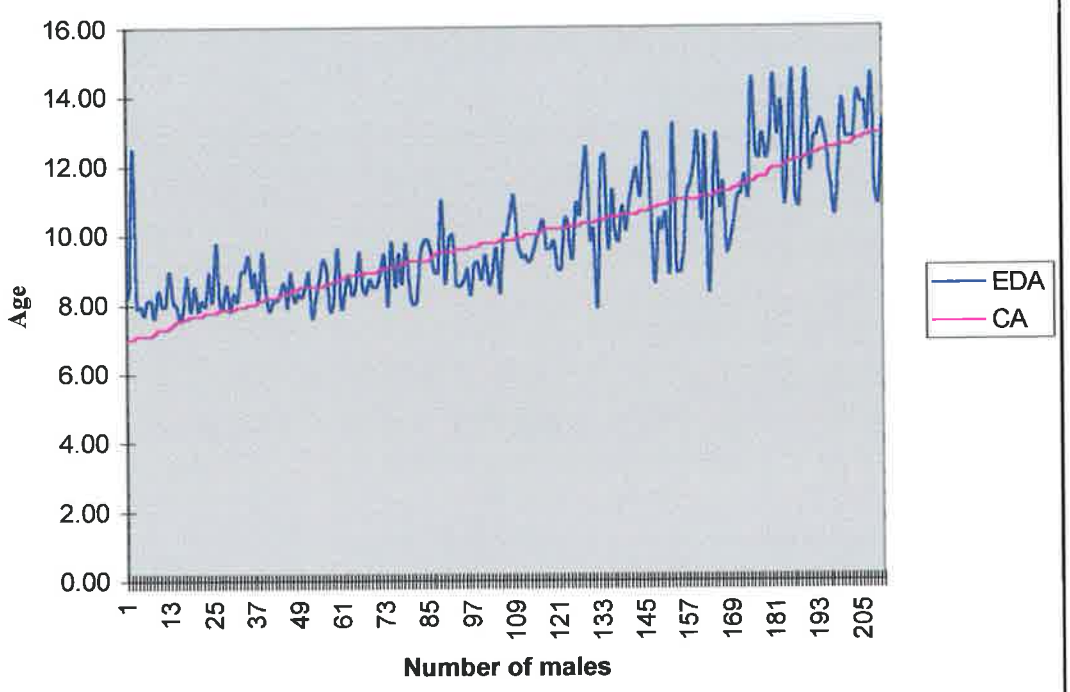


Figure 4.17 Difference estimations between EDA and CA in females

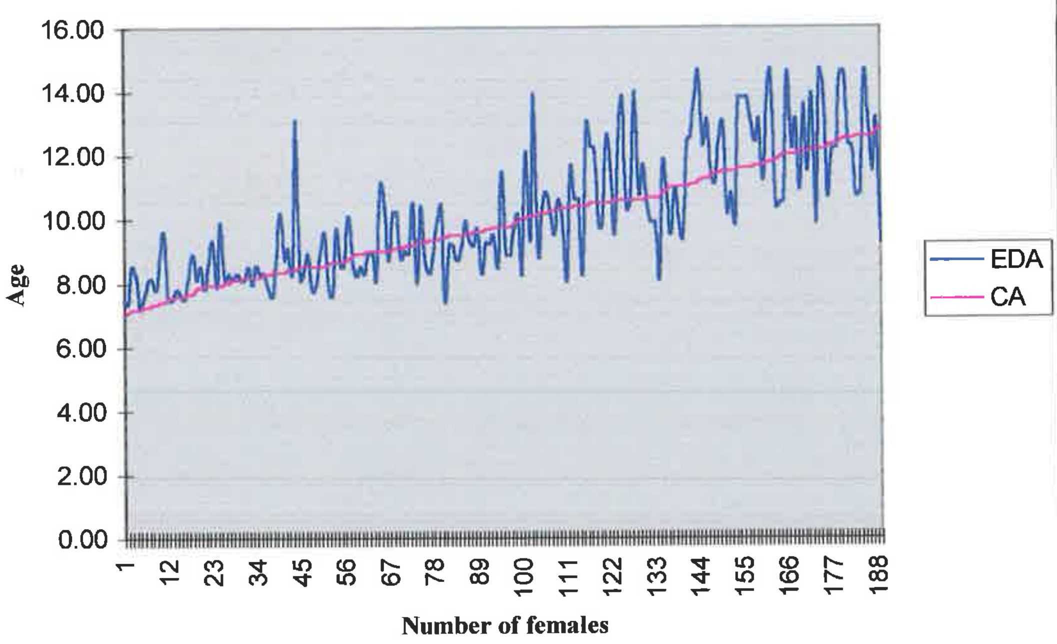
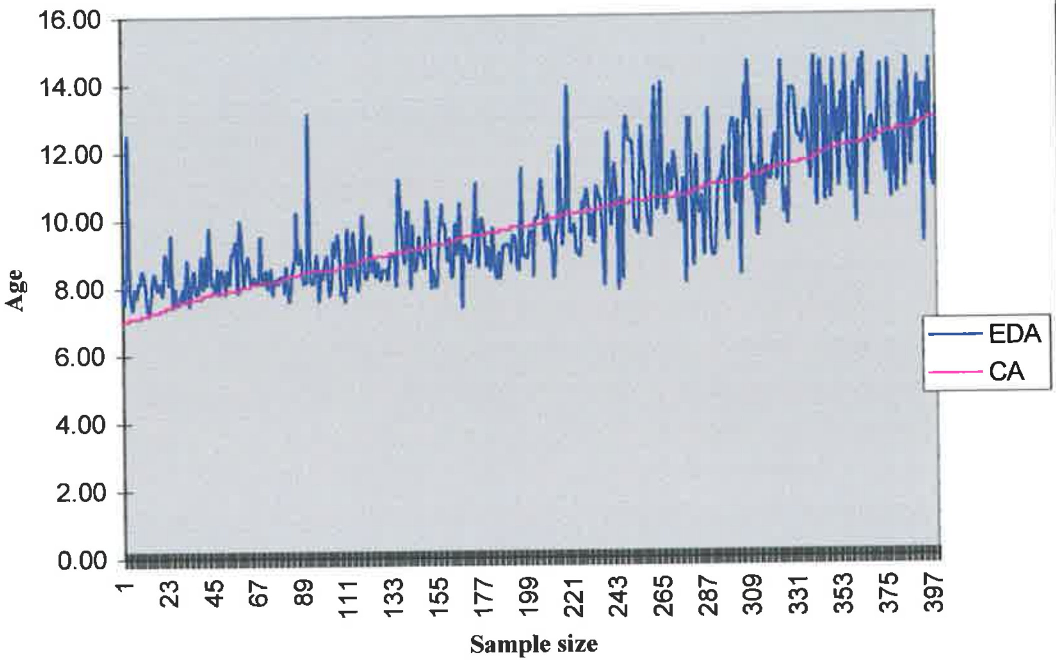


Figure 4.18 Difference estimations between EDA and CA in the whole group



4.7.4 Range of differences between estimated dental age and chronological age in each age group

The differences between estimated dental age and chronological age in each age group were plotted against each other. These graphs illustrated the range of differences including extremes between the ages in each age group.

When the percentage of sample in each age group with only ± 0.5 years difference between chronological age and dental ages were calculated, it was observed that 47.5% of the sample in 7-year-olds, 65% of 8-year-olds, 42.3% of 9-year-olds, 35.4% of 10-year-olds, 22.4% of 11-year-olds and 32% of 12-year-olds fell within that range of differences (Figures 4.19-4.24).

Figure 4.19 Difference estimations between EDA and CA in 7 year old children

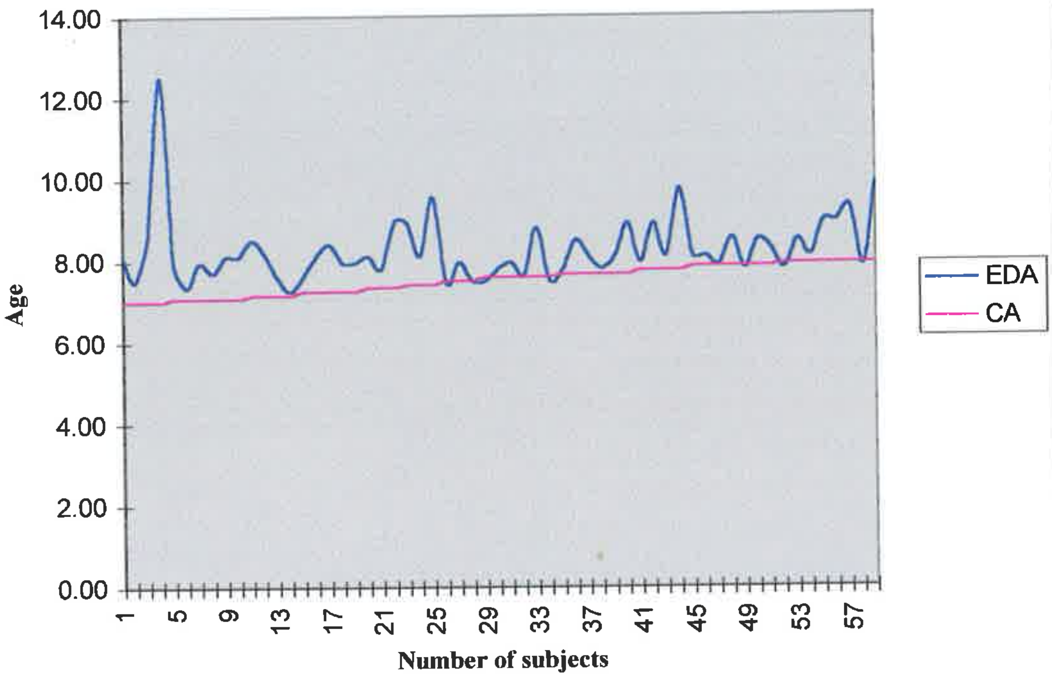


Figure 4.20 Difference estimations between EDA and CA in 8 year old children

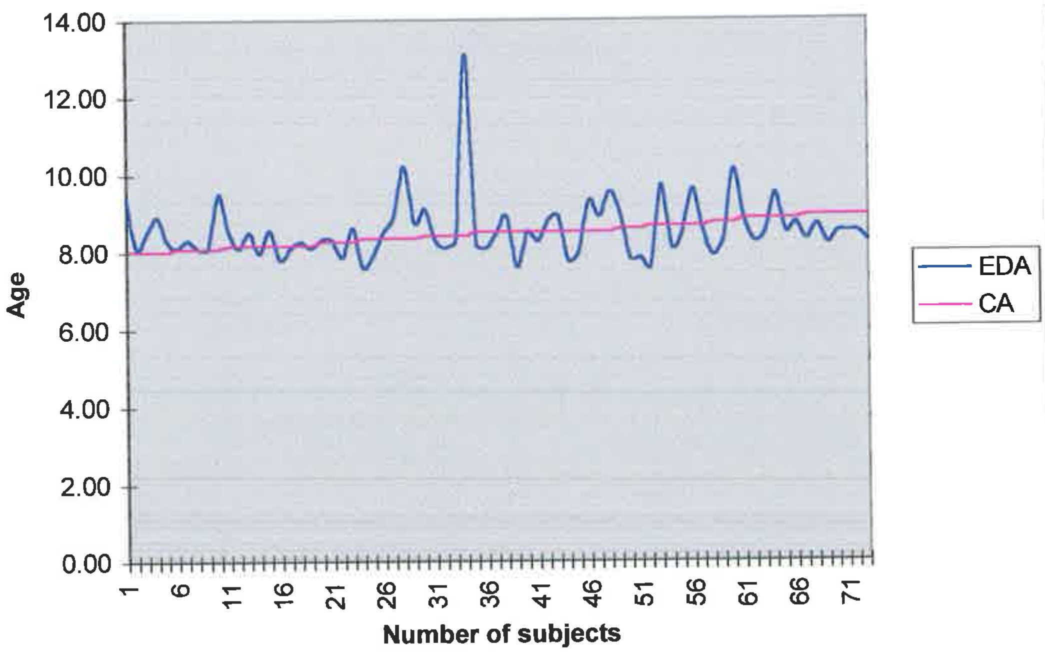


Figure 4.21 Difference estimations between EDA and CA in 9 year old children

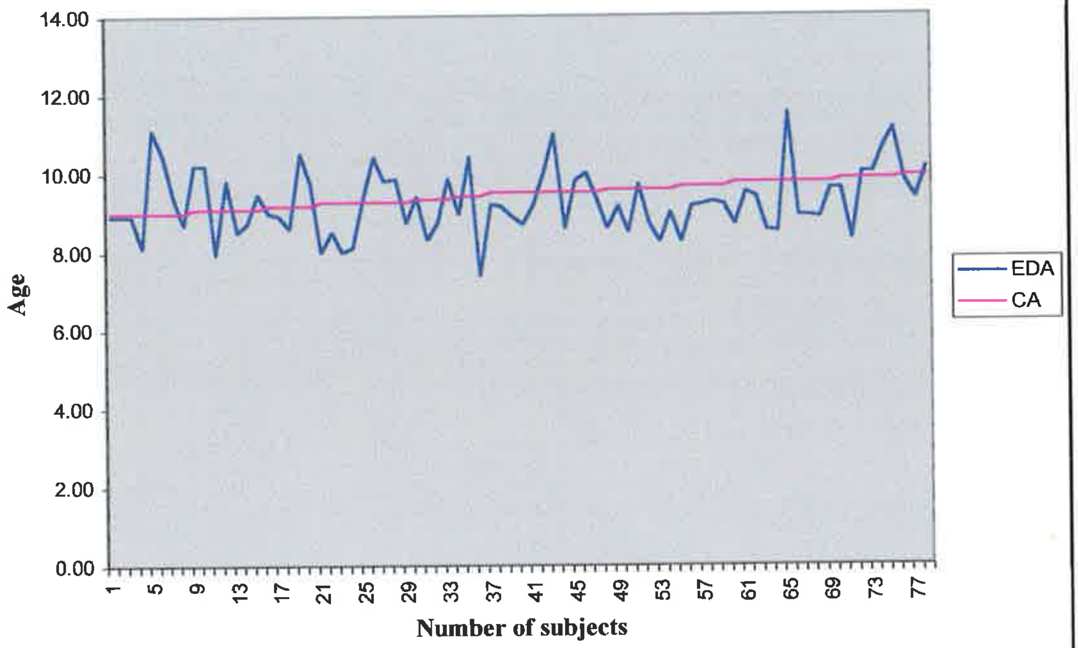


Figure 4.22 Difference estimations between EDA and CA in 10 year old children

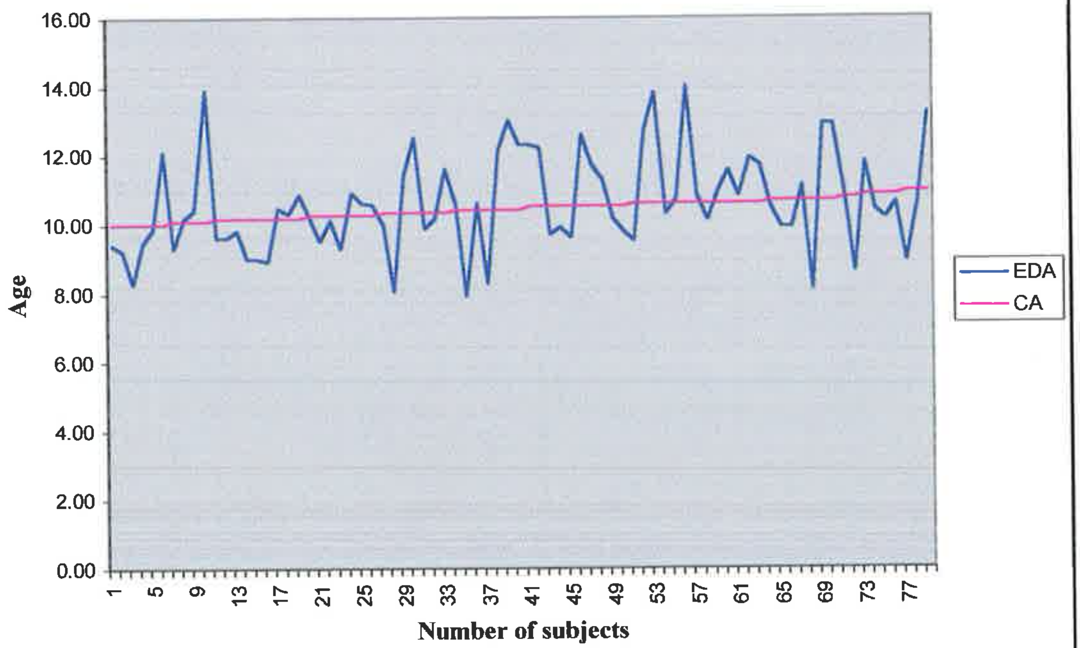


Figure 4.23 Difference estimations between EDA and CA in 11 year old children

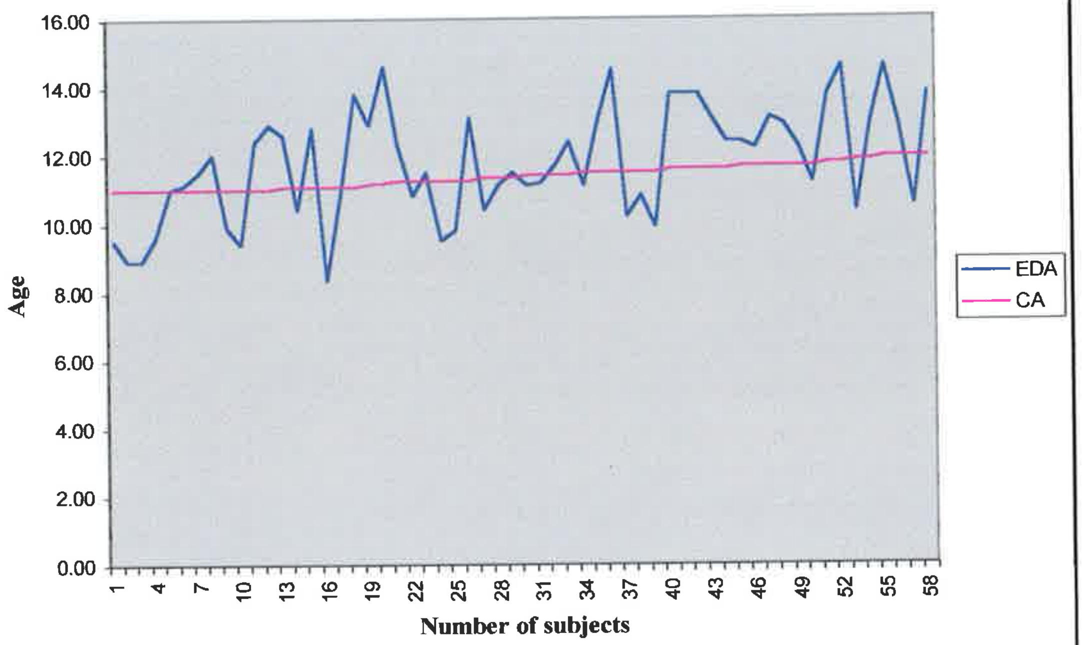
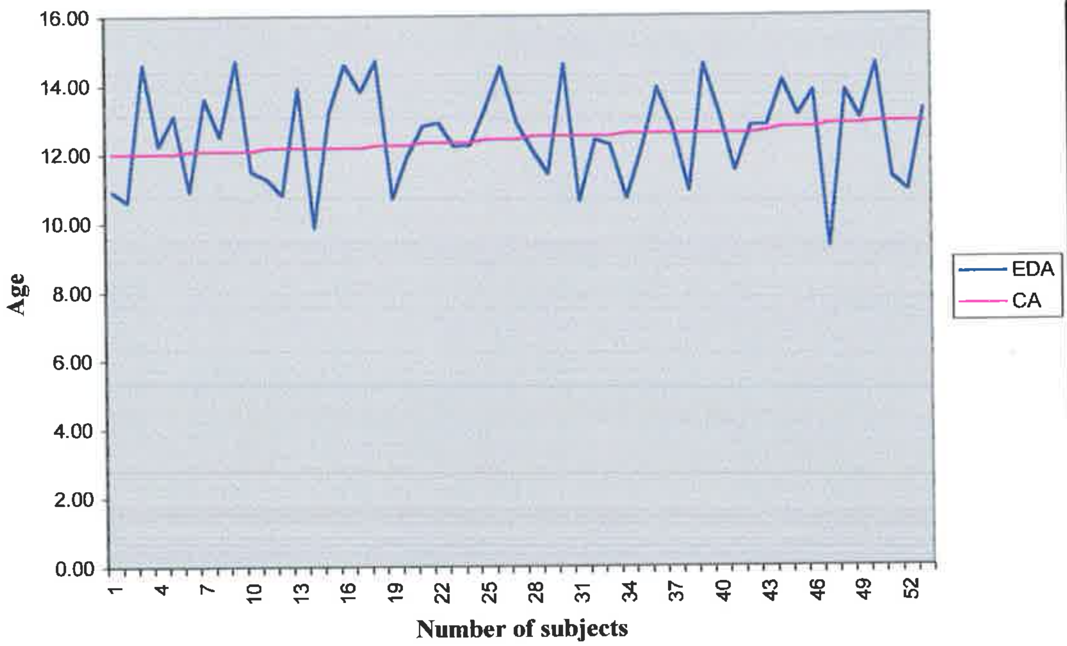


Figure 4.24 Differences between EDA and CA in 12 year old children



4.8.1 Range of differences between estimated skeletal age and chronological age in males

When the range of differences between estimated skeletal age and chronological age in males was analysed, it was observed that the skeletal ages for 17 (34%) males were overestimated while 33 (66%) males had their ages underestimated. None of the males had matching skeletal and chronological ages in the whole group but when the exact matches were extended to include differences less than 0.07 years (less than a month) one male had a matching age. When analysing the number of males, whose estimated skeletal ages differed only up to ± 0.5 years (6 months) from their chronological age, it was observed that only 9 males (18%) fell within this range. The remaining 41 (82%) differed more than ± 0.5 years from their chronological ages (Figure 4.25).

4.8.2 Range of differences between estimated skeletal age and chronological age in females

When the range of differences between estimated skeletal age and chronological age in females was analysed, it was observed that the skeletal ages in 15 subjects (42.8%) were overestimated while 19 (54.3%) had their ages underestimated. Only 1 female (2.9 %) had matching skeletal and chronological ages in the whole group but when the exact matches were extended to include differences less than 0.07 years (less than a month), then the number of matches rose to 3 (8.6 %). When analysing the number of females whose estimated skeletal ages differed only up to ± 0.5 years (6 months) from their chronological age it was observed that only 13 (37.1 %) of the females fell within this range. The remaining 22 (62.9%) differed more than ± 0.5 years from their chronological ages (Figure 4.26).

Figure 4.25 Difference estimations between ESA and CA in males

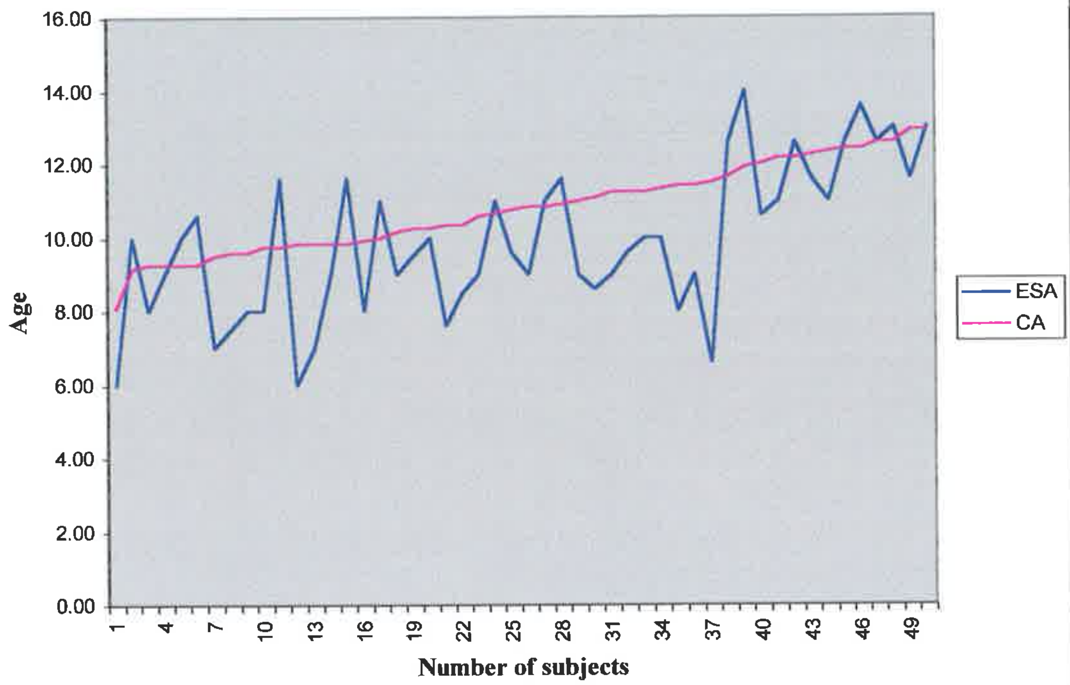


Figure 4.26 Difference estimations between ESA and CA in females

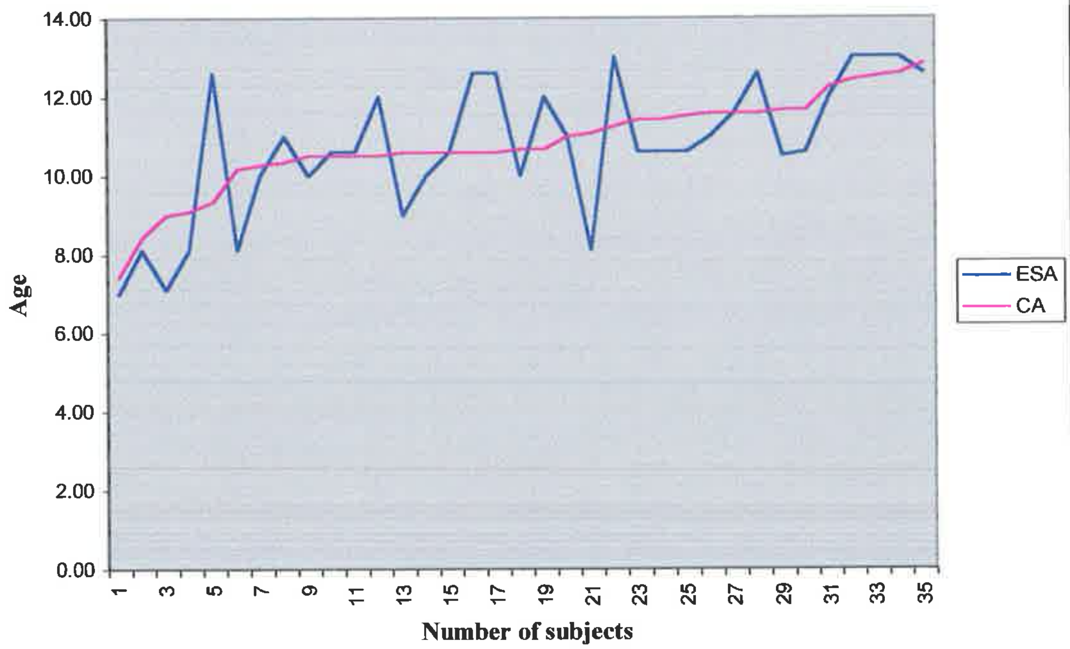
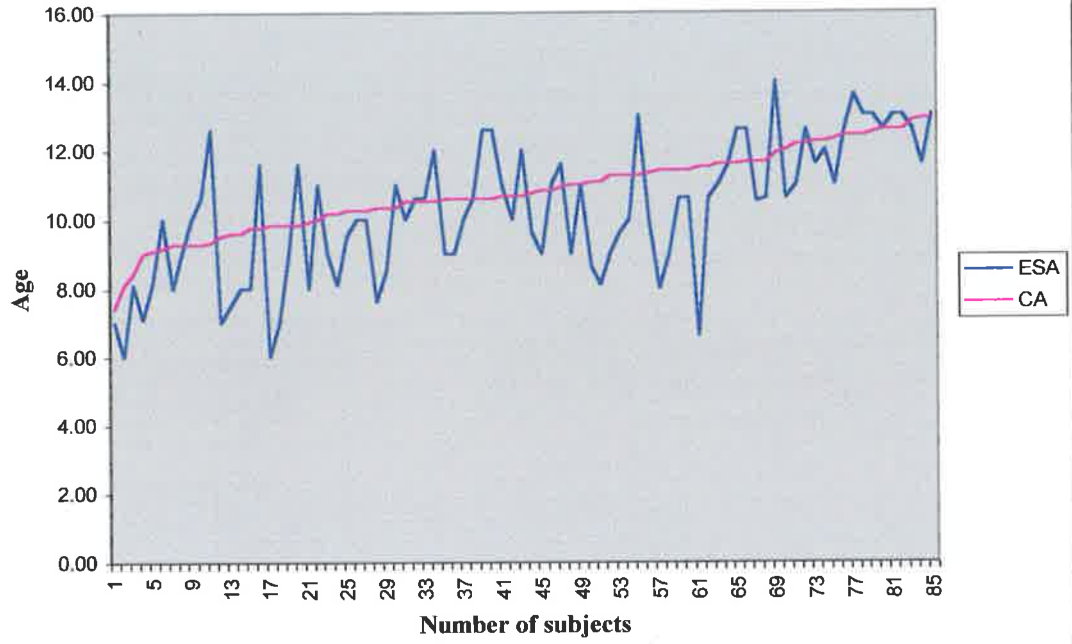


Figure 4.27 Difference estimations between ESA and CA in the whole group



4.8.3 Range of differences between estimated skeletal age and chronological age in the whole group

When the range of differences between estimated skeletal age and chronological age in the whole group was analysed, it was observed that the skeletal ages in 32 subjects (37.6%) were overestimated, ranging from 0.02 years to 3.27 years while 52 (61.2 %) had their ages underestimated ranging from -0.23 years to -4.90 years. Only 1 subject (1.2 %) had matching skeletal and chronological ages in the whole group but when the exact matches were extended to include differences less than 0.07 years (less than a month), then the number of matches rose to 4 (4.7%). When analysing the number of subjects whose estimated skeletal ages differed only up to ± 0.5 years (6 months) from their chronological age in the whole group, it was observed that only 22 subjects (25.9 %) fell within this range. The remaining 63 (74.1%) differed more than ± 0.5 years from their chronological ages (Figure 4.27).

4.9 Relationship between ages

The associations between the ages were analysed and degree of correlation was obtained by calculating the correlation coefficient using the Pearson's correlation method. The correlation coefficient provides an estimate of the strength of the association between the ages. The correlation of ages in males, females and the whole group were displayed as scatter diagrams.

4.9.1 Relation between chronological age and estimated dental age

When the CA and EDA were compared in males, females and in the whole group a positive correlation was seen between the ages with correlation coefficients of 0.814, 0.767 and 0.790 respectively (Figures 4.28, 4.29 and 4.30)

4.9.2 Relation between chronological age and estimated skeletal age

When CA and ESA were compared in males, females and the whole group, a positive correlation was observed with correlation coefficients of 0.648, 0.689 and 0.648 respectively (Figures 4.31, 4.32 and 4.33)

4.9.3 Relation between estimated skeletal age and estimated dental age

When ESA and EDA were compared in males, females and the whole group, a moderately high correlation was seen between males with a correlation coefficient of 0.626. In females a low correlation was seen with a coefficient of 0.368. In the whole subset, a slightly higher correlation with a coefficient of 0.544 was observed. (Figures 4.34, 4.35 and 4.36)

Figure 4. 28 Correlation between chronological age and estimated dental age in males

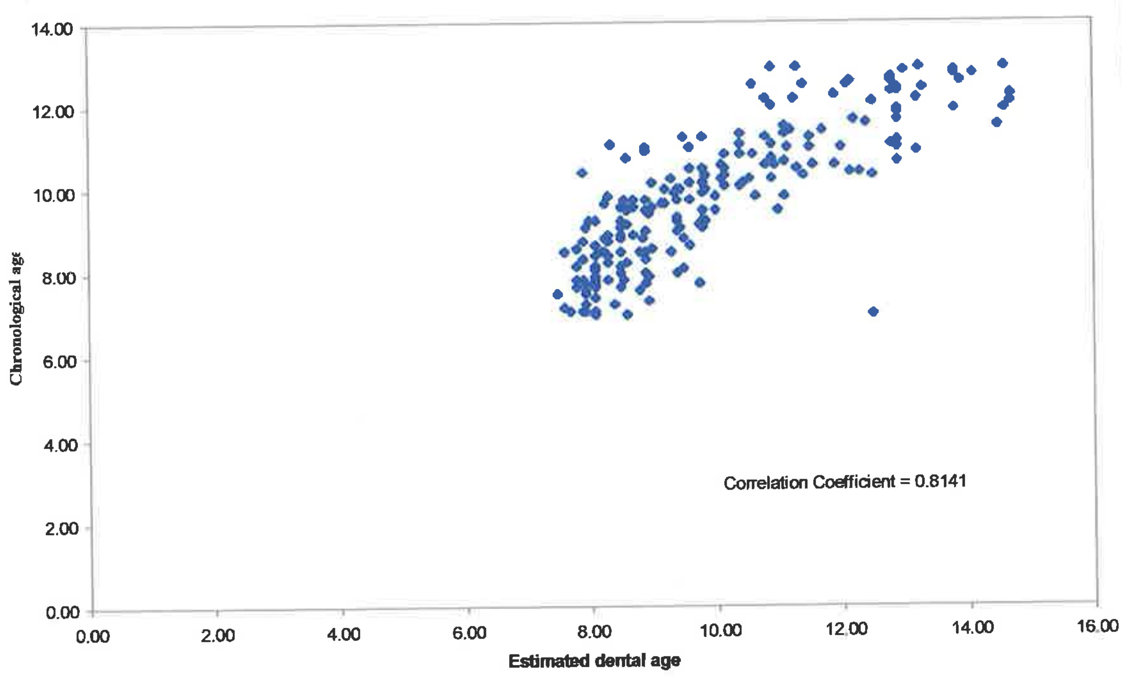


Figure 4.29 Correlation between chronological age and estimated dental age in females

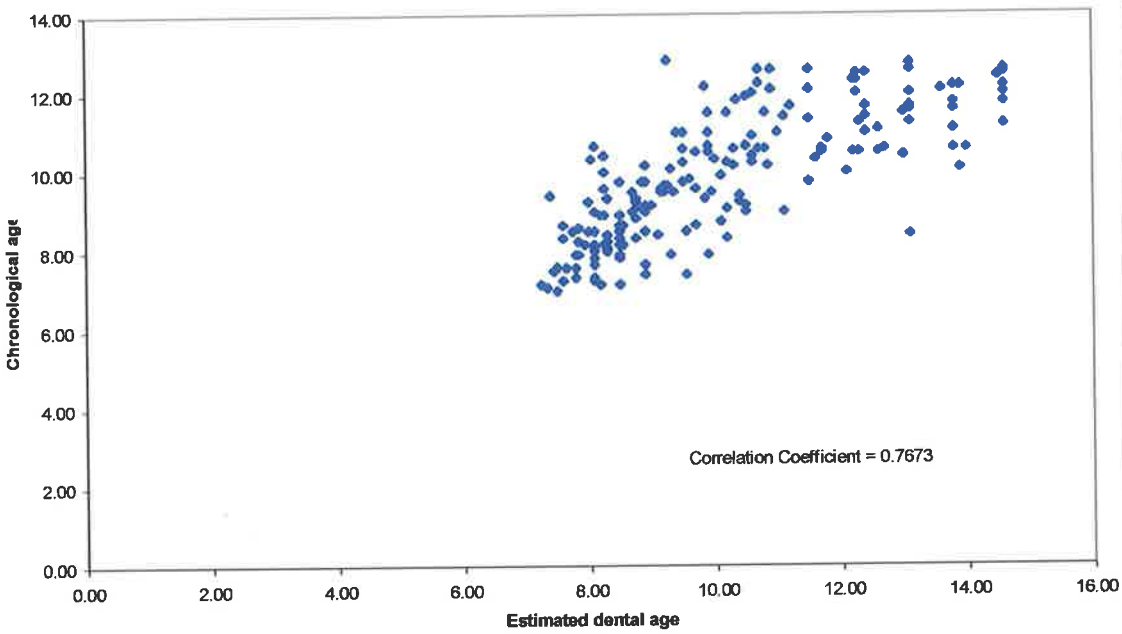


Figure 4.30 Correlation between chronological age and estimated dental age in the whole group

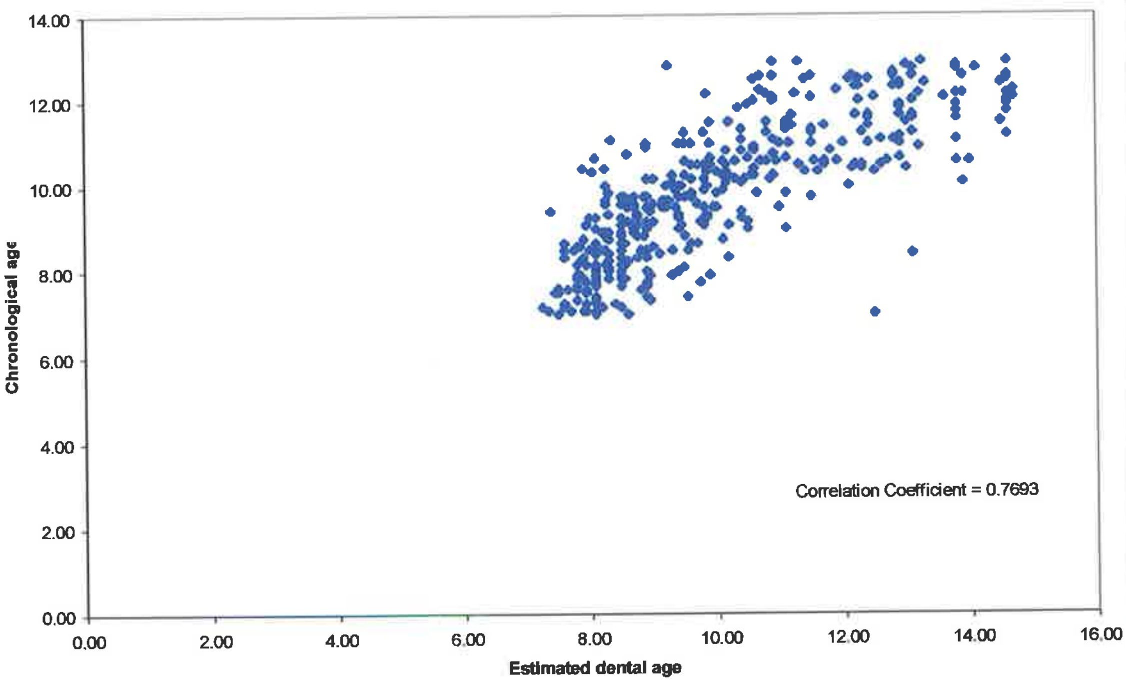


Figure 4.31 Correlation between chronological age and estimated skeletal age in males

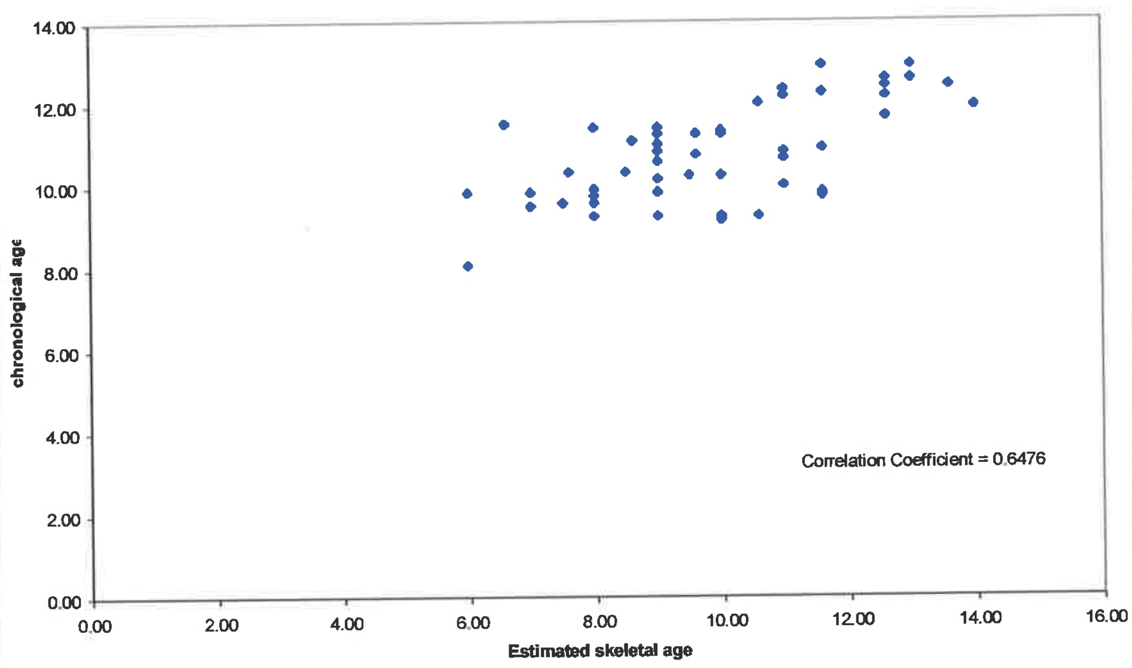


Figure 4.32 Correlation between chronological age and estimated skeletal age in females

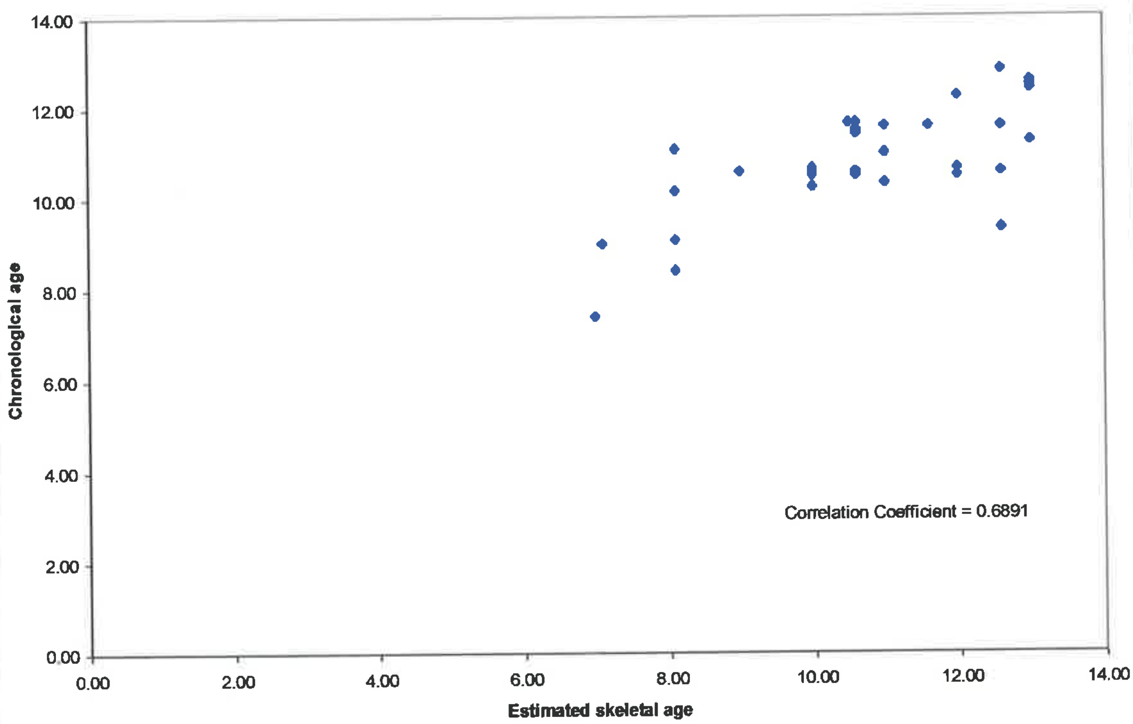


Figure 4.33 Correlation between chronological age and estimated skeletal age in the whole group

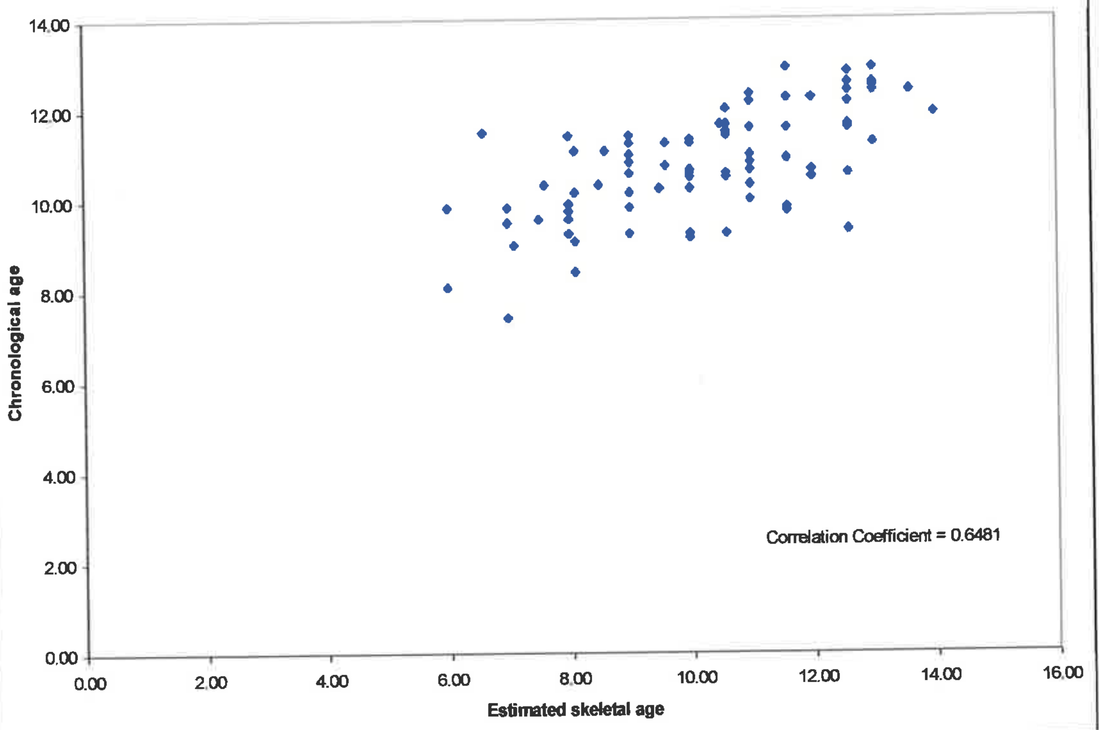


Figure 4.34 Correlation between estimated skeletal age and estimated dental age in males

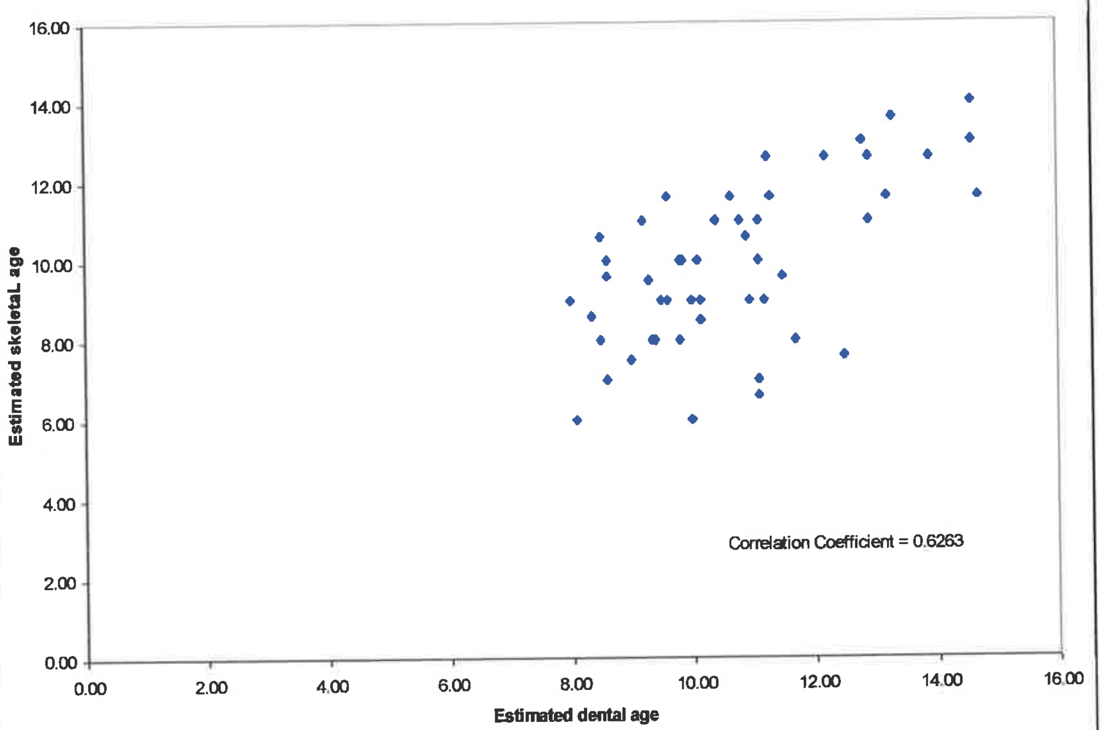


Figure 4.35 Correlation between estimated skeletal age and estimated dental age in females

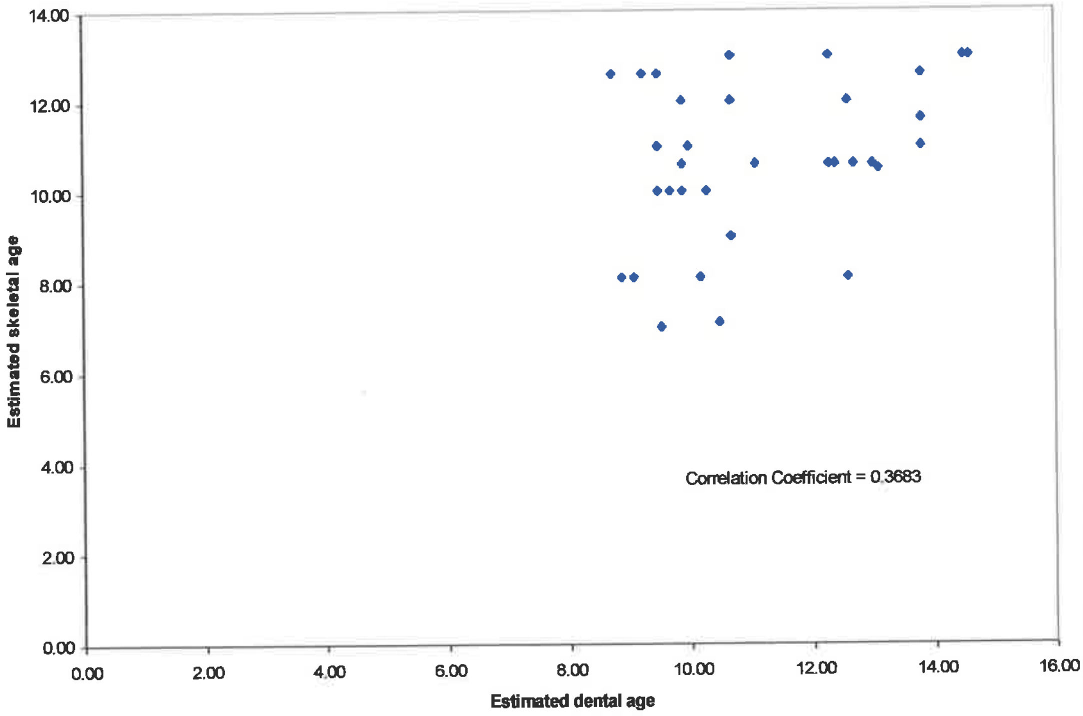
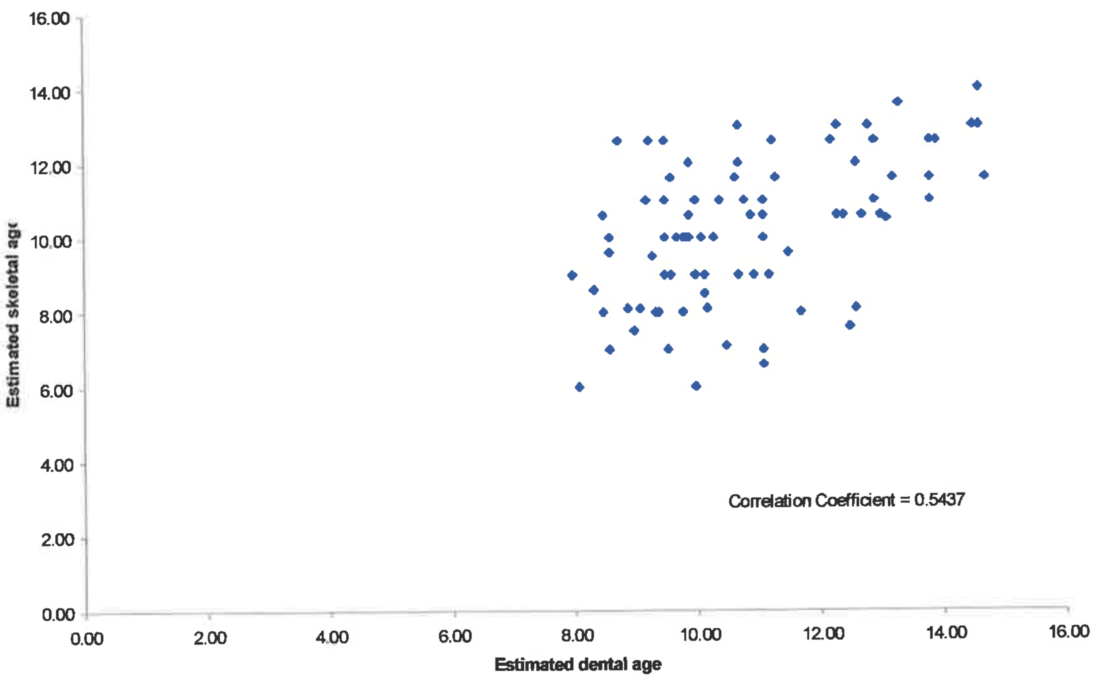


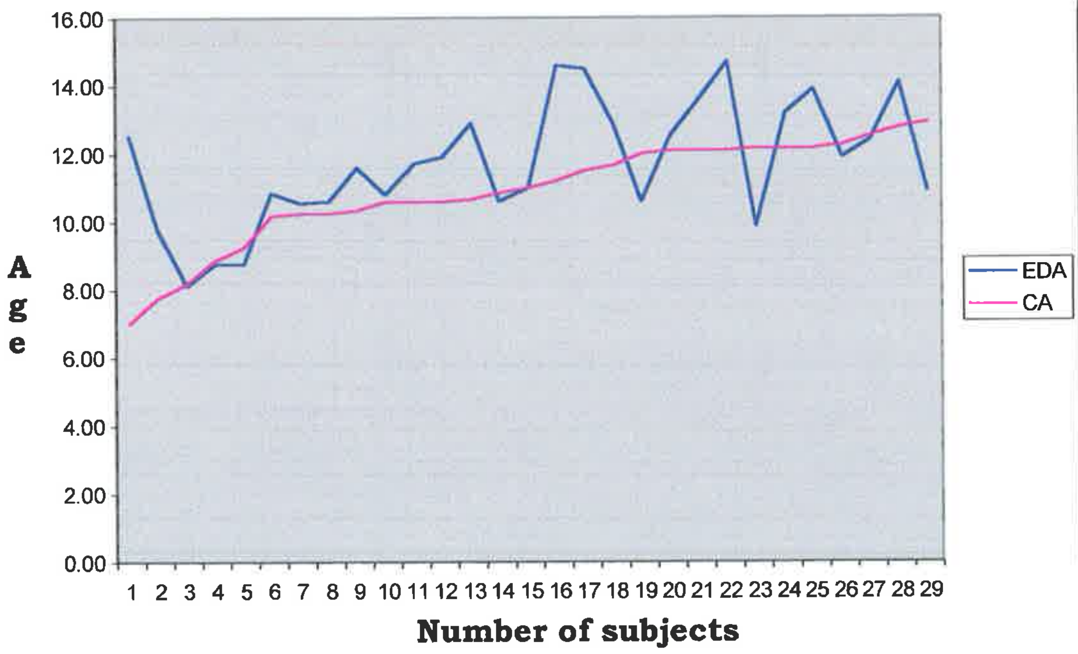
Figure 4.36 Correlation between estimated skeletal age and estimated dental age in the whole group



4.10 Comparison of estimated dental age and chronological age in medically compromised children

The estimated dental ages obtained from the 29 children comprising the medically compromised group were separated from the whole group and analysed. When the rate of overestimation and differences between the ages were calculated, it was observed that 59% of the group had overestimated dental ages. When the differences from chronological ages were calculated, it was seen that 38% of the sample fell within ± 0.5 year difference. When analysed separately, 33% of males and 42.8% females fell within the ± 0.5 year difference (Figure 4.37).

Figure 4.37 Difference between EDA and CA in medically compromised children



4.11 Analysis of cases with extreme differences of age

When the range of differences in dental and skeletal ages was observed, a few cases exhibited extreme differences from their chronological ages. Differences over ± 3.0 years were considered as extremes.

4.11.1 Extremes of dental age

In the whole group, eight subjects (2 males and 6 females) demonstrated extreme differences between chronological age and estimated dental age. The greatest difference demonstrated was an overestimation of 5.5 years (Figure 4.38). This subject belonged to the medically compromised group.

Figure 4.38 Extreme differences between EDA and CA

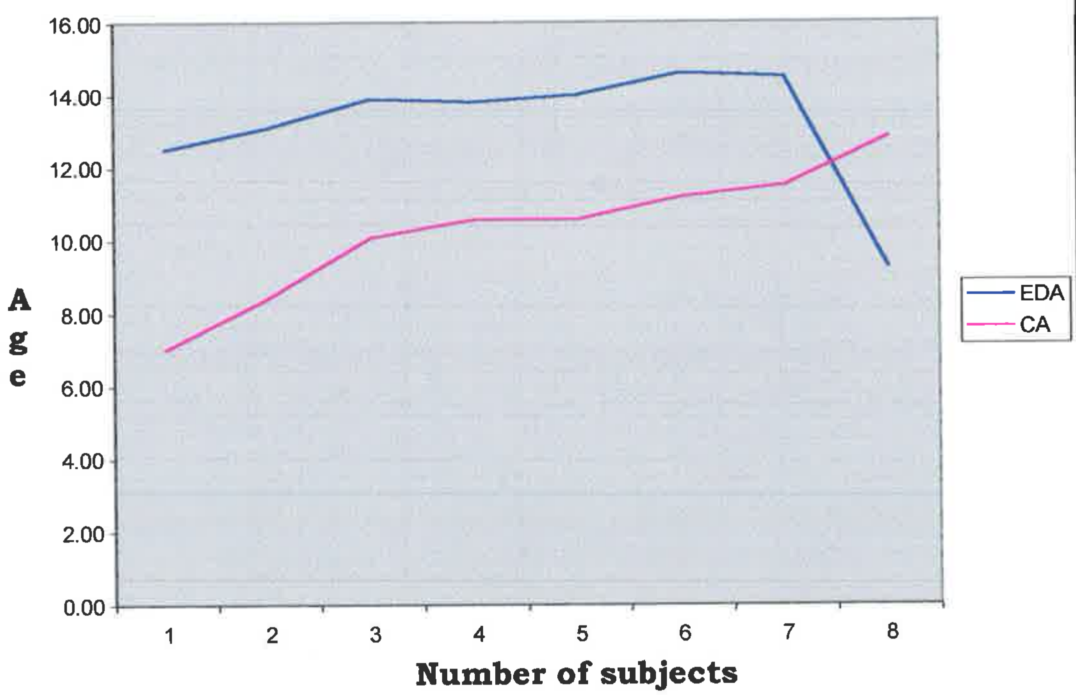
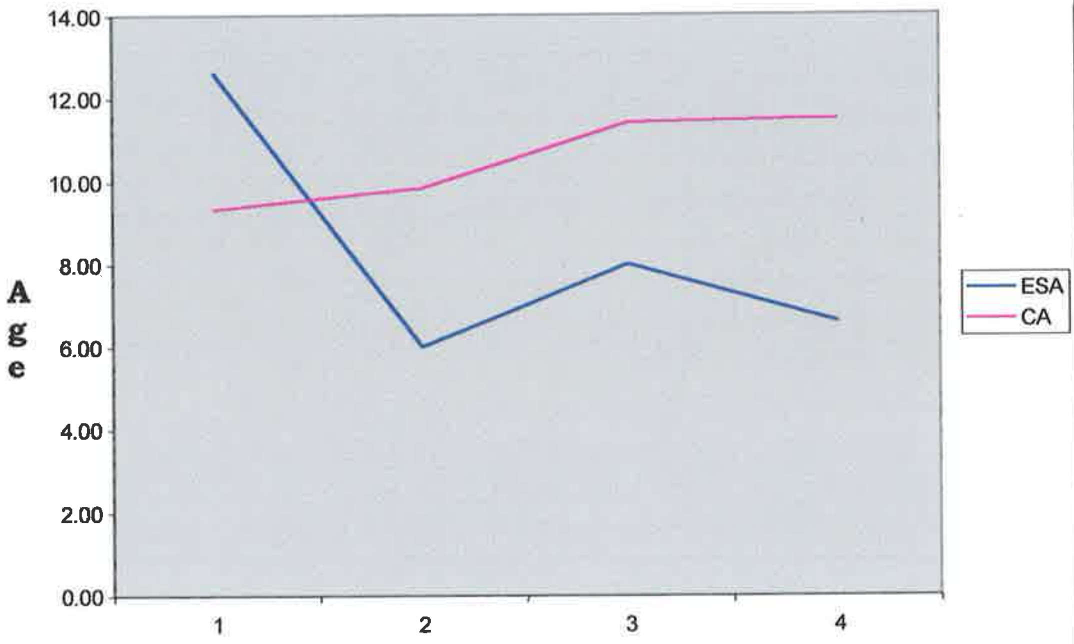


Figure 4.39 Extreme differences between ESA and CA



4.11.2 Extremes of skeletal age

Differences over ± 3.0 years were considered as extremes. In the subset with estimated skeletal ages, four subjects (3 males and 1 female) demonstrated extreme differences between chronological age and estimated skeletal age. The greatest difference demonstrated was 4.90 years of overestimation (Figure 4.39). Skeletal ages were not estimated in the medically compromised group.

CHAPTER 5

DISCUSSION

Accurate determination of an individual's age has great importance in many fields such as forensic sciences, paediatric dentistry, orthodontics, physical anthropology, endocrinology and nutrition. Although a variety of methods for age determination based on dental development have been proposed and applied to various populations, a universally accepted method has yet to been achieved. This may be due to the significant differences present in the rate of growth and development between various populations and ethnic groups.

There is currently limited published work on dental age determination in the Australian population. This study was primarily aimed at testing the reliability and accuracy of the method of Demirjian *et al.* (1973, 1976) in determining dental age in a group of South Australian children. The "Demirjian system" is based on standards obtained by studying a large number of children of French-Canadian background.

'*Reliability*' of a method refers to the capacity of the method to give the same values during repeated measurements while '*accuracy*' refers to the precision of a numerical value or estimates derived'. Precision is the variation in random error during repeated measurements (Kullman 1995). The reliability and accuracy of estimating dental age using 'Demirjian's system' has been tested by many workers in various populations with varied results. Hagg and Matsson (1985) reported that Demirjian's method was the most reliable when compared to other methods like Liliquist and Lundberg (1971) and Gustafson and Koch (1994) when dental ages in a group of Swedish children were assessed. Ciapparelli (1992) recommended the use of this method over the Moorrees, Fanning and Hunt (1963) method.

As part of this study the skeletal ages of a subset of 85 subjects in the group were also estimated using hand-wrist radiographs. The subjects in the subset belonged to a group of children who had a hand-wrist radiograph taken along with their OPG's on the sample day or within ± 7 days of exposing the OPG.

The purpose of estimating the skeletal age was to find the relationship between skeletal and dental ages in this group of children. It also provided an opportunity to examine the possibility of improving the accuracy of age determination in South Australian children by using skeletal age as an indicator of age in addition to the estimated dental age.

Greulich and Pyle (1959) found a close relationship between skeletal maturation and reproductive systems. Based on this, they hypothesised that, because root formation and bone formation are connective tissue responses, a close correlation between bone age and root calcification may be present.

Kullman *et al.* (1992) suggested that a possible way to increase the precision and accuracy of age estimation could be to use an additional age indicator like skeletal age from a hand radiograph as well as teeth during age estimation. They were of the opinion that together, these two age indicators may give a more precise estimation of chronological age especially because of a need for a high precision in age estimation. They also suggested that more research should be conducted in this area.

Greulich and Pyle (1959) stated that the radiological study of the hand and wrist is the single most useful method of studying the skeletal age of a child. O'Rahilly (1957) in a previous study mentioned that the skeletal age estimation using the hand-wrist radiograph is one of the most reliable methods in assessing skeletal age. The number of hand-wrist films available among the lower age groups in this study was very low because of the lack of any indication to obtain a hand-wrist radiograph in the child at that age. The hand-wrist films available were those requested by orthodontists for the purpose of orthodontic treatment planning in the older age groups. This was the reason for the large differences in sample size between age groups in this subset.

The sample used in this study was a group of South Australian children belonging to various ethnic backgrounds. The sample was not grouped according to their ethnicity during the estimation of age in this study. Grouping according to ethnic background was not possible because the radiographs used were obtained from archived records of children seen in school dental clinics, a private paediatric dental practice and the Adelaide Children's Hospital. The only personal details that were collected from the records were date of birth, date of radiograph and sex. The medical history of subjects obtained from the Children's Hospital was also noted.

The dental ages were estimated using orthopantomographs (OPG) based on the original study by Demirjian (1973) where OPG's were used to assess the maturity levels in the children. In addition to that, OPGs were easier to obtain in children and were the most readily available radiograph in their records. McDonald (1969) reported that OPGs emit less radiation for a full mouth view than standard intraoral radiographs and also produced less distortion.

Sapoka and Demirjian (1971) reported that there is a 3% to 10% enlargement on the left side of the mandible in an OPG, but they did not consider this significant when assessing the dental development in a child. This was because the method employed by Demirjian (1973) for estimating age used rating systems based on the shape and extent of development of roots rather than absolute lengths of roots. The stages of dental development were assessed by the examiner and maturity scores assigned to each radiograph. The total maturity score for each child was then converted to a dental age using the conversion charts of Demirjian (1976). The age corresponding to the 50th percentile was taken as the dental age.

The skeletal ages were determined by using the Greulich and Pyle (1959) Atlas method. The skeletal ages were estimated by comparing the hand-wrist radiographs with standards compiled by Greulich and Pyle (1959) in their Radiographic Atlas of Skeletal Development. This method is one of the most popular methods to assess skeletal age and has been used widely to assess the skeletal age. In this study, the Greulich and Pyle method was preferred over the Tanner-Whitehouse method (1962) because of its ease of use and proven reliability.

Biggerstaff (1977) mentioned that the film matching technique using the Greulich and Pyle radiographic atlas is commonly used by most observers and the collective features of all bones permit a reasonable assessment of skeletal age in an individual.

The Tanner-Whitehouse method required an experienced observer with thorough familiarity with the rating process prescribed in the method. It also required more time than the Greulich and Pyle method. Acheson *et al.* (1966) contrasted thc two methods and reported that the G-P Atlas method gave significantly less systematic error (bias) than the TW2 method. Roche, Davila and Eyman (1971) compared the two methods and found that the skeletal ages obtained were closer to chronological age when using the Greulich and Pyle Atlas method and would be suitable for clinical and research purposes.

Milner, Levick and Kay (1986) compared the Greulich and Pyle and Tanner-Whitehouse methods and suggested that the former has a valuable place in skeletal age assessment. King *et al.* (1994) compared the two methods and reported that the Greulich and Pyle method takes less time to perform and provided similar reproductibility with no clinically significant differences. Chen, Jee and Mohammed (1990) stated that the Greulich and Pyle atlas method could be used with a good degree of confidence for practical purposes.

Prior to the assessment of dental and skeletal maturity of the sample, the personal details provided on the radiographs were thoroughly masked and numerically coded to avoid any bias while estimating the age. The radiographs were decoded only after all the maturity scores and comparisons were made (Davis and Hagg, 1994).

The maturity scores obtained from each radiograph were converted into an estimated dental age of the child. Interestingly, when observing the lowest and highest maturity scores obtained in males, it was seen that the lowest maturity score when converted into estimated dental age (EDA) matched exactly with the corresponding chronological age (CA) whereas the highest obtained maturity score when converted to EDA overestimated the CA by more than 2 years. In females, when the maturity scores were converted to estimated dental age, the lowest EDA differed from the corresponding chronological age by only a month whereas the highest EDA was overestimated by over 3.5 years. These results indicate that this method may be more accurate in the lower age groups while overestimating the ages in the older age groups.

The estimated dental ages obtained for the whole sample were then compared to their respective chronological age. The estimated skeletal ages of the subset of 85 subjects were also compared with their chronological and estimated dental ages.

When the distribution of estimated dental ages in relation to their respective chronological age groups were analysed by cross tabulations, it was observed that the EDAs of only 39.3% of the sample fell into the corresponding chronological age groups. Among the males this was 41.2% and in females 37%. The highest percentage of matches (68.5%) was seen in the 8.00-8.99 years age group while the lowest percentage of matches (18.9%) was seen in the 11.00-11.99 years age group.

These results indicate a low percentage of matches in both males and females and in the whole group. The percentage of matches was observed to be higher in lower age groups and less in the higher age groups. This result is in general agreement with other studies testing the accuracy of 'Demirjian's method' of dental age estimation.

It should be noted that the comparisons and distributions obtained by cross tabulating dental and chronological age groups do not take into account the number of subjects falling into the immediate periphery of the age groups . However, this comparison gives us an idea about how the estimated ages in the sample are dispersed in relation to their corresponding chronological ages.

The differences between mean ages were statistically analysed using paired t-tests. When the mean differences of estimated dental ages and the chronological ages in the whole group were compared, a statistically significant difference of 0.2 years (SD=1.2), which is slightly over two months was observed. Among males, the mean difference indicated an average overestimation of 0.15 years (S.D = 1.1), which is almost two months and the mean differences between the ages in different age groups varied from -0.3 years to 0.85 years.

Among females, an average overestimation of 0.3 years (SD=1.3) which is approximately 4 months was observed and the mean differences between the ages in different age groups varied from -0.08 years to 0.65 years. These mean differences between the dental and chronological ages, though statistically significant ($p<0.05$), could be considered within acceptable limits for clinical applications.

Interestingly, the highest mean age difference in age groups in both males and females were seen in the lowest age group (7.00-7.99) which is different from the results obtained in similar studies conducted in other populations. Generally the lower differences are seen in the lower age groups and the differences increase as age increases (Hagg and Matsson, 1985).

The possible explanation for the high differences in 7-year-old males could be that one of the subjects in the group demonstrated an extreme difference of 5.50 years, thereby increasing the mean value. This child also suffered from a medical condition, which could have accelerated the dental development. This case will be discussed in detail later. No obvious reason could be found in the 7-year-old female group. Another possibility is that due to secular trends in growth the 7-year-olds in South Australia in the 1990's in general could be more advanced in dental development than the French Canadian children of the 1970's on whom the standards are based.

In all age groups, except the lowest age group (7.00-7.99 years), females exhibited a higher mean difference between the ages when compared to males. The results showed that the females were 0.15 years or approximately 2 months more advanced than males in their mean dental age. This may be a reflection of higher maturity level among this group of female South Australian children when compared to the males in the group.

Garn *et al.* (1959) stated that mean dental development ages at various stages was higher in females when compared to males. Demirjian and Levesque (1980) investigated the sexual differences in dental development, and found a common pattern for each tooth, chronological similarity between males and females in the early stages of development and advancement of females over males for the later stages. They found no significant difference in the timing of dental development between males and females up to the age of five to six years but in older ages, the girls were always more developed than boys.

Farah, Knott and Booth (1995) conducted a study aimed at assessing the dental age of children in Perth, Western Australia by using the Demirjian's method (1976). The results showed that Perth females were more dentally mature than males from ages 7.0 to 15.0

years. They also concluded from their overall results that the method proposed by Demirjian (1976) was accurate and reliable for dental age determination in Perth population and also could be used for forensic purposes.

Hagg and Matsson (1985) stressed that even though the accuracy seems to be higher in younger children, the difference between estimated dental age and chronological age, expressed in percentages of age, may be as high in older children.

Although the mean differences between the dental and chronological ages are statistically significant, when considered from a clinical perspective, these differences are minimal because the developmental parameters like root and crown development take a longer time to show a difference radiographically. On the other hand, eruption of teeth can show significant differences in the amount of crown exposure in a two-month period.

The mean age differences between dental age and chronological age in individual age groups could be a more reliable indicator of the accuracy of the system. This is because the range of ages within the groups is lower and thus the mean may be a more accurate measurement of the age in the group than in the whole sample.

When the differences between the dental and chronological ages within each age group were analysed, the mean differences ranged between -0.30 years to 0.85 years in males and -0.08 to 0.65 in females. Except in 9-year-old males and females, an overestimation of age was seen in all other age groups. The mean differences in ages were higher in females in most age groups, again indicating an advanced dental maturity in females than males in most stages of dental development. This is consistent with the findings obtained when the mean ages for the whole group were compared. The differences were generally lower in the lower age groups and increased in the higher age groups. The only exception was in the 7-year-old males and females, where a significant difference was observed between the mean ages. Most studies have results showing less differences in the lower age groups.

It is important to note that that although the mean estimated ages fall within acceptable limits, it cannot be assumed that this method of age determination is accurate for the population involved. The mean age is the average age of the whole sample. It does not take into consideration the degree of over or underestimation of the estimated age in individuals.

Even though mean differences between ages may be small, the individual variations in both positive and negative directions may be large. When the mean estimated dental ages and skeletal ages were compared with chronological age, it was observed that the standard deviation was higher for skeletal age estimates and lower for the dental age estimates. Estimated dental age in males had less deviation than females while for skeletal age, females had less standard deviation than the males. The estimated dental and skeletal ages of a few of the subjects demonstrated extreme variations.

These individual variations are important when making estimates because the standard deviations are greatly influenced by these extreme variations. The standard deviations of dental age estimates in individual age groups demonstrated higher deviations in older age groups and less in younger age groups. Some of the subjects who demonstrated extreme variations belonged to the younger age groups which would have increased the standard deviation from mean. In a practical setting this could result in individuals having a sizeable difference between their estimated ages and chronological ages which for example in a forensic situation could lead to significant doubts about the chronological age of an individual.

The percentage of subjects whose estimated dental age falls within the acceptable limits may also give a better idea of the accuracy of the system. The higher the percentage of the subjects whose ages fall within the acceptable limits, the more accurate is the system.

To analyse the extent of individual differences between dental age and chronological age in the sample, the range of differences between the ages including the percentage of sample whose dental ages varied only up to ± 0.5 years from their chronological ages were calculated.

Brown and Taylor (1999 personal communication) from the Forensic Odontology Unit at The University of Adelaide suggested that differences of up to ± 0.5 years (6 months) when estimating dental age were acceptable from a forensic point of view. Hence, the overestimation of 0.2 years observed in this group when the mean dental and chronological ages were compared, may be considered quite acceptable from both clinical and forensic points of view.

When the range of differences between the estimated dental age (EDA) and the chronological age (CA) were analysed, it was observed that 54.3% of the sample were overestimated, 44.8% were underestimated and only 1% had no differences between the ages. The differences ranged from 5.50 years to -3.60 years. Even when the acceptable differences of ± 0.5 years (6 months) were taken into consideration, the percentage of samples falling into the range rose only to 41.8% while the majority of the children fell outside the acceptable range of difference. Only 42.2% of males and 41.3% females fell within the acceptable range. No significant differences between the accuracy in males and females were seen.

When the range of differences between the dental age and chronological age were analysed individually in each of the six age groups, it was observed that the percentage of samples falling into the acceptable range of ± 0.5 years varied from 22.4% to 65% with the lower age groups again demonstrating less differences than the higher age groups.

In general, when analysing the results of this study, it was observed that the Demirjian's method was more accurate in the lower age groups and less accurate as the age increased and also was marginally more accurate in estimating ages in males than in females. Mean dental ages obtained showed a modest overestimation over chronological age in males, females and in the whole group. Even though the differences between mean estimated dental ages for the group was within acceptable limits for clinical purposes, the large range of individual differences among males, females and the whole group indicate the lack of accuracy of the method when applied in this group of South Australian children.

Hagg and Taranger (1984) gave a conceivable explanation for the low accuracy of Demirjian's method in the older age groups. They suggested that after a certain chronological age, dental age does not exhibit a Gaussian distribution. Hagg and Matsson (1985) commented that this would result in distorted results and thus lead to systematic overestimation of age when chronological age is estimated from dental development. They also suggested that the low accuracy of the method when applied to older children could reflect population differences, accentuated in the ages around puberty.

Hagg and Matsson (1985) stated that methods based on dental formation do not seem to be suitable for estimation of dental age above the age of 5-6 years, on an individual or a population basis, due to consistent over estimation of dental age independent of the system used. They suggested that considering the method is more accurate in the lower age group, estimation of age is preferably done during early childhood, when many indicators of short duration are available. This was confirmed in other studies by Davis and Hagg (1994).

From a forensic or legal point of view this is unacceptable because the need for age estimation can arise at any time. The dental age estimation methods should be able to be applied in the population at varied ages in order to be effective for various purposes.

The results obtained also show that the accuracy of Demirjian's method differs between different age groups with the lowest mean differences found in the lower age groups. The consistent overestimation of dental age should be considered carefully when there is a need to assess a child's age especially in the older age groups. These points should be carefully considered when the method is used in age estimation exercises.

When discussing the low level of accuracy of Demirjian's method in South Australian children, many facts should be considered such as ethnic differences, variation in dental development between individuals and differences in stages of tooth development even within an individual. The health of each individual child should be given due consideration because the general health or history of any major illness during childhood has been reported to interfere with normal dental development in children.

Demirjian and Goldstein (1976) discussed the applicability of their method of age determination in other populations. They expected appreciable changes in maturity standards between populations, but were of the opinion that the scores for the stages of dental development would not vary too much between populations.

Growth is controlled by many factors including genetic, endocrine and environment. The environmental factors include nutrition, socio-economic status, urbanisation, seasonal variation, exercise, disease and psychological stress and secular trends (Townsend and Brown, 1998).

Moorrees *et al.* (1963) stated that the assessment of dental maturation will be affected by the following factors:

1. the applicability of normative data to the population to which an individual child belongs;
2. the possible variation between rates of development of different teeth in a given child;
3. the experience of the examiner in recognizing sequential stages of tooth formation;

4. the availability of earlier or later records of the same child to serve as a basis of reference when rating tooth development and
5. the span of time between the occurrence of one stage of development and the next.

Eveleth and Tanner (1976) stated that the rate of maturation is influenced by both hereditary and environmental factors, and maturity standards may differ from one standard to another.

All the above authors emphasise the need to understand the factors which will affect and vary rate of maturity in different populations. This understanding will be beneficial when applying standards derived from different populations.

Brown and Townsend (1998) stated that 'secular trends are a tendency towards accelerated growth seen in successive generations'. They reported that heights and weights have been steadily increasing since recordings were made last century. The secular increase in adult height is about 1cm per decade. They also reported that growth ceases earlier than previously seen and this could be due to improved health and nutrition.

Eveleth and Tanner (1990) reported that children in industrialised and developing countries are attaining maturity more rapidly over the past 100 years. This trend could be due to improved nutrition, reduction in disease rates, lower family size and better living standards. Sinclair (1989) mentioned that more children in recent generations fall above the 50^{th} percentile showing that they have a higher growth rate than former generations at the same age. Weiland *et al* (1997) studied secular trends in malocclusion in Austrian men and reported that secular changes have occurred during the last 100 years. Holtgrave *et al* (1997) investigated acceleration in dental development in European population and reported a small acceleration in dental development for boys especially between ages 3 to 9 years of age.

Rahman *et al* (1999) studied the growth trends in South Australian children and adolescents and reported a change in growth trend in South Australian children. They suggested that new standards have to be established to enable more accurate assessments in clinical practice.

On the other hand, Hitchcock *et al* (1984) compared dental eruption ages in Australian children with studies from other countries and reported that no significant changes have occurred in a span of 40 years inspite of increased affluence of developed countries over that period. Liversidge (1999) compared the dental maturation of 18th and 19th century British children using Demirjian's method and reported that the differences were not significant. They suggested similar maturation over 200 years, however they mentioned that many of the young children born approximately 200 years ago were found to be dentally delayed probably due to illnesses to which they succumbed. They also pointed out one of the disadvantages of the Demirjian's method which is its lower scale limit and concluded that the method may not be suitable for very young children.

Taking into account the number of reports confirming secular trends in growth, it can be accepted that these changes can affect the estimation of ages based on older standards in the present population.

Various studies from around the world report the presence of large amount of variations in growth and development. These variations between and within populations point to the fact that there are differences in dental and skeletal development in different populations and ethnic groups. Differences are also present between normal healthy children and children who have had any disturbances during their growth due to medical or nutritional problems.

It can be assumed that a country like Australia with a large immigrant population would have varying maturity standards compared to other populations around the world as well as within the Australian population. Children born to parents coming from different ethnic backgrounds will present an even greater challenge to the complex picture of ethnicity. It will be almost impossible to develop multiple standards within the Australian population, but it may be possible to develop maturity scores in the current population giving due consideration to the mean maturity scores of various types of ethnic backgrounds and secular trends in growth and development.

The hand-wrist radiographs of the eighty-five South Australian children were compared with the standards given in the atlas of hand and wrist radiology by Greulich and Pyle (1959) and skeletal ages were estimated.

When the skeletal ages obtained were compared with the chronological ages the accuracy was found to be very low. Mean differences between skeletal and chronological age in the whole subset was found to be -0.6 years (S.D. = 1.5), was -0.9 years (S.D. = 1.3) and -0.07 years (S.D. = 1.5) in males and females respectively.

When the distribution of estimated skeletal ages in relation to their respective chronological age groups were analysed by cross tabulations, it was observed that the ESA's of only 23.5% fell in to their chronological age groups. Among males this was 12% and in females 37.14%. These results revealed a very low percentage of matches in both males and females and in the whole group.

When the means of estimated skeletal and chronological ages were compared, a statistically significant underestimation of skeletal age was observed. An underestimation of 0.91 years, 0.07 years and 0.56 years were observed in males, females and in the whole group respectively.

Blanksby *et al.* (1975) conducted a skeletal age survey of primary school children in Western Australia and reported similar overall mean underestimation of skeletal age in the group studied. He reported in his study that 10, 11 and 12-year-old females needed a correction factor of approximately 10 to 11 months added to their skeletal age when assessing their chronological age.

The results of skeletal age assessment in South Australian female children showed close, though not identical, differences in these age groups. The ten-year-old and eleven-year old girls in this study were 6 and 3 months behind in their skeletal development respectively.

Females in the subset demonstrated a skeletal age advancement of approximately 0.5 years (6 months) over males in this group of children. The mean difference in ages in females and the whole group fell within the acceptable range of differences (± 0.5 years) while the males were outside the range. It was interesting to note that females in this subset had demonstrated an advanced dental age as well. Similar findings were reported by Rahman *et al* (1999). They reported that South Australian boys had a tendency to be skeletally delayed when compared to girls of the same age.

As mentioned earlier these differences between mean ages, although statistically significant, from a clinical perspective are minimal differences. As for the dental ages, the extent of differences between the skeletal ages and the chronological ages including the percentage of samples whose skeletal ages varied only up to ± 0.5 years from their chronological ages were calculated. It was observed that 37.6 % of the sample were overestimated, 61.2% were underestimated and only 4.7% of sample showed no differences between the ages. The range of no differences included ages ± 0.07 years or less than a month (0.08 years). The differences ranged from -4.90 to 3.27 years. When the acceptable differences of ± 0.5 years (6 months) was taken into consideration the majority of the children fell outside this range. Only 25.9% of the subset fell within this age range and only 18% of males and 37.1% of females in the subset fell within this range and also demonstrated a difference between the sexes. A low accuracy of the method is clearly evident. These values clearly indicate that although the differences between mean ages are acceptable the actual percentages of the sample falling into the correct age groups are very low.

The study of skeletal age in this group of South Australian children was done only in a small sample group. The availability of hand wrist radiograph in the records of this subset was the main reason why this study was conducted as part of the main study on dental age estimation. Even though the sample size was small some interesting results were obtained.

Since no previously published studies on skeletal age estimation on South Australian children using the Greulich and Pyle atlas were found, it is suggested that the present study be considered as a pilot study in this area.

While assessing the skeletal age in this study, the Greulich and Pyle method was found to be convenient and easy to use and was not time consuming. The radiographic atlas provided clear instructions for undertaking the assessment and provided a range of radiographs in the different age groups as standards for comparison. It, however, should be noted that this is a purely subjective method of assessment and inter- examiner variations are inevitable.

The results obtained when the skeletal ages were compared with their chronological ages indicate clearly that the ages are consistently underestimated. The Greulich and Pyle method, though useful in a clinical setting for orthodontic treatment planning, is not accurate enough to reliably estimate the age of an individual in this population for the purpose of positive identification in a forensic setting.

When the skeletal age and dental age were compared and contrasted it was observed that only 20% of the ESA's matched the dental age groups. The highest percentage of matches (100) were seen in the 14.00-14.99 year old ESA group but none in the 6 and 7 year old groups. Among males alone, 28% fell into the corresponding EDA group and the highest and lowest matches were the same as for the whole group. In females, however, only a very low percentage of matches was seen. Many of the ESA age groups did not have any matching EDAs at all. The results indicate that the rate of dental development is more pronounced in females than in males.

When the dental and skeletal ages were compared it was quite obvious that the skeletal development and dental development were happening quite independently of each other. No direct relationship was found between dental and skeletal development, which could be used as a measure to improve the overall accuracy of the age determination process in an individual.

The associations between the chronologic, dental and skeletal ages were analysed and degree of correlation was obtained by calculating the correlation coefficient using the Pearson's correlation method. The correlation of ages in males, females and the whole group was displayed as scatter diagrams. The correlation coefficient provides an estimate of the strength of the association between the ages. Correlation coefficients between 0 and 0.39 are often termed as "low", those between 0.40 and 0.79 "moderate" and those between 0.80 and 1.00 as high. (Townsend, 1999).

When the association between chronological ages and estimated dental ages was analysed, a high correlation was seen in males, a moderate correlation in females and a moderate to high correlation in the whole group. A moderate correlation was observed between chronological age and estimated skeletal age in males, females and in the whole skeletal subset. When the estimated dental and estimated skeletal ages were analysed, a moderate correlation between the ages was seen in males and in the whole group. Females demonstrated a low correlation between the ages.

When the associations between all the ages was observed, it was evident that the correlation between dental age and chronological age were higher than that of skeletal age indicating the closer relationship between dental maturity and chronological age. The low level of association between skeletal and dental ages further indicates the differences between dental maturity and skeletal maturity and that the ages cannot be substituted for one other. It should however be remembered that the correlation coefficient obtained is only an estimate of the true population correlation.

5.1 Analysis of cases with extreme differences

When the range of differences between dental age, skeletal and chronological age were studied, a few subjects exhibited extreme differences. For the purpose of this study the subjects who demonstrated differences of more than ± 3 years were considered as extremes. Among the 400 subjects included in the study, eight showed extreme differences between dental and chronological age and four between skeletal and chronological age. Interestingly none of these subjects had both dental and skeletal age extremes. This again confirms the opinion that dental and skeletal maturity develop independently of each other.

The eight cases demonstrating extreme differences between ages were examined again and no significant errors in dental or skeletal maturity assessments were seen. All the data collected were checked again for any entry errors and none found. The medical and dental records of these children were then examined to find out evidence of any previous or existing medical or dental problems.

The findings were quite interesting in most of the cases. Three out of the eight subjects with extremes of dental ages were found to be from the medically compromised group. Among the three in the medically compromised group, two were diagnosed with cancer and had been long term patients in the Oncology Unit at the Adelaide Women's and Children's Hospital while the third child was a case of *Spina Bifida* along with major cardiac defects and was also a long term patient at the Women's and Children's Hospital.

These results were significant, because many studies have indicated that abnormal or delayed growth due to medical or other conditions can interfere with normal dental and skeletal development and can lead to an accelerated or retarded rate of development (Mornstad *et al.*, 1994 and Gulati, 1990).

The results of this study also clearly indicate a possibility of different developmental rates in medically compromised children. There needs to be further research into various types of medical conditions and their influence on dental age. The studies could be designed in way that the individual conditions affecting various systems of the body in relation to their influence on the dental growth and development of a child could be grouped together. The results thus obtained may help in understanding the range of differences in dental age that could be expected in each group of conditions. This may lead to an increase in accuracy of estimating dental age in children who have been identified with a particular condition. This will also help in forensic situations to help predict the extreme differences in dental age and thus be able to place or exclude individuals during an identification process.

Another interesting finding was that, among the other five samples with no known medical conditions, three samples appeared to be from ethnic groups other than Anglo-Saxon on whom the standards used were based. The remaining two were assumed to be of Anglo - Saxon origin by their names but again, it must be noted that no history of ethnicity was obtained during the collection of sample and the opinion is solely based on the names of the children.

Teivens *et al. (*1996) studied the distribution of dental developmental stages using Demirjian's method (1973) and reported that a large degree of individual variation of tooth development was seen and that children of the same age usually showed dispersion over four stages. They also observed that in extreme cases, children with an age difference of almost 7 years could show the same developmental stages. They stated that dental age determination in children will always have the disadvantage of a wide range due to the individual variation in tooth development.

The extreme results obtained in the sample with no obvious reasons for the large differences could be attributed to the large degree of individual variation in tooth development mentioned above.

When the dental history of subjects with extremes of skeletal age were analysed, it was interesting to find that three out of the four samples were found to have undergone active functional orthodontic therapy for moderate to severe skeletal discrepancy in development of their jaws, while the fourth subject was definitely from a different ethnic group.

Even though the ethnic groups were not identified for the purpose of this study, it is important to note that ethnic variations have been found to cause differences in dental development between population groups. Demirjian (1986) stated that the possible explanation for low accuracy of the 'Demirjian system' when applied in children of different racial origin could be due to ethnic differences in dental development.

The measurement of stages of maturity is a largely a subjective method. Some authors have proposed and tried many objective methods such as digitized readings for the assessment of maturity standards (Kullman *et al.* 1988, 1995).

In this study the assessments were purely subjective bringing about a possibility of examiner error or variations while examining the radiographs. The nature of the study and other factors allowed only a single examiner to do all the data collection and assessments and hence no inter-observer variations were present. To assess the intra-examiner variations between radiographs, a group of children had their developmental stages determined, maturity scores assigned and dental ages estimated three times by the same examiner. The estimations were made on three different days in an attempt to avoid familiarisation of the radiographs by the examiner. When the results of the three estimations were analysed a low rate of intra- examiner variation with an overall agreement of 87.6% as described in Chapter -3 was obtained.

Levesque and Demirjian (1980) mentioned that the inter-examiner approach shows more frequent differences than the intra-examiner approach. They studied the inter-examiner accuracy and stressed the need for cross checking of evaluation when two or more examiners were involved in a study using the same system.

Mornstad, Staaf and Welander (1990) found in their study that when dental ages are assessed from radiographs, the estimations may differ between examinations when only one examiner is involved. Other workers like Hagg and Matsson (1985), Fanning (1961) and Sapoka and Demirjian (1971) demonstrated similar findings.

It is important to understand that age estimation is largely a subjective exercise and there is a need to recheck the results obtained in an attempt to reduce the margin of error wherever possible.

Taking all this into account, it would be better practice to base age determination methods on studies made in the same population for which they are going to be used as suggested by Nystrom (1986). Staaf, Mornstad and Welander (1991) stated that the ultimate goal of methods for age estimation must be to eliminate the methodological variations as much as possible, leaving only the unavoidable individual variability of development between children of similar ages.

These results point out the limitations of dental age assessment and the need to consider these when it is being used for various purposes. Developmental charts in various populations take into account only the average values and are not designed to pick up the cases which may have reasons to produce extreme values. The individual variability will remain a major challenge for the formulation of developmental charts which will produce uniform results in the population.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Accurate determination of age of an individual has great importance in diverse fields like forensic sciences, paediatric dentistry, orthodontics, physical anthropology, endocrinology and nutrition. There are various methods available to determine age and the evaluation of dental development plays an important role in this process. A variety of methods have been proposed and applied to various populations. To date, there is limited published work on dental age determination in the Australian population. Demirjian's method is one of the most widely used methods for dental age determination around the world. The Greulich and Pyle Atlas method for assessing skeletal ages from hand-wrist radiographs is commonly used by both clinicians and researchers. The estimation of skeletal ages provides an opportunity to examine the relationship between skeletal, dental and chronological ages and the possibility of improving the accuracy of age determination in this population.

In this study, the dental ages in a group of South Australian children were assessed using the 'Demirjian's method' for age determination. When Demirjian's standards were applied to the South Australian children, the accuracy was found to be low. When the distribution of estimated ages with regards to their respective chronological age groups were analysed, a modest pattern of dental age overestimation was observed when compared to chronological age for the whole sample. When analysing the number of children whose dental ages were within ± 0.5 years difference of chronological age, nearly 60% (57.8% males and 59.8% females) fell outside this range. Females demonstrated an advanced dental age when compared to males in the same age group.

This study also tested the accuracy of skeletal ages estimated using the Greulich and Pyle method from hand-wrist radiographs as an indicator of chronological age in this population.

The skeletal ages of a subset of this group of South Australian children were estimated using this method and compared with dental and chronological ages. When the mean differences between skeletal and chronological ages were compared, the accuracy was found to be very low. A significant pattern of underestimation was observed in males while a less significant pattern was seen in females. When analysing the number of children whose dental ages were within ± 0.5 years (6 months) of chronological age, 82% of males and 32% females fell outside this range.

When the subjects who demonstrated extreme differences in their ages were investigated, it was found that most of these cases had either a significant medical history or possible ethnic variations.

From the results of this study, it can be concluded that:

1. The Demirjian's method is a reliable method for estimation of dental age but consistently overestimates the age of children in South Australia when applied for the purpose of age determination. The accuracy of estimations is low and hence is considered not suitable for estimation of age in this group especially for accurate estimations for forensic purposes.

2. The Greulich-Pyle system consistently underestimates skeletal age in both males and females. The accuracy is low when used as an indicator of chronological age.

3. South Australian female children are dentally and skeletally advanced than males in similar age groups.

4. Dental and skeletal stages develop independently of each other and rarely can be used together to improve the accuracy of age determination.

5. Medical conditions can also interfere with the dental development of children and have to be given due consideration when a need for age determination arises. In addition, more studies into the range of conditions and extent of interference to growth and dental development are essential.

6. Ethnic differences may cause differences in dental development between individuals. Ethnic backgrounds should be considered during age determination exercises.

7. Secular trends in growth and development may also be responsible for the differences in estimated ages in the present population. Maturity standards need to be established within the present South Australian population taking into account the various factors, which can affect the pattern of growth. Maturity standards thus developed in a South Australian population should assist in more accurate dental age determination of South Australian children.

8. Individual biologic variability can cause large differences in developmental stages between individuals of the same chronological age groups and remains as the biggest challenge for the compilations of developmental charts which could produce uniform results in the whole population.

Further research is needed and is planned in this area to isolate and investigate the various factors influencing the dental age in South Australian children.

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