Dental maturation of the permanent mandibular teeth of South African children and the relation to chronological age

By

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Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Date: ___________December 2009___________________________________

ABSTRACT

Age estimation of the skeletal remains of children can be accomplished by examination of the ossification centres and the fusion of the epiphyseal plates of long bones. Dental age estimation is done by examining the eruption of the deciduous and permanent teeth. Both these methods are inaccurate and are subject to the nutritional status of the individual. A more accurate method of age estimation is by the examination of radiographic images of the developmental stages of the tooth crown and root formation. Two methods of dental age estimation used are those of Moorrees, Fanning and Hunt (1963) (MFH) and that of Demirjian, Goldstein and Tanner (1973) (DGT). These methods were tested on a sample of 913 Tygerberg dental patients; a random mixture of Caucasoid and Khoisanoid children. The MFH method under-estimated the ages of the sample by an average of 0.91 years and the DGT method over-estimated the ages by an average of 0.89 years. Samples of Indian and Negroid children from Kwa-Zulu Natal were tested in a similar manner and the results showed similar under and over-estimation of the ages by these methods. The Negroid children were labelled the Zulu sample. Correction factors were derived for the MFH and DGT methods of dental age estimation when used on Tygerberg, Indian and Zulu children. These correction factors were tested on the samples and found to improve the accuracy of the age estimation methods of MFH and DGT significantly. A second sample group of Tygerberg, Indian and Zulu children were then tested firstly using the standard method of MFH and DGT and the using the correction factors. The results showed that the correction factors improved the age estimation on these samples except in the case of the DGT method on Zulu children. A sample of Xhosa speaking children were added to the two Zulu samples and made an Nguni sample. The Tygerberg samples were combined as were the Indian samples to form data bases for the construction of dental age related tables for Tygerberg, Indian and Nguni children. These tables show that there are distinct differences in the ages at which the teeth develop in the different sample groups and that dental age related tables are necessary for children of different population origins. Statistical analysis of the age related tables from this study (Phillips Tables) show these tables are more accurate in the age estimation of South African children.

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CHAPTER 1

THE DENTAL MATURATION OF THE PERMANENT MANDIBULAR TEETH OF SOUTH AFRICAN CHILDREN AND THE RELATION TO CHRONOLOGICAL AGE

1.1 RATIONALE FOR THIS STUDY

The main reason for undertaking this study was as a result of a series of child murders that occurred in Cape Town in the 1980’s. Several children were reported missing during this period. The discovery of decomposed juvenile human remains on the ‘Cape Flats’ over 3 years eventually resulted in the recovery of the bodies of 18 children in various stages of decomposition. Some of these were so badly decomposed that it was impossible to determine either the race or gender of the individual.

The attempts at identification included age estimation using the recognized tables of Moorrees, Fanning and Hunt, a study that was published in 1963 on the developmental stages of permanent teeth in American children from Boston Massachusetts.

These age estimation tables did not fit the age profiles of these children and was of little help in the attempted identification process. The Demirjian *et al* method (1973) was attempted and was not successful either. Most of these children were not positively identified as the age estimations from these two methods did not correspond to the age profiles of the children. The use of DNA analysis was in its infancy and not available at this stage. The clothing and footwear worn by the children was used as the only means of identification and burials took place using these items as the only identification criteria.

The murders of these children was thought to have been committed by a man described by the media as the ‘Station Strangler’, most of the victims having commuted by rail and the murders having taken place in the proximity of train stations. An 18 year old woman was also raped and murdered during this period and the ‘Station Strangler’ was arrested and subsequently convicted of this crime. The Police suspected that he was also guilty of the murders of the children, but the evidence was circumstantial and dismissed by the High Court. The 'Strangler' was sent to prison for 25 years and is about to be released soon, but the murders of these children has never been solved.

The lack of dental age related tables for South African children was a major factor in the failure to identify these children and was the motivation to undertake this study and produce dental age related tables applicable to the South African child population.

1.1.2 HYPOTHESIS

The use of the standard dental age estimation tables of Moorrees, Fanning and Hunt (1963) and that of Demirjian, Goldstein and Tanner (1973) on the murdered children associated with the 'station strangler' were inaccurate and thereby suggested that these tables were not applicable for South African children. This suggested that dental age related tables be compiled for a representative sample of South African children of appropriate ethnic groups. This is formally stated as the aim of this study.

1.2 HUMAN TOOTH FORMATION AND DENTAL AGE ASSESSMENT

The age standards for human growth and development are essential in human biology and clinical medicine. The clinical assessment of the growth of a child requires normal standards as references to assess the physiological age of a system compared with the chronological age. In forensic anthropology and forensic dentistry the age of an individual is vitally important. The age will narrow the investigative field and aid in identification of skeletal remains.

Dental age is one method of physiological age assessment and is comparable to ages based on skeletal development, height and weight or sexual maturation. It is also much less affected than other tissues by endocrinopathies and other developmental insults (Garn, Lewis and Blizzard, 1965).

It has been shown in studies of children with major abnormalities affecting sexual maturation, stature and bone age that there are comparatively small deviations in the timing of dental development (Garn, Lewis and Blizzard, 1965). Dental development has two main aspects: the formation of crowns and roots, and the eruption of teeth. Of the two, formation of teeth seems to be more robust against environmental influences; caries, tooth loss and severe malnutrition can affect tooth eruption (Alvarez and Navia, 1989). Formation of teeth and tooth size or morphology is heritable, but the stages of tooth formation have lower coefficients of variation than the stages of skeletal development (Garn *et al.*, 1973). This is not to say that the dentition shows no effects attributable to environmental influences, but that it tends to be the least affected tissue. Thus the dentition is the single best physiological indicator of chronological age in juveniles (Smith, 1991).

1.3 CHRONOLOGY OF HUMAN DENTAL DEVELOPMENT

Dental age may be based on the formation or eruption of teeth. In most studies of eruption times they are limited to timing the emergence of the teeth through the gingiva. This is a single event in time for the development of each tooth (Smith, 1991). The formation of teeth, however, is more advantageous as it offers continuous development during the juvenile years. Human teeth have a definitive growth period, the last tooth completing its development as the skeleton nears maturation.

In adults teeth undergo attrition and erosion. There is an increase in the amount of secondary dentine deposition in the pulp chamber and cementum at the root apex. The root dentine undergoes hyper-mineralization. These changes have been used to provide an estimate of the chronological age of adult teeth (Gustafson, 1950; Johansen, 1971). The accuracy for the estimation of adult age is in the order of ± 5 years in the best cases.

It is, however, possible to estimate the age of juveniles far more accurately. The development of the dentition spans a period of approximately 20 years during which formation and eruption takes place. Tooth formation includes formation of an organic matrix and its subsequent calcification or mineralization. Most of the chronological studies of mineralization of teeth have been done radiographically as this is a non-invasive procedure and easily assessed. Mineralization, however, can be demonstrated at a slightly earlier age by dissection when compared to radiography (Logan and Kronfeld, 1933). Prenatal tooth formation has been studied mainly by dissection of anatomical material whereas most postnatal development has been studied radiographically. Because of this, it is not possible to assemble a complete chronology of human tooth formation based on a single technique (Johansen, 1971).

The age of emergence of teeth is known for a great variety of human groups and socioeconomic levels within groups (Adler, 1958; Steggerda and Hill, 1942; Garn, Nagy and Sandusky, 1973). There have been several recent studies of tooth emergence (Moorrees and Kent, 1978; Gillet, 1997; Gillet, 1998). Tooth emergence is the appearance of a tooth through the gums; it is an acceptable means of estimating age and has the advantage of being a quick and fairly non-invasive procedure requiring only sufficient light and a dental mirror. By contrast less is known about chronologies of tooth formation as there have been few major studies. The explanation for this is that tooth formation requires radiography or dissection whereas the study of tooth emergence requires only looking into a child’s mouth. Deciduous teeth start forming prenatally with mineralization commencing in the 2^{nd} trimester of pregnancy between 12 and 16 weeks (Kraus, 1959). Crowns are partially completed at birth and deciduous tooth root formation is complete some 2 to 3 years after initial mineralization. Calcification of the permanent dentition is however entirely postnatal and the formation of each tooth occupies between 8 to 12 years (Garn *et al*, 1965).

The events in the formation of the human permanent dentition occur in several phases. The 1st molar (M1) and the anterior teeth (I1, I2 & C) all begin formation within the 1st year. A second phase of formation is the premolars (Pm1, Pm2) and the 2nd molar (M2) between the ages of 2 to 4 years. The 3rd molars are considerably delayed and develop some 5 to 6 years after the M2 in European populations.

1.4 RADIOGRAPHIC PICTURES OF THE DEVELOPMENTAL STAGES OF TEETH

In order to visualize the developmental stages of the permanent teeth the following images of the teeth are presented. These images show the progressive development of the crowns and roots of the teeth starting with the incisors and progressing to the canine, premolars and then the molars.

Table 1: The standard abbreviation of developmental stages of teeth

Ci	Cusp initiation
Cco	Cusp coalescence
Coc	Cusp outline complete
Cr½	Crown half formed
Cr¾	Crown three quarters formed
Crc	Crown completely formed
Ri	Root initiation
Cli	Cleft initiation (molars only)
R¼	Root one quarter formed
R½	Root half formed
R¾	Root three quarters formed
Rc	Root complete
A½	Apex one half complete
Ac	Apex complete

Moorrees, Fanning & Hunt (1963)

1.4.1 Development of the incisors and early formation of the canine

The following images show the progressive stages of the development of the first incisor I1 the second incisor I2 and the canine C. The cusp initiation of the incisors begins to calcify at or just before birth; the stage of crown development in the image (Figs.1&2) is at approximately 4 years of age. The captions under each image describe the various stages of development of the teeth with relation to the adjacent teeth.

Figure 1: Incisor I1 at the 'crown complete' (Crc) stage. I2 is almost at the 'crown complete' (Crc) stage, the canine (C) & the first premolar Pm1 are at the 'crown ¾' stage (Cr¾)

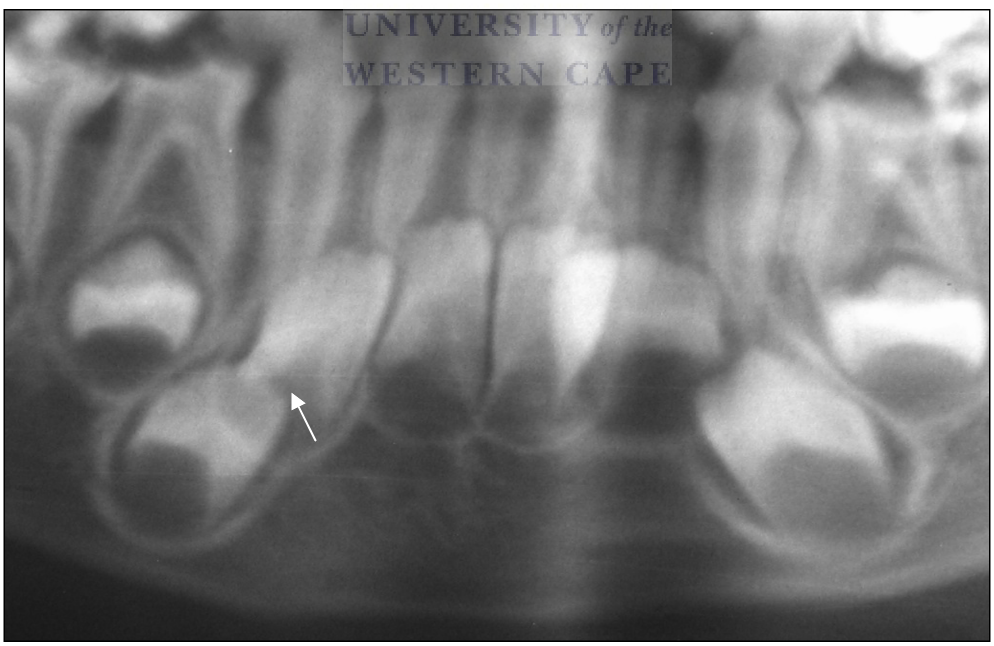


Figure 2: I1 is at the 'root initiation' stage (Ri); the I2 (arrow) is at the 'crown complete' stage (Crc), the Canine is at the 'crown ¾' stage (Cr¾), the Pm1 is at the 'crown ¾' stage (Cr¾)

The 'crown ¾' stage (Cr¾) shows calcification of the crown with thin elongations of enamel to the lower border of the follicle; the pulpal area has an early bell shape with a short pulp horn. As the crown develops further to the 'crown complete' stage (Crc), the dentine surrounding the pulp chamber calcifies and reveals a pulp chamber with a distinct bell shape and elongated pulp horn (similar to an inverted amphora vessel). The 'root initiation' stage (Ri) is seen as an elongation of the thin calcification lines from the crown into the underlying follicle. The pulp chamber and pulp horn have an elongated bell formation (Fig.3).

Figure 3: I1 is at the root ¼ stage (R¼), I2 is at the root initiation stage (Ri), the canine is at the root initiation stage (Ri). [Note the distinct round bell shape of the pulp chamber of the canine as the root starts to form (arrow)]

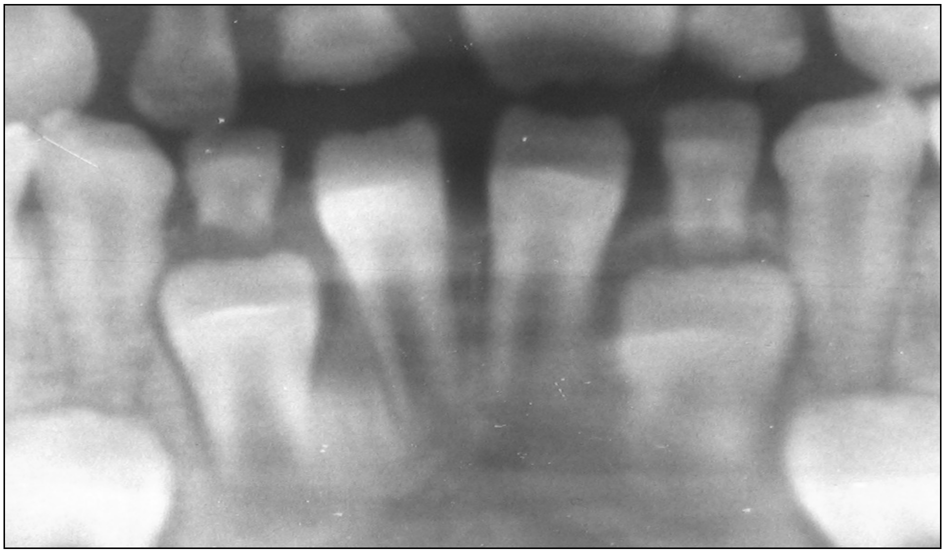


Figure 4: I1 is at the ‘root ½’ stage (R½), I2 is at the ‘root ¼’ stage (R¼)

As the root of the incisor starts to form it reaches the ‘root ¼’ stage (R¼), the root walls are short and pointed at the ends; the crown and root are of equal length; the pulp chamber and initial root canal is conical in shape with the base of the cone at the apical area. The ‘root ½’ (R½) stage has elongated root walls with pointed ends and with a pulp chamber and root canal having parallel sides; the root is approximately twice the length of the crown. The canine at the ‘root initiation’ stage (Ri) has a distinct form; the pulp horn is elongated and the pulp chamber has a round bell shape (Fig 5).

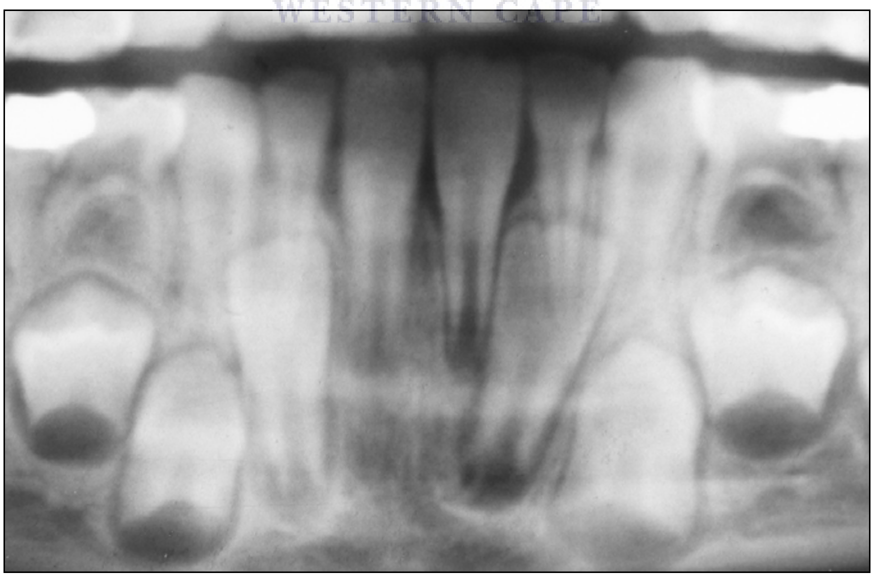


Figure 5: I1 is at the ‘root ¾’ stage (R¾), I2 is at the ‘root ½’ stage (R½), the canine (C) is at the ‘root initiation’ stage (Ri), the Pm1 is at the ‘crown complete’ stage (Crc)

Figure 6: I1 is at the 'apex ½' calcified stage (A½), I2 is at the 'root complete' stage (Rc), the canine (C) is at the 'root ¼' stage (R¼).

The 'root ¾' (R¾) stage for the incisors is attained when the root length is greater than twice the length of the crown; the tip of the root is still funnel shaped. The 'root complete'(Rc) stage is when the root is almost 3 times the length of the crown, the sides of the root canal are parallel and the width of the apical canal is the same as the width of the canal above it. As the apex of the root starts to form the walls of the root converge and narrow the root canal. This is the 'apex ½' (A½) stage; there is still a distinct radiolucent 'bulge' of the uncalcified future root apex (Figs 6 & 7). The stage at which the apex is complete (Ac) is seen when the apical calcification has converged the tip of the root to a point and the apical periodontal lamina dura of the bone surrounds the apex.

Figure 7: I1 is at the 'apex ½' calcified stage (A½), the I2 is at the 'root complete' stage (Rc), the canine is at the 'root ¼' stage (R¼), the left Pm1 is at the 'root initiation' stage (Ri), the right Pm1 is at 'root½' stage (R½) (arrow). [The roots of the permanent teeth appear to develop more rapidly when the overlying primary teeth are prematurely extracted]

1.4.2 Development of the canine and premolars

The canine and premolars go through similar developmental stages albeit at different times. Initially a radiolucent follicle appears at the apex of the overlying deciduous tooth (Fig 9); the well circumscribed radiolucency then develops points of calcification which are the cusps of the permanent tooth starting to form. Then follows the stages of cusp coalescence (Figs 8 & 10), crown formation and eventually root development (Figs 11-15).

Figure 8: The Pm1 is at the 'crown ½' stage (Cr½), the Pm2 is at the 'cusp outline Complete' stage (Coc), the M1 is at the 'cleft initiation' stage (Cli).

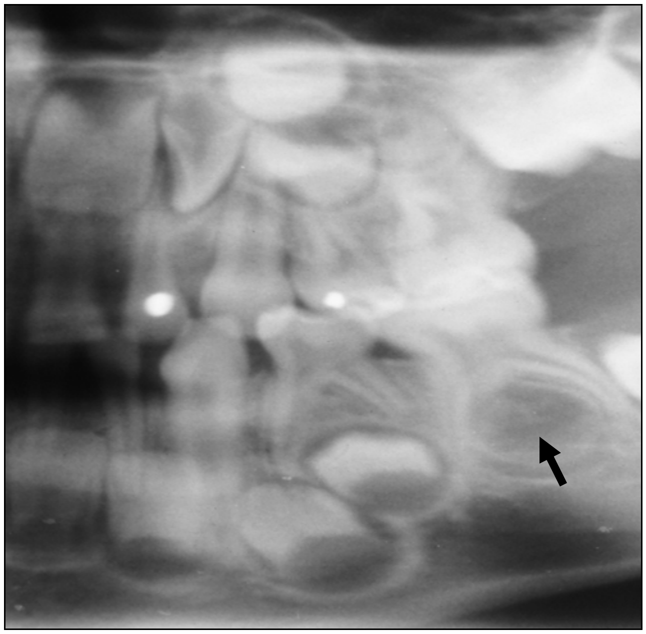


Figure 9: The canine and the Pm1 are at the 'crown ¾' stage (Cr¾), the Pm2 shows the 'follicle' stage (F) without any calcification of the cusps (arrow)

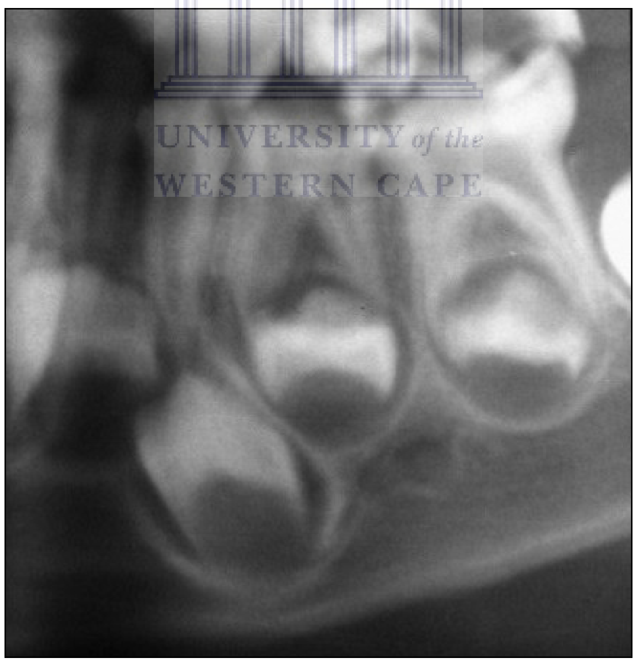


Figure 10: The canine is at the 'crown complete' stage (Crc), the Pm1 is at the 'crown ¾' stage (Cr ¾), the Pm2 is at the 'crown ½' stage

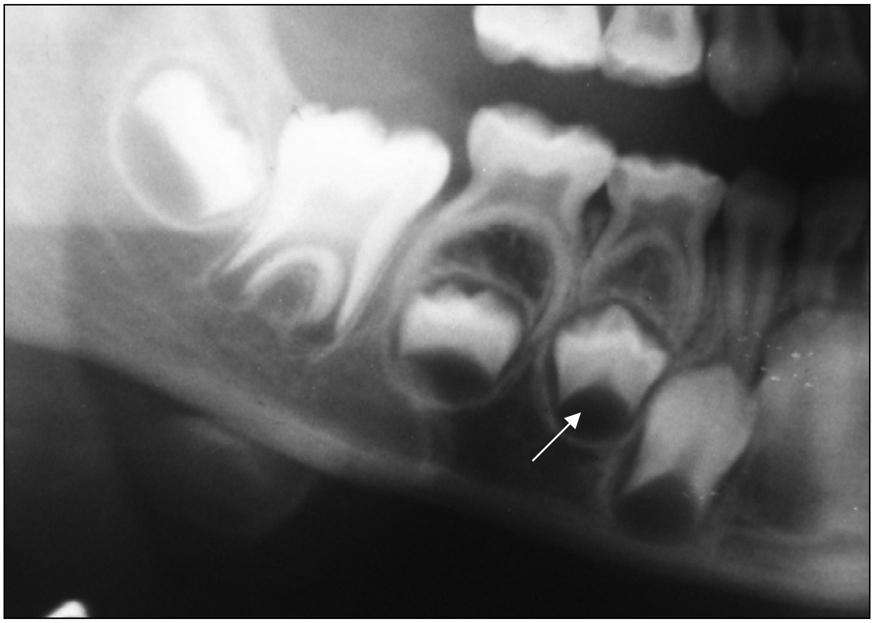


Figure 11: The canine is at a stage between root initiation and root ¼, note the elongated bell shape of the pulp extending from the crown to the root area. The Pm1 is at the 'crown complete' stage (Crc), the Pm2 is at the 'crown ¾' stage (Cr¾). The M1 is at the 'root ½' stage (R½), the M2 is at the 'crown ¾' stage (Cr ¾). Note that the Crc stage of the premolar has an early bell-shaped radiolucency in the pulp-horn / root area (Arrow).

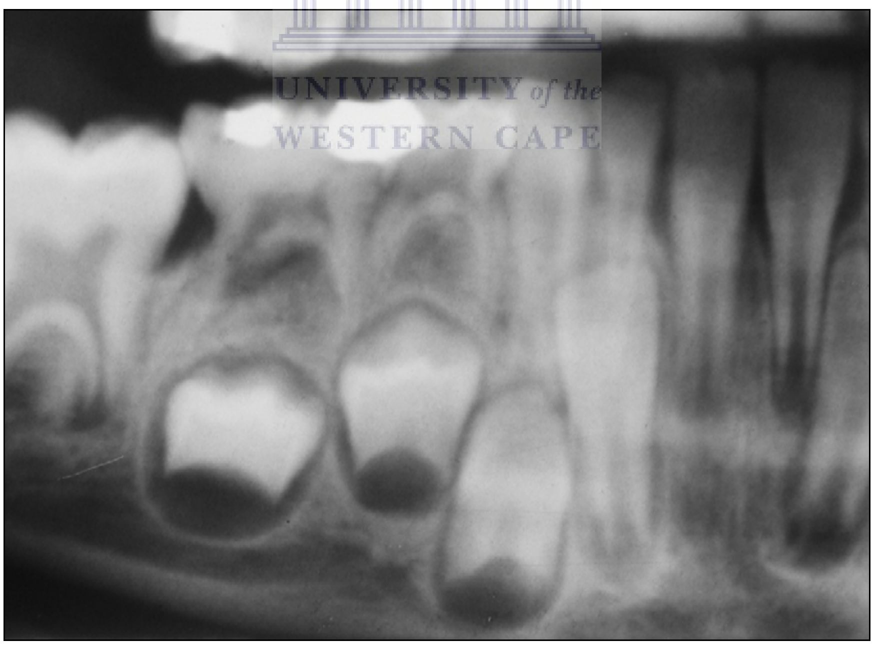


Figure 12: The I1 is at the 'root ¾' stage (R¾), the I2 is at the 'root ½' stage (R½), the canine is at the 'root ¼' stage (R¼), the Pm1 is at the 'root initiation' stage (Ri), the Pm2 is at the 'crown ¾' stage (Cr¾) [The pulp-horn is not yet visible].

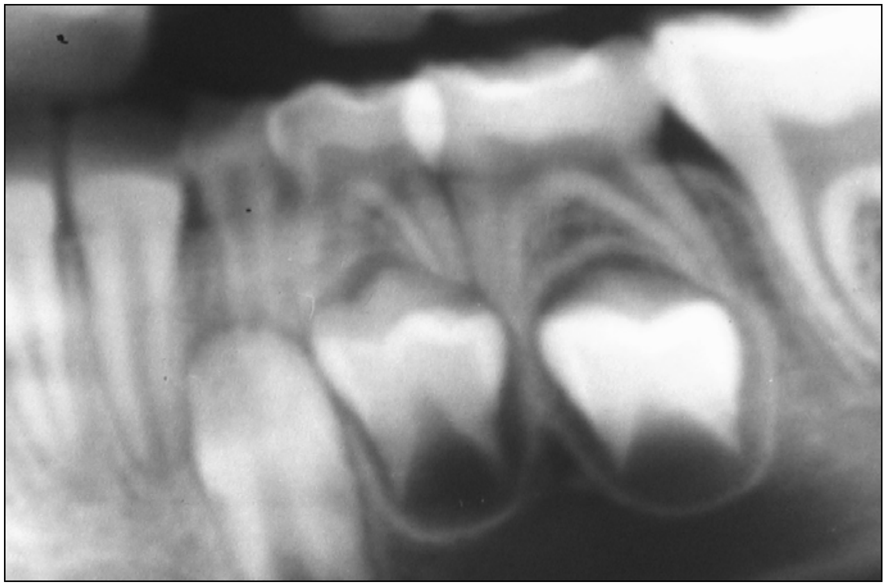


Figure 13: The Pm1 is at the late ‘root initiation’ stage (Ri) almost ‘root ¼’ stage (R¼), the Pm2 is at the ‘root initiation’ stage (Ri)

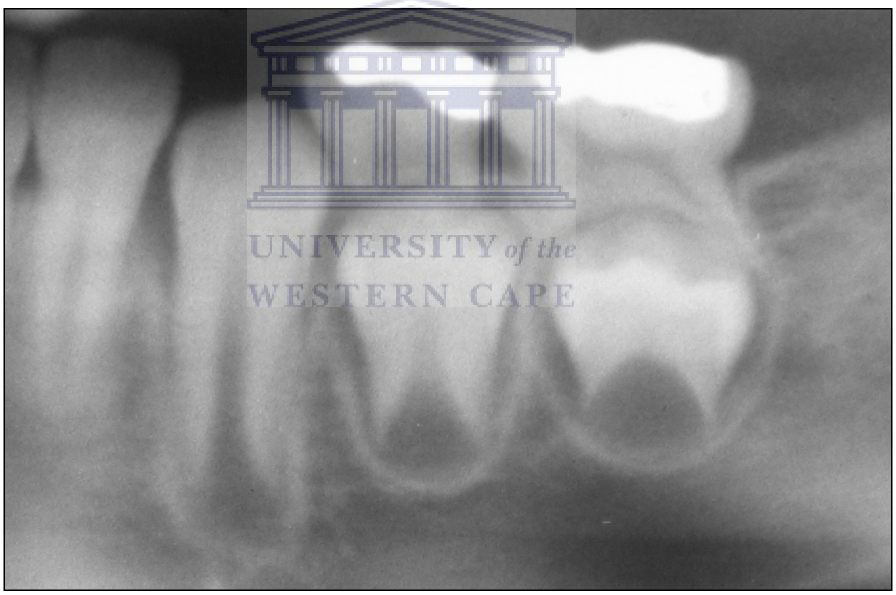


Figure 14: The canine is at the ‘root ¾’ stage (R¾), the Pm1 is at the ‘root ¼’ stage (R¼), the Pm2 is at the ‘root initiation’ stage (Ri)

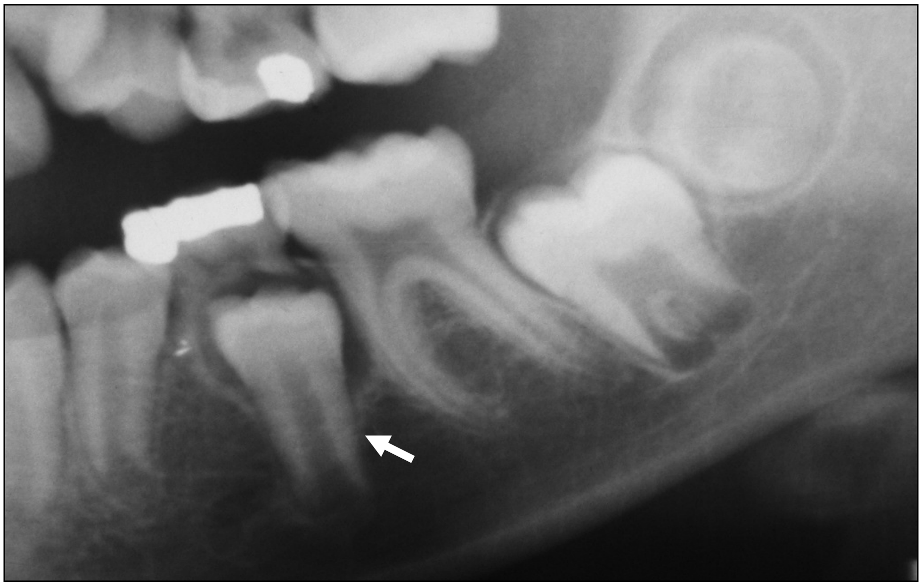


Figure 15: The Pm1 is at the 'root ¾' stage (R¾) almost 'root complete' stage (Rc), the Pm2 (arrow) is at the 'root ½' stage (R½) almost 'root ¾' stage (R¾). The apices of the M1 are at the 'apex ½' calcified stage (A½), the M2 is at the 'root ¼' stage (R¼). The M3 is at the 'cusp coalescent' stage (Cco)

1.4.3 Development of the molars

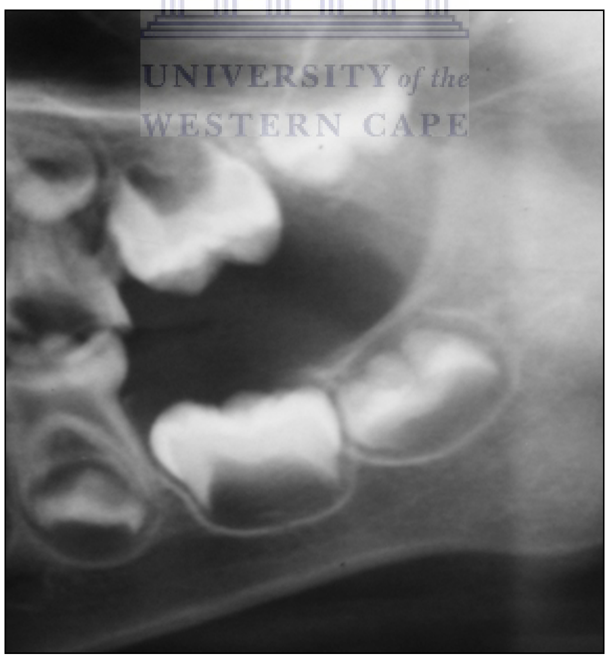


Figure 16: The M1 is at the 'crown complete' Stage (Crc), this is the stage just before 'root initiation' (Ri), followed by the root cleft formation; the M2 is at the 'cusp outline complete' stage (Coc)

The 1st molar starts to form intra-utero and the tips of the cusps begin calcification at birth. Figure 16 shows the 1st molar at the crown complete stage (Crc) (approximate age 4 years); the image shows the enamel cap and the underlying dentine covering the mesial and distal pulp horns and ending in a sharp point. As the dentine of the root starts to develop there is increased development of the dentine which has a beveled edge (Fig 17); this is the root initiation (Ri) stage that is followed by calcification of the cleft between the roots (Cli). Initially the cleft calcification is a point of calcified tissue but soon develops an inverted curve (Fig 18); as this curve elongates downwards the roots start to form and calcify leading to the 'root ¼' stage of development (R¼). The root length at stage 'root ¼' is less than the crown height. When the root length is equal to the crown height, the stage of 'root ½' (R½) is reached. 'Root ¾' stage (R¾) is reached when the root is longer than the crown height, the root canals are parallel and the root tip is conical shaped. The 'root complete' (Rc) stage is attained when the root shape has narrowed and the root canal has started to narrow slightly compared to the canal above. The root apex is still wide open and the radiolucent area in the adjacent bone is prominent.

The closure of the apex begins with narrowing of the root canal and the adjacent radiolucency reducing in size (A½) (See Fig.19 – distal root of M1). When the apex is closed (Ac) the periodontal ligament space is a uniform width around the root tip.

Figure 17: The 1st molar (M1) at the 'root initiation' stage (Ri). The cusps of the 2nd molar have fused and the stage of 'cusp outline complete' (Coc) has been attained. [Note: There is initial calcification of the crown of the Pm2 within the follicle]

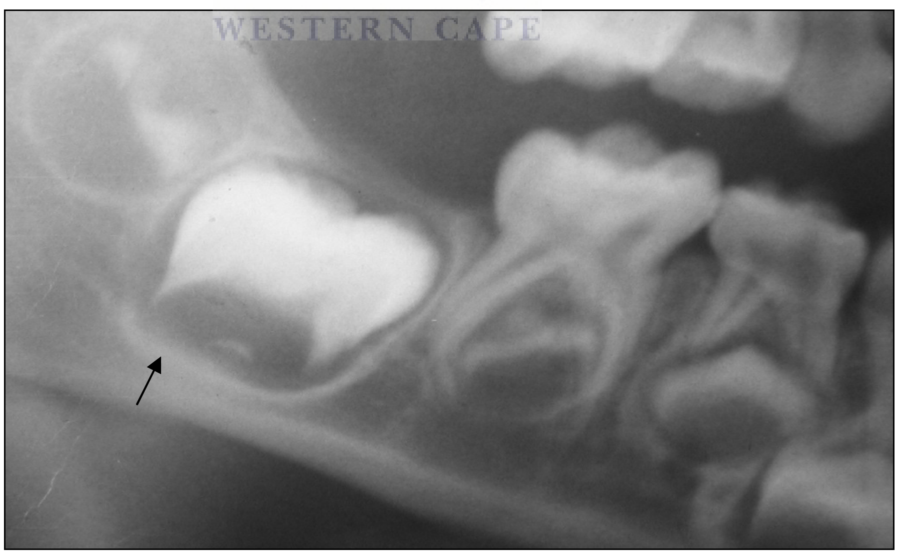


Figure 18: The first molar (M1) showing the 'root initiation' and early root cleft (arrow) calcification with an inverted 'U'

Figure 19: The 2nd molar shows that as the cleft of the root formation continues to calcify the stage of 'root ¼' (R¼) is reached

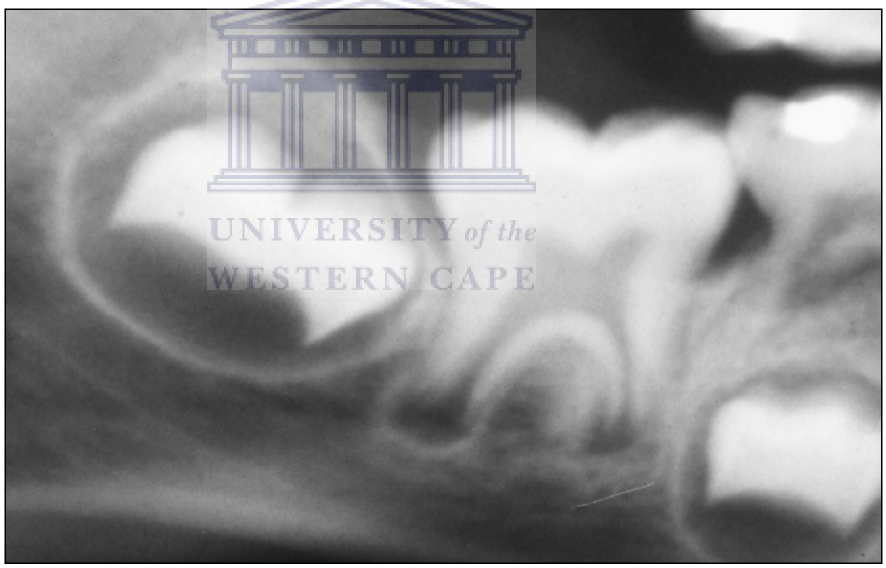


Figure 20: The roots of the 1st molar show 'root ¼' stage (R¼) of development. The 2nd molar is at the 'crown ¾' (Cr ¾) stage.

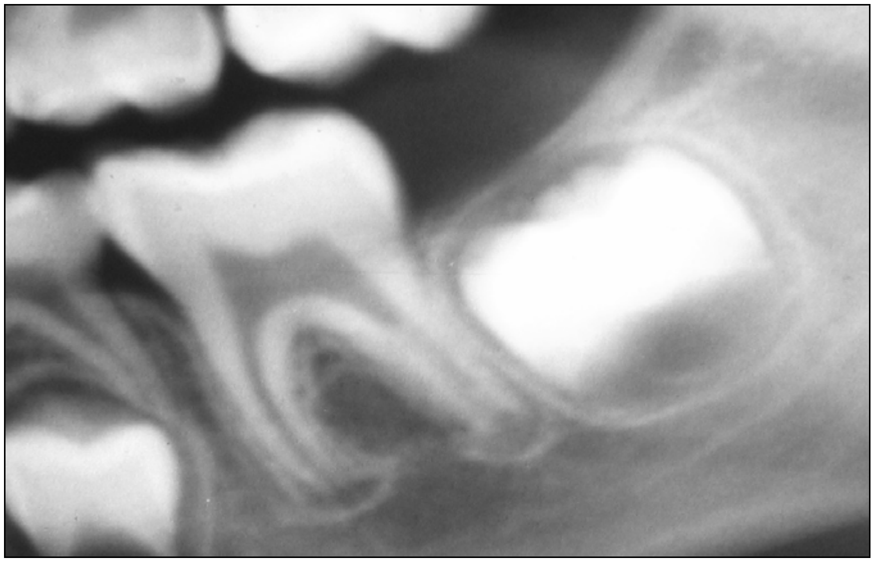


Figure 21: The roots of the 1st molar have elongated; the mesial root is at the 'apex ½' stage (A½) showing the narrowing of the root canal; the distal root is at the 'root complete' stage (Rc), showing parallel root walls and the apex having the same width as the root canal

The roots of the molars develop at different rates; the mesial root often develops faster than the distal root. Figure 21 shows that the mesial root apex is starting to close whereas the distal root is at the 'root complete' stage (Rc) and the apex has not narrowed at all. Figure 22, however, shows both roots at the same stage of development. The distal root of the 1st molar often appears longer than the mesial root (Fig 22).

The development of the crown of the 2nd molar progresses through the various stages from cusp initiation, cusp coalescence, cusp outline complete and then crown formation and eventually root formation. The mesial and distal roots also develop at different rates but not as markedly as those of the 1st molar.

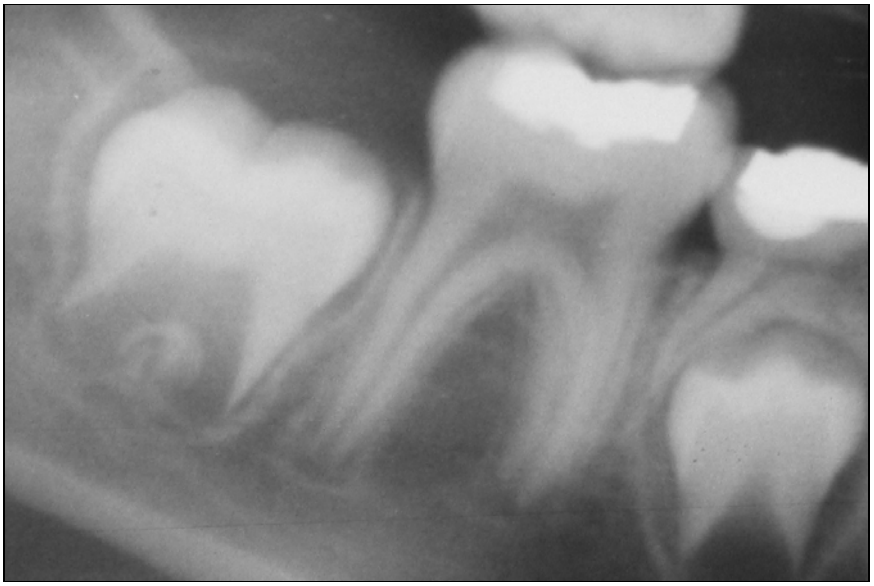


Figure 22: The 1st molar shows the mesial and distal roots at the same stage of development ‘root complete’ (Rc). The 2nd molar is at ‘root ¼’ stage (R¼)

1.4.4 Variations during development

1.4.4.1 Canine & Premolars

The canine and premolars develop at similar rates and stages. The root development has been divided into Ri, R¼, R½, R¾ and Rc; these stages are often difficult to establish as there are intermediary stages where the length of the root is between two stages.

Figure 23 shows the PM1 and Pm2 at the R¼ stage of root development; the root of PM1 is distinctly longer than Pm2, but is not yet twice the length of the crown and must therefore be designated as at the ‘root ¼’ stage (R¼).

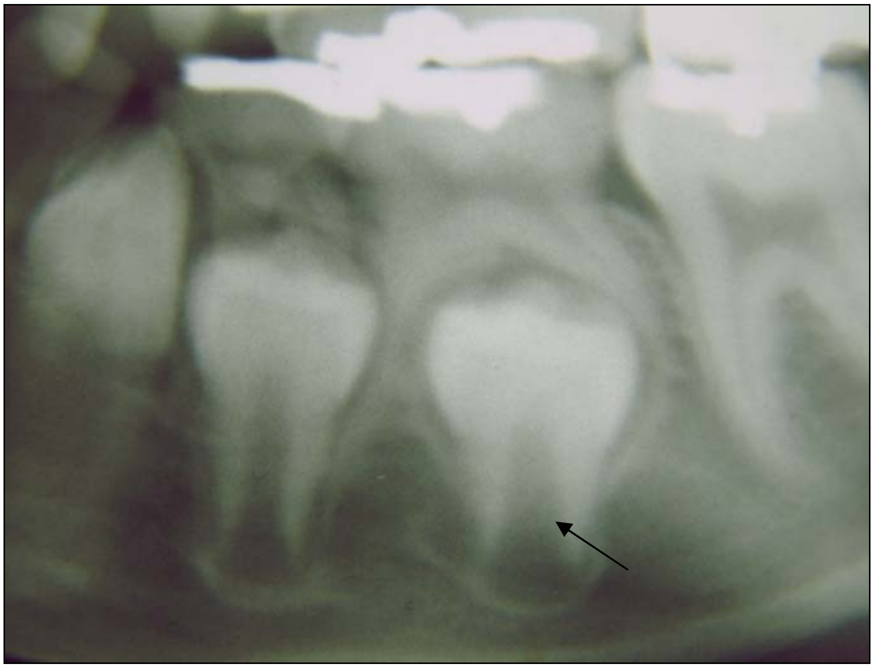


Figure 23: The Pm1 and the Pm2 are both at the 'root ¼' stage (R¼). The root of Pm1 is slightly longer than Pm2.

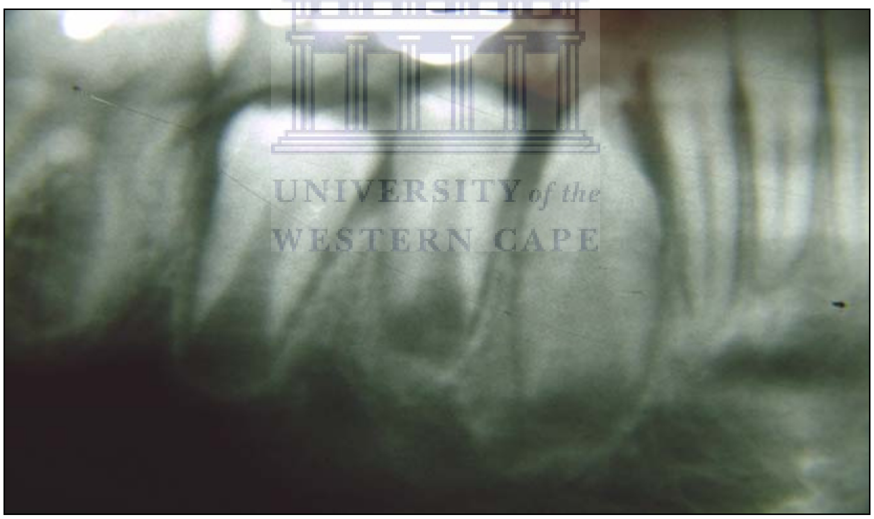


Figure 24: Both Pm1 & Pm2 and the canine are at 'root ½' stage (R ½). [Note the conical shape of the root canals.]

The stage of 'root half' (R½) shows the root canal to be an elongated cone with a wide open apex and the root walls pointed (Fig 24). As the root elongates to the 'root complete' stage (Rc) (Fig 25), the root walls become parallel, the root canal is of even width and the apex is slightly flared. The uncalcified root apical area is visible as a small radiolucency.

Figure 25: The apex of the Pm1 is at ‘apex ½’ stage (A ½); the Pm2 is at the ‘root complete’ stage (Rc). Both the mesial and distal root apices of the M1 have calcified (Ac)

The calcification of the root apex from half complete to the complete stage shows initial narrowing of the apical walls of the root (A½) and subsequent closure of the apex (Ac).

1.5 AIMS AND OBJECTIVES

1.5.1 Aim

The aim of this study was to establish the accuracy of the standard dental age estimation methods of Moorrees, Fanning and Hunt (1963) [MFH] and Demirjian, Goldstein and Tanner (1973) [DGT] on samples of the South African child population. If these existing tables were found to be inaccurate to then construct applicable dental age related tables for South African children.

1.5.2 Objectives

(a) Compare age estimation of tooth eruption with crown and root calcification

(b) To develop dental age related tables for South African male and female children of different population groups.

(c) Estimation of the ages of South African children using the methods of Moorrees *et al* [MFH] and Demirjian *et al* [DGT] and gauge the accuracy of these methods

(d) The development of correction tables for the MFH and DGT methods of age estimation applicable to South African children

(e) Testing of the correction tables for MFH and DGT on the original samples of South African children

(f) Testing of the correction tables for MFH and DGT on new samples of South African children

(g) The development of new dental age related tables for South African children from the data of the study

(h) Testing the new dental age estimation tables on different samples of South African children and statistically analyzing the results compared to the MFH and DGT methods.

1.6 STYLE OF THE THESIS

The style of this thesis is in a format in which each chapter from 3 to 8 is a self-standing analysis.

CHAPTER 2

COMPARISON OF AGE ESTIMATION BY TOOTH ERUPTION WITH CALCIFICATION STAGES OF CROWNS AND ROOTS; A REVIEW

This chapter compares the age estimation of children by means of the eruption times of their teeth with age estimation by radiographic imaging of the developing teeth.

Eruption is the process by which teeth, in their bony crypts, migrate through the jaws and emerge into the mouth. It continues as each tooth moves into occlusion and beyond, to compensate for the effects of wear, so that eruption is a continuous process that never completely ceases. Clear-cut stages are therefore difficult to define (Hillson, 1996).

2.1 ALVEOLAR EMERGENCE OF THE TEETH.

The emergence of the tooth through the crest of the alveolar process is not a sudden event. In dry bone specimens it is first seen as a small aperture which gradually widens as the tooth crown rises higher until it has opened out to the full crown diameter. In radiography the same process is seen as a gradual decreasing rim of lamina dura overlying the tooth. Anthropologists studying dry specimens define alveolar emergence as the first appearance of the tooth cusps above the alveolar crest; in radiographs it is the stage at which the alveolar bone has been completely resorbed over the occlusal surface of the tooth (Hillson, 1996).

2.2 GINGIVAL EMERGENCE (CLINICAL ERUPTION)

The appearance of the teeth through the gingiva is also a gradual process. Cusp tips appear as small pinpoint nodules before the bulk of the occlusal surface follows.

Haavikko (1970) defined tooth eruption as clinically erupted when the crown of the tooth or part of it has roentgenologically been observed to have penetrated the mucous membrane. Saleemi *et al* (1994) recorded teeth as emerged if any part of the crown was visible in the mouth seen with the naked eye.

2.3 ENTRY OF THE CROWN INTO OCCLUSION

With the dentition in situ each crown may be judged with reference to its neighbours, or by first signs of wear. This is a definition that is difficult to use clinically but may be useful for anthropological purposes (Hillson, 1996).

2.4 EXFOLIATION OF DECIDUOUS TEETH

The process of deciduous tooth resorption can be observed in dry specimens and radiographically. The timing of deciduous teeth resorption is known from several radiographic studies (Fanning, 1961; Moorrees, Fanning and Hunt, 1963; Haavikko, 1973). Depending on the definitions used, alveolar emergence may be in advance of gingival emergence by a few months to a year or more (Haavikko, 1973). In addition, the sequence with which teeth emerge at the alveolar crest may be different from the gingival emergence sequence as stated by Garn and Lewis in 1963, (Hillson, 1996). Eruption has been considered the traditional method for dental age estimation (Clements *et al*, 1957) and the emergence of teeth as an indicator of age has been used by physical anthropologists, dentists and forensic pathologists for many years. It has therefore been accepted as a rough guide of the stage of development compared to chronological age of a child.

Studies on the emergence of the teeth through the gingiva show that eruption takes place during three periods of childhood and early adulthood (Hillson, 1996).

1. Period of deciduous dentition
2. Period of mixed dentition, when the permanent first molars emerge distal to the deciduous tooth row; the deciduous incisors are replaced by the permanent incisors
3. Period of permanent dentition, when all the deciduous teeth are replaced by permanent teeth.

The deciduous teeth start to emerge through the gums during the first few months of life (5 to 7 months), and the first 4 teeth are usually apparent by 14 months. The eruption pattern is constant; central incisors appear first then the lateral incisors. The 1st molars emerge at about 15 to 18 months, the canines between 16 and 19 months and the 2nd molars at 23 to 30 months. Most children have a normal complement of 20 deciduous teeth at the age of 3 years.

2.5 ERUPTION OF PERMANENT TEETH

In 1837 Saunders established gingival emergence of molars as an indicator of children's ages (Hillson, 1996). Exploitation of young children in factories during the industrial revolution in Britain became widespread, and led to a series of legislative measures to apply limits to the age at which a child could be employed. Modern forensic odontology rarely relies on gingival or alveolar emergence for age estimates. The eruption of the permanent dentition begins at about 6 years. There are four distinct phases in human tooth emergence into the mouth (Hillson, 1996);

Stage1: deciduous teeth most of which emerge during the 2^{nd} year of life

Stage 2: the emergence of the permanent 1^{st} molar (M1), the central incisor (I1) and then the lateral incisor (I2) at 6-8 years

Stage 3: the eruption of the canine (C), followed by the 1^{st} premolar (Pm1), the 2^{nd} premolar (Pm2) and the 2^{nd} molar (M2) at 10-12 years

Stage 4: is the eruption of the 3^{rd} molar (M3) at 18+ years.

This is theoretically interesting, but is subject to several factors that could either accelerate or retard the eruption of the teeth, i.e. early loss of teeth due to caries, trauma, or early extractions would accelerate the eruption pattern. Early loss of deciduous molars causes tooth drifting which closes the gap for the erupting permanent premolars and results in impaction and subsequent delayed eruption of these teeth.

There are important differences between maxillary and mandibular growth patterns and the emergence of teeth in these jaws, but there is no significant difference between left and right sides of either jaw (Bambach, Saracci and Young, 1973; Billewitcz, et. al, 1973; Demirjian, Goldstein and Tanner, 1973). Individual variation will produce uncertainty in age estimation due to variable rates of development. Prematurity and infant mortality do not introduce bias in the rate of dental development, but they do contribute to variance (Khan, Chakraborty and Paul, 1981). Nutritional status plays a major role in eruption times and was shown to retard deciduous tooth eruption in rural Guatemalan children by 2 months (Delgardo et. al, 1975).

Radiographic studies are far more accurate in correlating age with the development of the teeth. Gingival emergence has, however, been used in growth studies in which the children cannot be routinely radiographed (Filipsson, 1975; Moorrees and Kent, 1978).

The eruption data for permanent teeth of 2847 African and Asian children age 4-14 years in Nairobi was analysed by Hassanali and Odhiambo (1982). They found the range of error varies from 18-30% of the median age for African males, 21-29% for African females, 15-33% for Asian males and 18-33% for Asian females.

A longitudinal study of Swedish urban children from birth to 18 years was undertaken by Hagg and Taranger (1986). All deciduous teeth in this study, except the mandibular 2nd molars, emerged earlier in boys than in girls. All permanent teeth emerged earlier in girls, the sex differences being 2.5 to 14 months. The comparison between dental eruption age and chronological age for deciduous teeth varied by ± 4 months, but for permanent teeth it varied by ± 3 years Hagg and Taranger (1985).

The eruption of permanent teeth has been studied in far greater detail in several studies (Hurme, 1949, 1951; Dahlberg and Menegaz-Bock, 1958; Jaswal, 1983; Smith and Garn, 1987). There is considerable variation in both sequence and timing of tooth eruption; however, it is possible to state a normal sequence that applies to many populations around the world (Hillson, 1996).

The order of emergence for the upper permanent dentition: M1, I1, I2, Pm1, C, Pm2, M2, M3.

The order of emergence for the lower permanent dentition: M1, I1, I2, C, Pm1, Pm2, M2, M3.

Gingival emergence (Table 1) has a strong correlation between the left and right sides (antimeres) and equivalent teeth in the upper and lower jaws (isomeres). Lower teeth emerge earlier than their equivalents in the upper jaw, especially the anterior teeth. The permanent dentition (especially canines) in girls usually emerges before that of boys in the same population, but there are differences in other population groups (Garn *et al*, 1973a). The permanent teeth of Europeans (particularly molars) erupt later than in other populations, whereas children from poorer families show slightly later tooth emergence than the children from a higher socio-economic level (Garn *et al*, 1973b).

Table 1: Summary of gingival emergence of deciduous and permanent teeth (Hillson, 1996)

Deciduous dentition
First incisors (lower then upper)
Second incisors (upper then lower)
First molars
Canines
Second molars (lower then upper)
Permanent dentition
First molars
First incisors
Second incisors
Upper first premolars, or lower canines
Upper canines, or lower first premolars
Second premolars
Second molars
Third molars

Some pairs of teeth are particularly close in eruption timing and the eruption order is frequently reversed (Smith and Garn, 1987). The most common variation (especially in the lower jaw) is a reversal of the eruption sequence of the first incisors and first molars (I1, M1 instead of M1, I1). Later there is considerably more variation; the most stable sequences are Pm2, Pm1 in the lower jaw and Pm2, M2 in the upper jaw. Common deviations are Pm2, C; C, Pm1; Pm1, C; and M2, Pm2.

The following sequences therefore encompass the most likely pattern of variation (the brackets indicate that the order is commonly reversed) (Hillson, 1996):

Upper jaw   M1, I1, I2, (Pm1, C, Pm2) M2, M3

Lower jaw   (M1, I1), I2, (C, Pm1), (Pm2, M2), M3

The stages of development of the teeth were thought to be affected by environmental factors as well as genetic inheritance until Lavelle (1976) showed that the development of the teeth is primarily under genetic control. The enamel formation of deciduous teeth is almost completed before the child is born and there has been no evidence that climate or disease have any major effect on the development of deciduous teeth in contrast to musculo-skeletal development (Neill *et al.* 1973; Trustwell and Hanson, 1973; Friedlander and Bailit, 1969; Khan, Chakraborty and Paul, 1981). There has however been evidence that the socio-economic factors of a family play an important role in the time of emergence of teeth (Enwanwu, 1973). The use of emergence of teeth as a marker of age introduces an important variance and thereby limits its applicability at certain ages. The number of teeth that have emerged in a mouth is a discontinuous variable that represents a continuous process; the eruptions are sufficiently close to one another in time to provide estimates of age only during particular periods of growth.

Aging by tooth emergence is limited to children under the age of 3 and from 6 to 12 years of age. Only approximate categorization can be achieved between the ages of 3 and 6 years (Townsend and Hammel, 1990).

Schour and Massler (1941) published the well known diagram of both tooth formation and eruption dividing the sequence into 22 stages (Fig. 1). This study was based on the work of Logan and Kronfeld (1933). Although this study was carried out on a small number of terminally ill children most of whom were under 2 years of age when they died, it performs well in comparison with the studies of Moorrees, Fanning and Hunt (1963) and Gustafson and Koch (1974). A revision of this work was undertaken by Ubelaker (1978), who removed one prenatal stage and added a new stage at 18 months and applied data drawn from numerous studies. The Ubelaker chart (Table 3) was developed for studies on Native Americans, but is recognised as a standard reference throughout the world (Buikstra and Ubelaker, 1994).

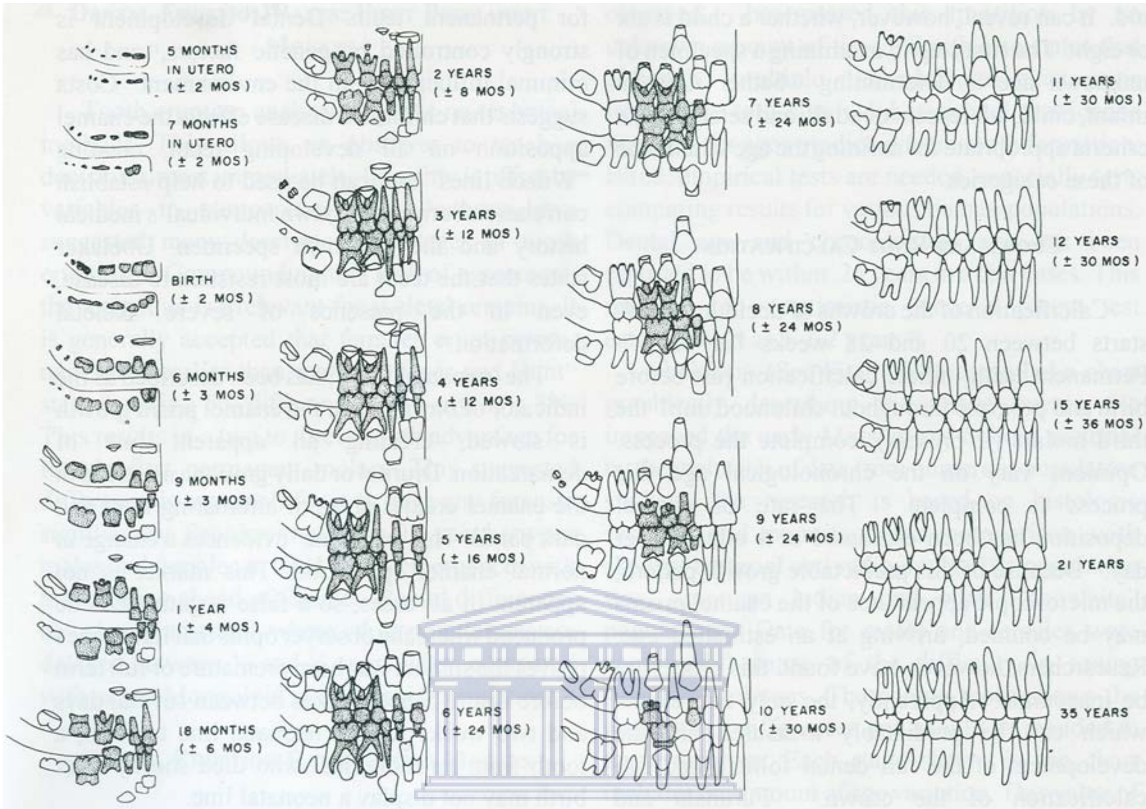
Conclusion

Estimation of age is a task of the physical anthropologist and the eruption and development of the dentition have been used extensively to estimate the ages of children at death. The most widely used are the charts of Schour and Massler (1941) and that of Buikstra and Ubelaker (1994) as these are pictorial and easy to use. The clinical emergence of the primary and secondary dentition in the mouth is at best a rough guide as to the chronological age of children, but this method is not as accurate as the developmental stages of crown and root formation as seen on radiographic images.

Figure 1: Schour and Massler Chart

Figure 5.8 Schour and Massler's original dental development diagram. Reproduced from Schour, I. & Massler, M. (1941) The development of the human dentition, *Journal of the American Dental Association,* **28,** 1153–1160, with the kind permission of the American Dental Association, 211E Chicago Avenue, Chicago 60611.

Figure 2: Ubelaker Dental Age Development Chart



Ubelaker DH. Human skeletal remains: excavation, analysis, interpretation, Chicago: Aldine, 1978.

CHAPTER 3

THE PUBLISHED STUDIES OF DENTAL AGE ESTIMATION BY CALCIFICATION OF PERMANENT MANDIBULAR TEETH

A period of investigation took place during 1950's and 1960's when a large number of radiographs of children were examined as part of an ongoing study of growth amongst American children (Gleiser and Hunt, 1955; Demisch and Wartmann, 1956; Nolla, 1960; Fanning, 1961). Thereafter, Canadian growth studies on French-Canadian children in Montreal were carried out utilizing radiographic data (Demirjian, Goldstein and Tanner, 1973; Haavikko, 1974; Demirjian and Goldstein, 1976; Demirjian and Levesque, 1980). Similar studies have been carried out on European children in the Netherlands and Finland (Nylström *et al*, 1986) as well as a cross-sectional study on Finnish children (Haavikko, 1970). Subjects in all these studies were of European derivation. Gustafson and Koch (1974) published a chart (Table 1) covering the development of the dentition from 8 months before birth to 16 years of age. The chart was based on pooled data collected from 19 sources published between 1909 and 1964. Four landmarks in the process of development of each tooth were recorded, the commencement of mineralization, the completion of crown formation, the completion of tooth eruption and the termination of root formation. Each landmark is represented graphically on the chart by a small triangle.

Trodden (1982) studied the eruption and calcification times of a small group of Inuit and Amerindians from Canada and derived dental age estimation tables for this population group. All the radiographic studies included at least three stages of tooth formation beginning with crown calcification following with crown completion and root formation and completion. Originally Nolla (1960) started with 11 stages of tooth formation

(Table 2) that was subsequently modified (Moorrees, Fanning and Hunt, 1963; Andersen, Thompson and Popovich, 1976; Nyström *et al*, 1986). The stages are based on simple fractions of crown and root formation and are simple to use and are easily modified. Demirjian *et al*. (1973) proposed an 8 stage system of crown and root calcification labeled from A to H (Table 3). The developmental stage of each tooth is gauged by comparison with Table 3 then given a 'self-weighted' score from Table 6 (male or female). The sum of the 'self-weighted' scores is converted to an age from Table 4 and 5. This method of Demirjian has subsequently been tested on several population groups with varying success.

Table 1: Tooth development tables of Gustafson and Koch (1974)

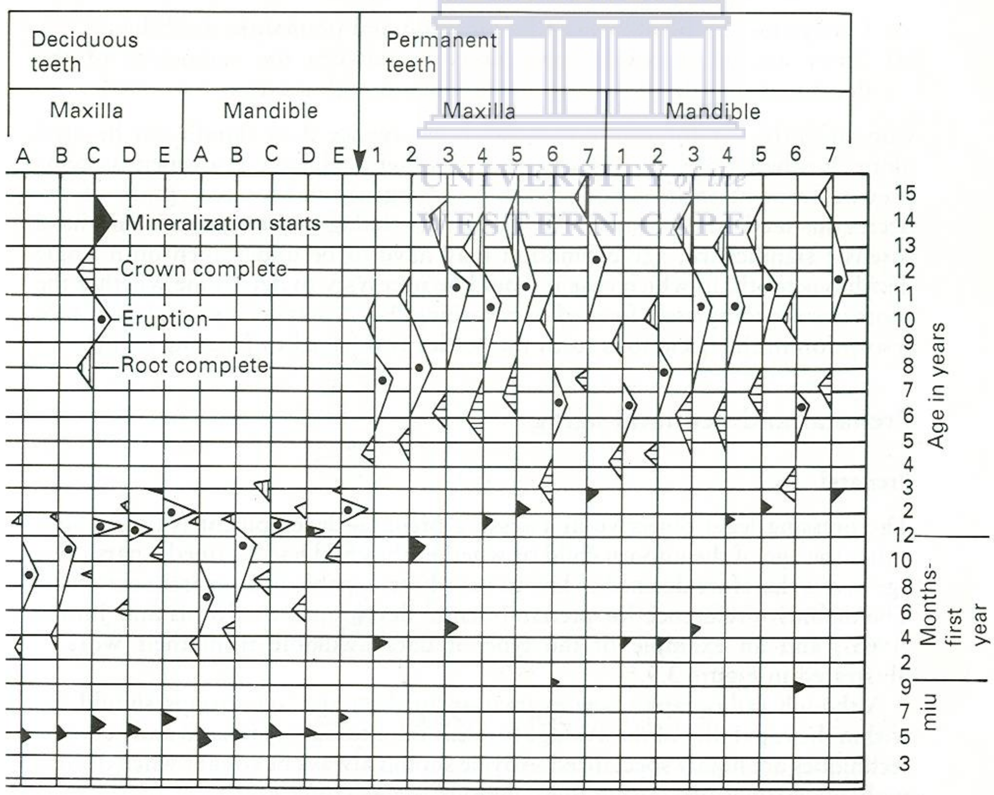


Table 2: The developmental stages of adult teeth by Nolla (1960)

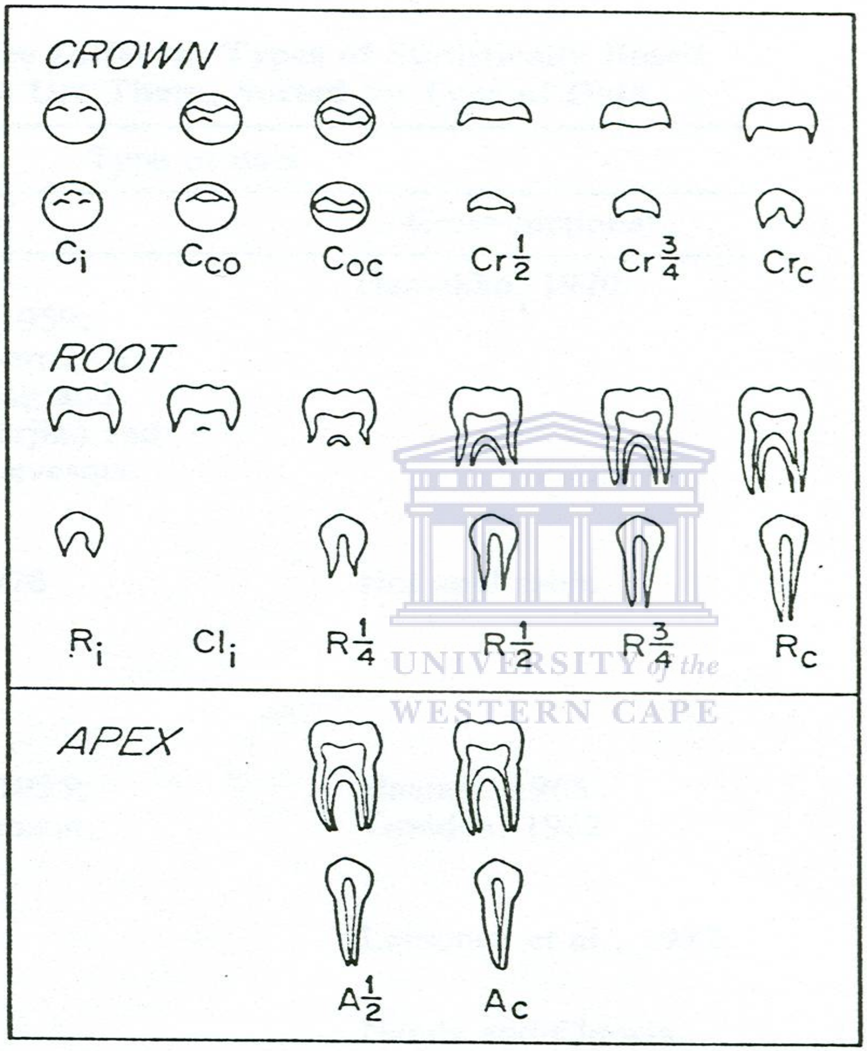
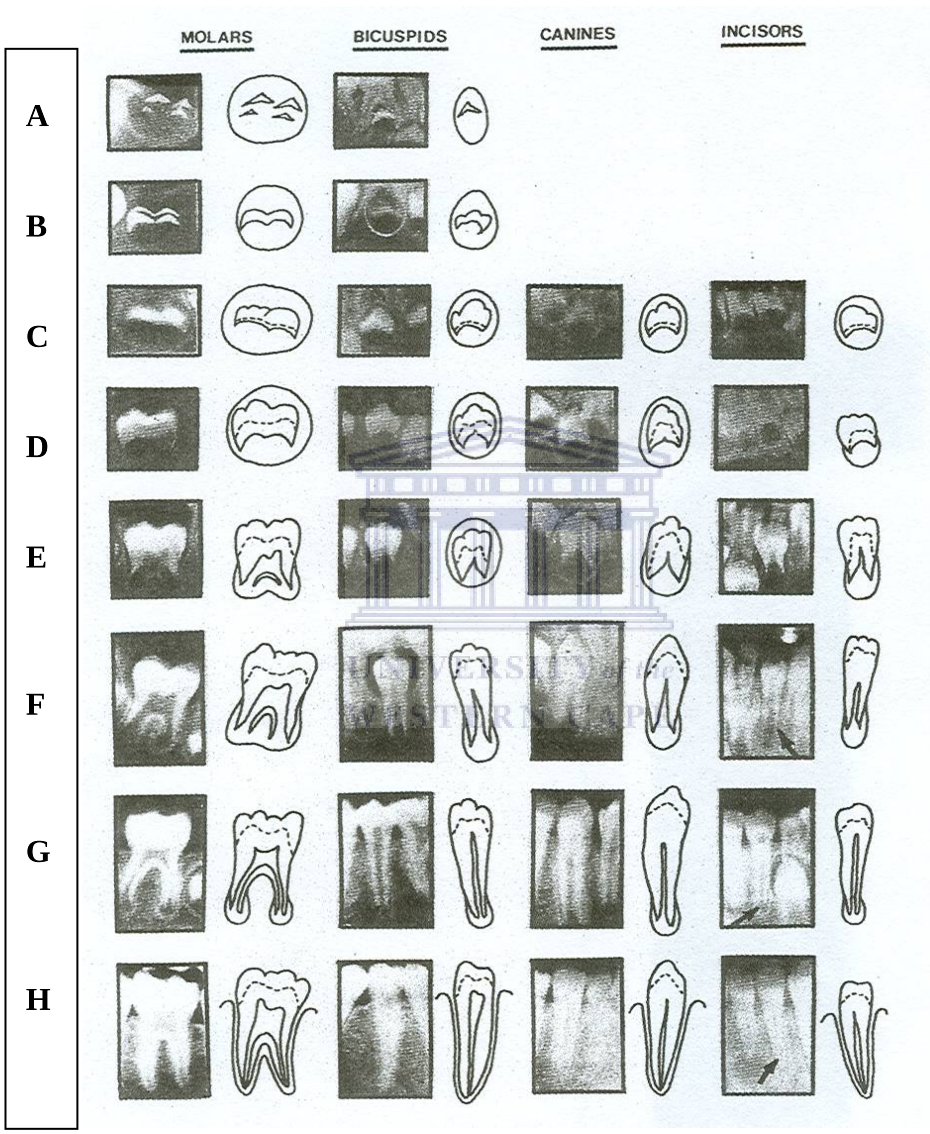


Fig. 3. Stages of permanent tooth formation redrawn from Moorrees et al. (1963a). This scale represents a detailed division of stages and the system has been widely used. The 14 stages are shown here with their standard abbreviations. Capitals: C = cusps; Cr = crown; R = root; Cl = cleft; A = apex; subscripts: i = initiated; co = coalescence; oc = outline complete; c = complete. It is best to designate these stages by abbreviation rather than number because the system is often modified by interpolating in additional stages, or omitting others (e.g., Anderson et al., 1976; Haavikko, 1970; and even Moorrees et al, 1963a).

Table 3: Developmental stages of teeth of Demirjian



Demirjian A, Goldstein H, Tanner JM. (1973).

Table 4: Demirjian *et al* (1973) conversion table for boys

Conversion of Maturity Score to Dental Age (7 Teeth)

Age	Score	Age	Score	Age	Score	Age	Score
			Boys				
3.0	12.4	7.0	46.7	11.0	92.0	15.0	97.6
.1	12.9	.1	48.3	.1	92.2	.1	97.7
.2	13.5	.2	50.0	.2	92.5	.2	97.8
.3	14.0	.3	52.0	.3	92.7	.3	97.8
.4	14.5	.4	54.3	.4	92.9	.4	97.9
.5	15.0	.5	56.8	.5	93.1	.5	98.0
.6	15.6	.6	59.6	.6	93.3	.6	98.1
.7	16.2	.7	62.5	.7	93.5	.7	98.2
.8	17.0	.8	66.0	.8	93.7	.8	98.2
.9	17.6	.9	69.0	.9	93.9	.9	98.3
4.0	18.2	8.0	71.6	12.0	94.0	16.0	98.4
.1	18.9	.1	73.5	.1	94.2		
.2	19.7	.2	75.1	.2	94.4		
.3	20.4	.3	76.4	.3	94.5		
.4	21.0	.4	77.7	.4	94.6		
.5	21.7	.5	79.0	.5	94.8		
.6	22.4	.6	80.2	.6	95.0		
.7	23.1	.7	81.2	.7	95.1		
.8	23.8	.8	82.0	.8	95.2		
.9	24.6	.9	82.8	.9	95.4		
5.0	25.4	9.0	83.6	13.0	95.6		
.1	26.2	.1	84.3	.1	95.7		
.2	27.0	.2	85.0	.2	95.8		
.3	27.8	.3	85.6	.3	95.9		
.4	28.6	.4	86.2	.4	96.0		
.5	29.5	.5	86.7	.5	96.1		
.6	30.3	.6	87.2	.6	96.2		
.7	31.1	.7	87.7	.7	96.3		
.8	31.8	.8	88.2	.8	96.4		
.9	32.6	.9	88.6	.9	96.5		
6.0	33.6	10.0	89.0	14.0	96.6		
.1	34.7	.1	89.3	.1	96.7		
.2	35.8	.2	89.7	.2	96.8		
.3	36.9	.3	90.0	.3	96.9		
.4	38.0	.4	90.3	.4	97.0		
.5	39.2	.5	90.6	.5	97.1		
.6	40.6	.6	91.0	.6	97.2		
.7	42.0	.7	91.3	.7	97.3		
.8	43.6	.8	91.6	.8	97.4		
.9	45.1	.9	91.8	.9	97.5		

Table 5: Demirjian *et al* (1973) conversion table for girls

Conversion of Maturity Score to Dental Age 7 Teeth (Mandibular Left Side)

Age	Score	Age	Score	Age	Score	Age	Score
Girls							
3.0	13.7	7.0	51.0	11.0	94.5	15.0	99.2
.1	14.4	.1	52.9	.1	94.7	.1	99.3
.2	15.1	.2	55.5	.2	94.9	.2	99.4
.3	15.8	.3	57.8	.3	95.1	.3	99.4
.4	16.6	.4	61.0	.4	95.3	.4	99.5
.5	17.3	.5	65.0	.5	95.4	.5	99.6
.6	18.0	.6	68.0	.6	95.6	.6	99.6
.7	18.8	.7	71.8	.7	95.8	.7	99.7
.8	19.5	.8	75.0	.8	96.0	.8	99.8
.9	20.3	.9	77.0	.9	96.2	.9	99.9
4.0	21.0	8.0	78.8	12.0	96.3	16.0	100.0
.1	21.8	.1	80.2	.1	96.4		
.2	22.5	.2	81.2	.2	96.5		
.3	23.2	.3	82.2	.3	96.6		
.4	24.0	.4	83.1	.4	96.7		
.5	24.8	.5	84.0	.5	96.8		
.6	25.6	.6	84.8	.6	96.9		
.7	26.4	.7	85.3	.7	97.0		
.8	27.2	.8	86.1	.8	97.1		
.9	28.0	.9	86.7	.9	97.2		
5.0	28.9	9.0	87.2	13.0	97.3		
.1	29.7	.1	87.8	.1	97.4		
.2	30.5	.2	88.3	.2	97.5		
.3	31.3	.3	88.8	.3	97.6		
.4	32.1	.4	89.3	.4	97.7		
.5	33.0	.5	89.8	.5	97.8		
.6	34.0	.6	90.2	.6	98.0		
.7	35.0	.7	90.7	.7	98.1		
.8	36.0	.8	91.1	.8	98.2		
.9	37.0	.9	91.4	.9	98.3		
6.0	38.0	10.0	91.8	14.0	98.3		
.1	39.1	.1	92.1	.1	98.4		
.2	40.2	.2	92.3	.2	98.5		
.3	41.3	.3	92.6	.3	98.6		
.4	42.5	.4	92.9	.4	98.7		
.5	43.9	.5	93.2	.5	98.8		
.6	45.2	.6	93.5	.6	98.9		
.7	46.7	.7	93.7	.7	99.0		
.8	48.0	.8	94.0	.8	99.1		
.9	49.5	.9	94.2	.9	99.1		

Table 6: Self weighted scores for dental stages for 7 teeth (Mandibular left side) Demirjian *et al* (1973)

Boys

Tooth	Stage 0	A	B	C	D	E	F	G	H
M_2	0.0	2.1	3.5	5.9	10.1	12.5	13.2	13.6	15.4
M_1				0.0	8.0	9.6	12.3	17.0	19.3
PM_2	0.0	1.7	3.1	5.4	9.7	12.0	12.8	13.2	14.4
PM_1			0.0	3.4	7.0	11.0	12.3	12.7	13.5
C				0.0	3.5	7.9	10.0	11.0	11.9
I_2				0.0	3.2	5.2	7.8	11.7	13.7
I_1					0.0	1.9	4.1	8.2	11.8

Girls

Tooth	Stage 0	A	B	C	D	E	F	G	H
M_2	0.0	2.7	3.9	6.9	11.1	13.5	14.2	14.5	15.6
M_1				0.0	4.5	6.2	9.0	14.0	16.2
PM_2	0.0	1.8	3.4	6.5	10.6	12.7	13.5	13.8	14.6
PM_1			0.0	3.7	7.5	11.8	13.1	13.4	14.1
C				0.0	3.8	7.3	10.3	11.6	12.4
I_2				0.0	3.2	5.6	8.0	12.2	14.2
I_1					0.0	2.4	5.1	9.3	12.9

NB: Stage 0 is no calcification

Table 7: Comparison Table of Tooth Developmental Stages to Demirjian's A to H Stages

Molar		Premolar		Canine		Incisor	
	Demirjian		Demirjian		Demirjian		Demirjian
Ci	**A**	Ci	**A**				
Coc	**B**	Coc	**B**				
Cr1/2	**C**	Cr1/2	**C**	Cr1/2	**C**	Cr1/2	**C**
Crc	**D**	Crc	**D**	Crc	**D**	Crc	**D**
Ri	**D**	Ri	**D**	Ri	**D**	Ri	**D**
Cli	**D**						
R1/4	**E**	R1/4	**E**	R1/4	**E**	R1/4	**E**
R1/2	**F**	R1/2	**F**	R1/2	**F**	R1/2	**F**
R3/4	**G**	R3/4	**G**	R3/4	**G**	R3/4	**G**
Rc	**G**	Rc	**G**	Rc	**G**	Rc	**G**
A1/2	**H**	A1/2	**H**	A1/2	**H**	A1/2	**H**
Ac	**H**	Ac	**H**	Ac	**H**	Ac	**H**

Table 7 shows the equivalent Demirjian, Goldstein and Tanner (1973) stages (A to H) compared to the stages of Moorrees, Fanning and Hunt (1963). The Cli (Cleft initiation) stage pertains only to molars.

Table 8: Age related tables for males indicating the mean and two standard deviations for each stage of tooth development by Moorrees *et al* (1963)

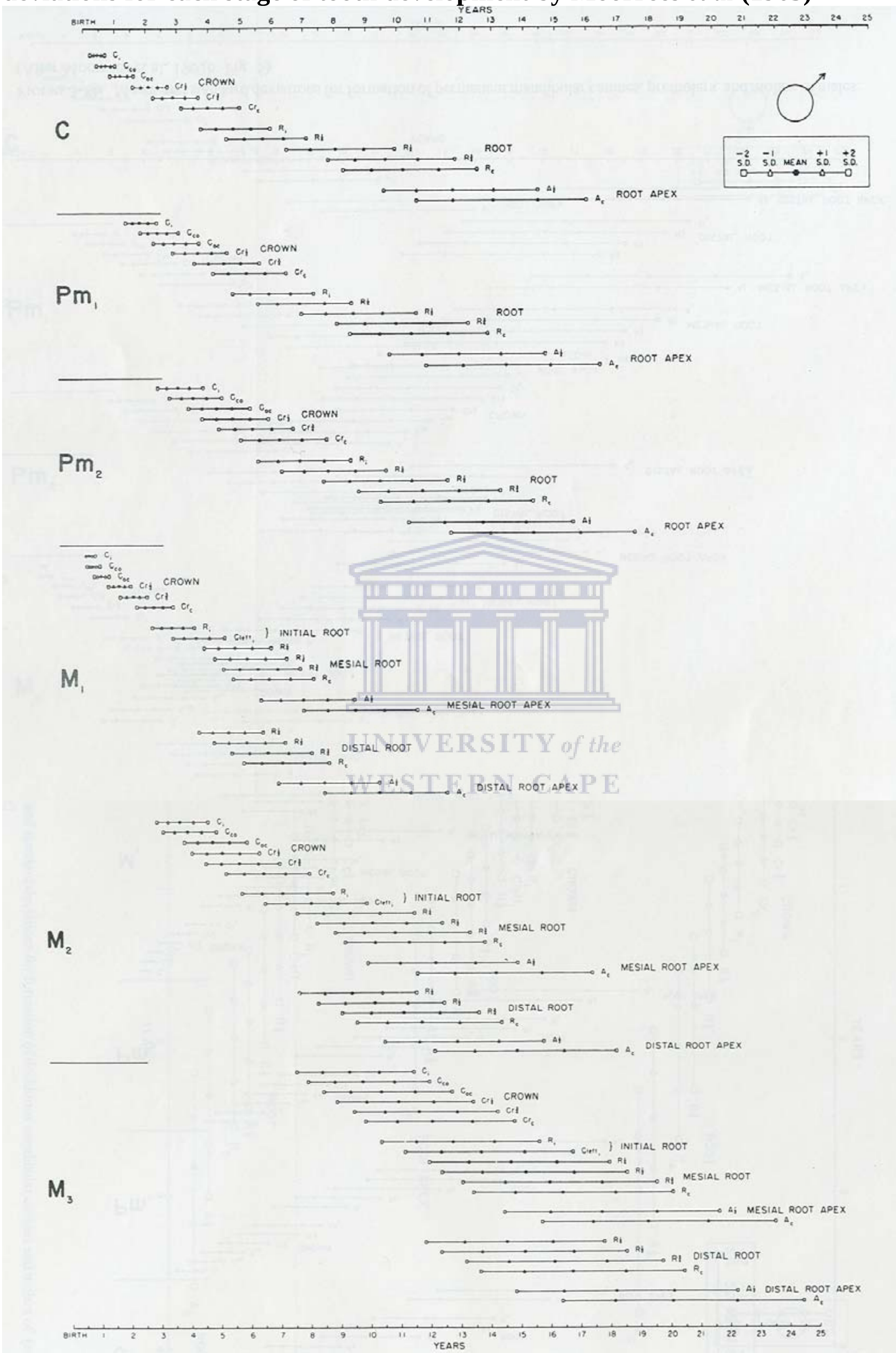
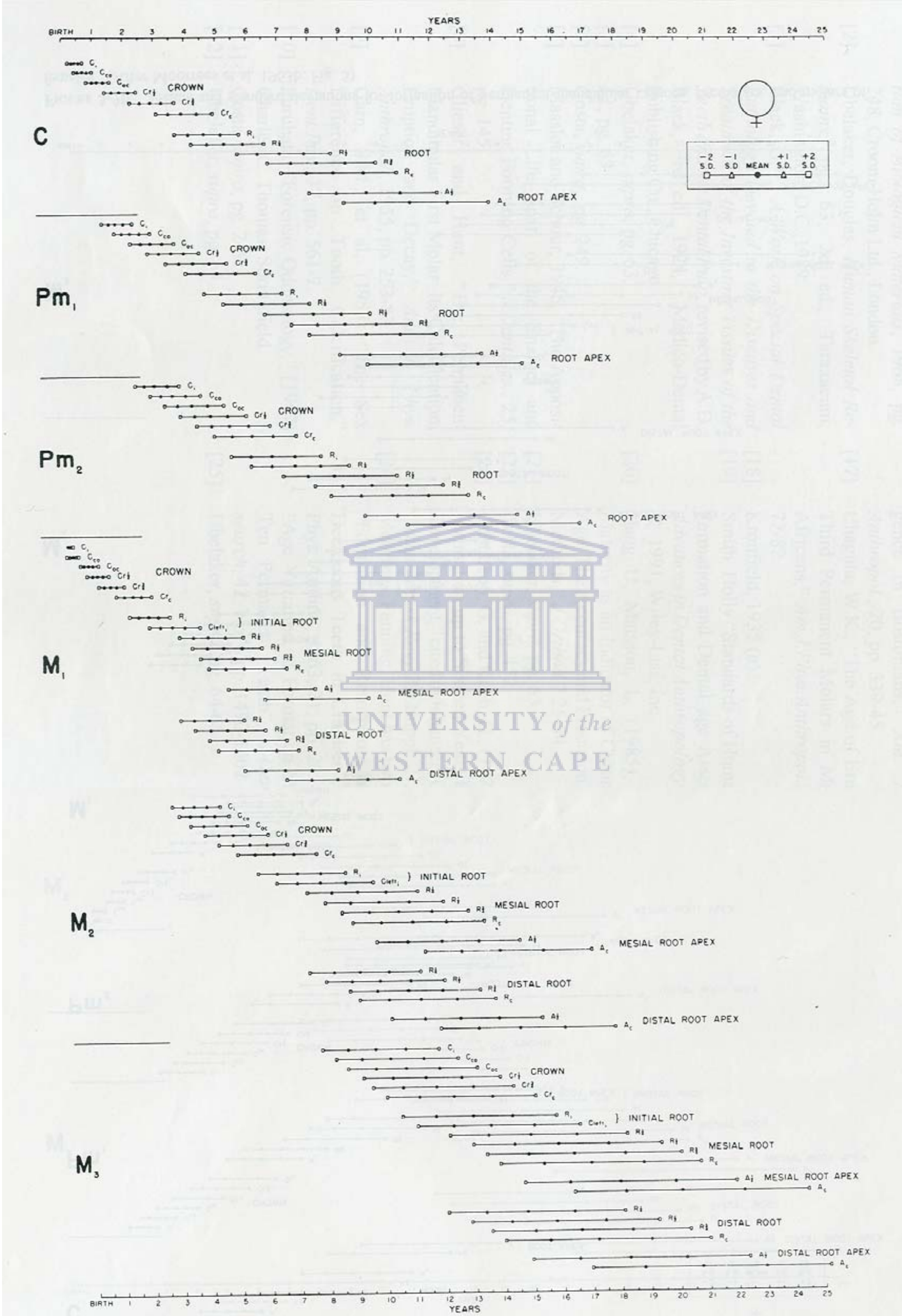


Table 9: Age related tables for females indicating the mean and two standard deviations for each stage of tooth development by Moorrees *et al* (1963)



3.1 AGE OF ATTAINMENT OF DEVELOPMENTAL STAGES

Tables 12 and 13 present the age of attainment chronologies for stages of tooth development for males and females as published by Smith (1991). In each case the mean age of attainment has been derived from the graphic charts of Moorrees, Fanning and Hunt (1963) (Tables 8 & 9). This work indicates the variances for each stage of tooth development of all the teeth of one jaw quadrant. These tables show the age at which the transition from one stage into the next developmental stage occurs. The standard abbreviation of developmental stages of teeth is shown in Table 10 and the tooth notations for each quadrant in Table 11.

3.2 AGE PREDICTION

In contrast, Tables 14 and 15 were designed by Smith (1991) for age prediction based on the stage of tooth development using the work of Moorrees, Fanning and Hunt (1963). These tables are appropriate at predicting the age of the individual by the developmental stages of the teeth. These tables contain the same data as Tables 12 and 13 above, but the data have been reworked to show the following; the age opposite a stage represents the midpoint between age of appearance of that stage and the next stage. To assign a dental age, each tooth is assessed independently, and the mean of all available ages is assigned as the dental age. One key difference between the two types of tables can be noted in the last lines, i.e. the ‘apex completed’ (Ac) stage. An age can be shown for this terminal stage in Tables 12 and 13, however the (Ac) stage in Tables 14 and 15 reflects that the subject has passed this maturity stage by an unknown amount of time. The system has some limitations as it lacks data for early stages of incisor development and is limited to mandibular teeth. Moorrees, Fanning and Hunt (1963) give some data for maxillary incisors, but data for maxillary teeth are rare in all studies.

Table 10: The standard abbreviation of developmental stages of teeth

Ci	Cusp initiation
Cco	Cusp coalescence
Coc	Cusp outline complete
Cr½	Crown half formed
Cr¾	Crown three quarters formed
Crc	Crown completely formed
Ri	Root initiation
Cli(Rcl)	Cleft initiation (molars only)
R¼	Root one quarter formed
R½	Root half formed
R¾	Root three quarters formed
Rc	Root complete
A½	Apex one half complete
Ac	Apex complete

Table 11 Tooth notation for each quadrant

I1	Central incisor
I2	Lateral incisor
C	Canine
Pm1	1st Premolar
Pm2	2^{nd} Premolar
M1	1^{st} Molar
M2	2^{nd} Molar
M3	3^{rd} Molar

Table 12: Mean age of Development Stages for Males (Smith, 1991) (Permanent Mandibular Teeth)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.5	1.8	3	0	3.7	9.3
Cco			0.7	2.4	3.5	0.2	3.9	9.7
Coc			1.4	2.9	4.2	0.5	4.7	10.4
Cr½			2.1	3.7	4.7	1.1	5.1	10.9
Cr¾			2.9	4.5	5.4	1.6	5.6	11.6
Crc			4	5.2	6.3	2.2	6.5	12
Ri			4.8	5.9	6.9	2.8	7.1	12.8
Rcl						3.6	8	13.7
R¼		5.4	5.7	6.9	7.7	4.6	9.4	14.5
R½	5.3	6.3	8	8.6	9.5	5.2	10.1	15.1
R⅔	5.9	6.9						
R¾	6.5	7.4	9.6	9.9	10.8	5.9	11.1	16.3
Rc	7	8	10.2	10.5	11.6	6.3	11.7	16.7
A½	7.7	8.6	11.8	11.9	12.7	7.6	12.9	18.2
Ac	8.1	9.3	13	13.4	14.3	9.4	14.9	20

Values from Moorrees *et al*. (1963); all stages in years

Table 13: Mean age of Development Stages for Females (Smith, 1991) (Permanent Mandibular Teeth)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.5	1.8	3	0	3.5	9.6
Cco			0.8	2.2	3.6	0.3	3.7	10.1
Coc			1.2	2.9	4.2	0.8	4.2	10.7
Cr½			2	3.6	4.8	1	4.8	11.3
Cr¾			3	4.3	5.4	1.5	5.4	11.7
Crc			4	5.1	6.2	2.2	6.2	12.3
Ri			4.7	5.8	6.8	2.7	7	12.9
Rcl						3.5	7.7	13.5
R¼	4.5	4.7	5.3	6.5	7.5	4.5	9.2	14.8
R½	5.1	5.2	7.1	8.2	8.8	5.1	9.8	15.7
R⅔	5.6	5.9						
R¾	6.1	6.4	8.3	9.2	10	5.7	10.7	16.6
Rc	6.6	7.6	8.9	9.9	10.6	6	11.2	17.2
A½	7.4	8.1	9.9	11.1	12	7	12.5	18.3
Ac	7.7	8.5	11.3	12.2	13.7	8.7	14.6	20.7

Table 14: Values for Predicting Age from Stages of Permanent Mandibular Tooth Formation (Males) (Smith, 1991)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.6	2.1	3.2	0.1	3.8	9.5
Cco			1	2.6	3.9	0.4	4.3	10
Coc			1.7	3.3	4.5	0.8	4.9	10.6
Cr½			2.5	4.1	5	1.3	5.4	11.3
Cr¾			3.4	4.9	5.8	1.9	6.1	11.8
Crc			4.4	5.6	6.6	2.5	6.8	12.4
Ri			5.2	6.4	7.3	3.2	7.6	13.2
Rcl						4.1	8.7	14.1
R¼		5.8	6.9	7.8	8.6	4.9	9.8	14.8
R½	5.6	6.6	8.8	9.3	10.1	5.5	10.6	15.6
R⅔	6.2	7.2						
R¾	6.7	7.7	9.9	10.2	11.2	6.1	11.4	16.4
Rc	7.3	8.3	11	11.2	12.2	7	12.3	17.5
A½	7.9	8.9	12.4	12.7	13.5	8.5	13.9	19.1
Ac								

Values from Moorrees *et al*. (1963); all stages in years

Table 15: Values for Predicting Age from Stages of Permanent Mandibular Tooth Formation for (Females) (Smith, 1991)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.6	2	3.3	0.2	3.6	9.9
Cco			1	2.5	3.9	0.5	4	10.4
Coc			1.6	3.2	4.5	0.9	4.5	11
Cr½			2.5	4	5.1	1.3	5.1	11.5
Cr¾			3.5	4.7	5.8	1.8	5.8	12
Crc			4.3	5.4	6.5	2.4	6.6	12.6
Ri			5	6.1	7.2	3.1	7.3	13.2
Rcl						4	8.4	14.1
R¼	4.8	5	6.2	7.4	8.2	4.8	9.5	15.2
R½	5.4	5.6	7.7	8.7	9.4	5.4	10.3	16.2
R⅔	5.9	6.2						
R¾	6.4	7	8.6	9.6	10.3	5.8	11	16.9
Rc	7	7.9	9.4	10.5	11.3	6.5	11.8	17.7
A½	7.5	8.3	10.6	11.6	12.8	7.9	13.5	19.5
Ac								

Values from Moorrees *et al*. (1963); all stages in years

3.3 DENTAL AGE

Dental age conveys the age best associated with a developmental stage in a normal reference population. This can be either an age prediction or a maturity assessment (Gustafson and Koch, 1974). Several studies have investigated the dental age using children of known age and have provided information on some test subjects aged by their systems; these studies claim estimated dental ages to within a few months of the actual ages (Gustafson and Koch, 1974; Crossner and Mansfeld, 1983; Liliequist and Lundberg, 1971).

Crossner and Mansfeld (1983) compared age predictions using the system of Liliequist and Lundberg (1971) with that of Gustafson and Koch (1974) for 44 children adopted into Sweden from countries in Asia and South America. They found that ages from the two systems agreed within two months in 40% of cases and disagreed by 3 – 6 months in 60% of cases. They reported that 70% of the estimates of dental age fell within ± 3 months of the true age, and discrepancies are no more than 6 months in a subset of 23 children with known age (age ranged from 2.5 to 11 years). Smith (1991), however, commented that the degree of accuracy was remarkable considering the extreme heterogeneity of the sample. She also remarked that this study, in which they stated that the system based on Swedish children when used on children from Asia and South America worked just as well, was doubtful and that the system was lacking precision.

A more rigorous test was applied by Hagg and Matsson (1985) in which they compared the methods of Liliequist and Lundberg (1971), Gustafson and Koch (1974) and Demirjian, Goldstein and Tanner (1973) for accuracy in the prediction of age in 150 Swedish children aged 3.5 – 12.5 years. Their results showed that the method of Liliequist and Lundberg (1971) systematically under estimated age and had the lowest overall accuracy. That of Gustafson and Koch (1974) was the most difficult to replicate between examiners and its age estimates were poor for females, but acceptable for males. The maturity scales of Demirjian, Goldstein and Tanner (1973) based on French Canadian children gave the most accurate age predictions. The subject age could be estimated to within 15 to 25 months with 95% confidence.

In juvenile skeletal material, age prediction is often complicated by unknown sex of the individual (Smith, 1991). In these cases it would be appropriate to average the dental age estimates for males and females (Tables 14 & 15). The dental ages in the worst case were found to be inaccurate by 0.1 to 0.5 years. The overall success of age prediction is partly due to the advantage gained by averaging the age estimation using several teeth and not a single tooth.

Davis and Hagg (1994) tested the Demirjian method on Chinese children between the ages of 5 to 7 years and found that there was an error between the estimated age and the chronological age of 11months in boys and 7 months in girls. The 95% confidence level interval was approximately ± 15 months for both sexes.

In a study by Farah, Booth and Knott (1999) of Australian children they found the Demirjian method to be accurate, but suggested however that the accuracy could vary in different population groups. A study by Willems *et al* (2001) found that the method of Demirjian over-estimated the chronological age of Belgian children by 0.5 years for boys and 0.6 years for girls. By performing a weighted ANOVA they adapted their scoring system for this population group. This resulted in age scores expressed in years that were more accurate for these children (Tables 17 & 18).

In a modified Demirjian method where a cubic regression model was derived and used to compare the dental maturity rate of Swedish and Korean children, Tievens and Mornstad

(2001) found that the tooth development in Swedish boys was 2 months ahead and the girls 6 months ahead of their Korean counterparts.

Chaillet, Nylstrom and Demirjian (2005) tested the Demirjian method on several ethnic groups and found the method to be efficient with a standard deviation of 2.15 years. They also found that Australian children have the fastest dental maturation rate and the Koreans the slowest.

A subsequent study by Maber, Liversidge and Hector (2006) of the ages of a sample of Bangladeshi and British White children was recently undertaken in which the pantomographic radiographs of each child were used to estimate the age using the individual methods of Demirjian, Nolla, Haavikko and Willems with varying success (Table 16). They found that the Willems adjusted data of the Demirjian's method was the most accurate method of age estimation for this group of children (Table 16). The Willems *et al* method calculates the age of the individual by the sum of the scores for each tooth in the left mandible excluding the 3rd molar.

Recently Rózylo-Kalinowska, Kiworkowa-Raczkowska and Kalinowski (2007) tested the Demirjian method on a Polish group of 994 children between the ages of 6 and 16 and found that the developmental standards set by Demirjian, Goldstein and Tanner (1973) were not suitable for the Polish children.

Table 16: Mean accuracy (in years) for each method for children aged 3.00-16.99 years by Maber, Liversidge and Hector (2006)

	Sex	N	Mean	S.E.	S.D.
D	Boys	491	0.25	0.04	0.84
	Girls	455	0.23	0.04	0.84
	Both	946	0.24	0.03	0.86
W	Boys	491	-0.05	0.04	0.81
	Girls	455	-0.20	0.04	0.89
	Both	945	-0.12	0.04	0.85
N	Boys	491	-0.87	0.04	0.87
	Girls	455	-1.18	0.05	0.96
	Both	946	-1.02	0.03	0.93
H	Boys	437	-0.56	0.04	0.91
	Girls	395	-0.79	0.06	1.11
	Both	832	-0.67	0.04	1.01
H < 14	Boys	392	-0.39	0.04	0.77
	Girls	357	-0.57	0.05	0.87
	Both	749	-0.47	0.03	0.82

D: Demirjian, **W**: Willems, **N**: Nolla, **H**: Haavikko; **H** <**14**: Haavikko age less than 14 years; SE: standard error, SD: standard deviation. (Maber *et al*. 2006)

TABLE 17:
Developmental tooth stages according to Demirjian's technique with corresponding age scores expressed directly in years for 7 left mandibular teeth; Boys (Willems *et al*, 2001)

Stage / Tooth	A	B	C	D	E	F	G	H
Central Incisor			1.68	1.49	1.5	1.86	2.07	2.19
Lateral Incisor			0.55	0.63	0.74	1.08	1.32	1.64
Canine				0.04	0.31	0.47	1.09	1.9
First bicuspid	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
Second Bicuspid	0.08	0.05	0.12	0.27	0.33	0.45	0.4	1.15
First Molar				0.69	1.14	1.6	1.95	2.15
Second Molar	0.18	0.48	0.71	0.8	1.31	2	2.48	4.17

TABLE 18:
Developmental tooth stages according to Demirjian's technique with corresponding age scores expressed directly in years for 7 left mandibular teeth; Girls (Willems *et al*, 2001)

Stage / Tooth	A	B	C	D	E	F	G	H
Central Incisor			1.83	2.19	2.34	2.82	3.19	3.14
Lateral Incisor				0.29	0.32	0.49	0.79	0.7
Canine			0.6	0.54	0.62	1.08	1.72	2
First bicuspid	-0.95	-0.15	0.16	0.41	0.6	1.27	1.58	2.19
Second Bicuspid	-0.19	0.01	0.27	0.17	0.35	0.35	0.55	1.51
First Molar				0.62	0.9	1.56	1.82	2.21
Second Molar	0.14	0.21	0.21	0.32	0.66	1.28	2.09	4.04

CONCLUSION

The tables of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) are useful when comparing dental maturation with skeletal development in White children, but it has been shown that these methods vary in accuracy when used on different population or ethnic groups when trying to estimate the chronological age of a child. The method derived by Demirjian, Goldstein and Tanner (1973) has been used extensively, but was found only to be relatively accurate in European child populations.

Willems *et al* (2001) tested the Demirjian method on Belgian children and found that it over estimated the ages of their child sample. Similarly Davis and Hagg (1994) were unsuccessful with this method in Chinese children.

The process of identification of skeletal remains is complicated by the fact that it is not easy to establish whether a skeleton of a juvenile is either male or female and often it is impossible to accord racial traits. It therefore follows that the age estimation charts of Moorrees *et al* and Demirjian *et al* are questionable if used on South African children.

This has thus led to the conclusion that these tables that were derived from American (Moorrees, Fanning and Hunt, 1963) and French-Canadian children (Demirjian, Goldstein and Tanner, 1973) may not be applicable for other population groups and need to be tested on samples of South African children.

CHAPTER 4

THE DEVELOPMENT OF DENTAL AGE RELATED TABLES FOR SOUTH AFRICAN CHILDREN

Dental age related tables for permanent teeth by Schour & Massler (1941), Moorrees, Fanning and Hunt [MFH] (1963), Gustafson & Koch (1971) and Demirjian, Goldstein & Tanner [DGT] (1973) have been used by forensic scientists for estimating the chronological ages of juvenile skeletal remains with varying success. The tables of Moorrees, Fanning and Hunt (1963), that utilized developmental stages for the adult canine to the 3rd molar, were routinely used for comparing juvenile dental development with skeletal maturity. The accuracy of the MFH tables was questioned by Smith (1991) who reworked the data and thereby produced tables that predicted the average dental age of juvenile males and females. It became evident that the accuracy of the MFH tables was not always applicable to other population groups and the standard deviations of each stage were too vague to be of use for age estimation. Demirjian, Goldstein and Tanner (1973) devised a method of dental age estimation by weighting the tooth developmental stages of 7 of the mandibular teeth and deriving a conversion table that related the combined weighting to the chronological age for males and females. In the research of MFH (1963) they studied the development of the permanent canine, premolars and the 3 molars; that of DGT (1973) included the incisors, but excluded the 3rd molar. The DGT (1973) method has been used by several authors with varying success and has resulted in publications debating its accuracy on different population groups in Europe, Asia and Australia (Davis and Hagg, 1994; Tievens and Mornstad, 2001; Willems *et al* 2001; Maber, Liversidge and Hector; 2006). A study undertaken on Indian children in south India by Koshy and Tandon (1998) utilized the DGT method to estimate the chronological age. They found that this method was not applicable and gave an overestimation of the age by 3.04 and 2.82 years in males and females respectively.

In a study of White and Black children by Chertkow (1980) using the ossification of the hand and wrist bones compared to the calcification of the teeth, he found that the stage of calcification of the mandibular canine was a possible indicator of the growth spurt in white children during puberty. Black children in comparison to White were found to be slightly ahead in their calcification of the canines.

The use of both of the MFH (1963) and DGT (1973) tables by the author (VMP) to estimate ages of skeletal remains of children and juveniles in South Africa was disappointingly inaccurate. It was therefore deemed necessary to derive dental age related tables for South African children. This investigation of South African children included the stages of development of all 8 teeth of the left mandible. Both the studies of MFH (1963) and DGT (1973) were of White children; this study, however, took cognisance of the different population origins in our samples of South African children.

The Black and Indian children who attend orthodontic dental practices in Kwa-Zulu Natal are from a similar socio-economic background and are exposed to similar environmental conditions that may have an effect on their skeletal maturation rate. These samples were chosen in conjunction with the Tygerberg sample to have children from different population origins to develop dental age related tables.

There has been no comprehensive published data with regard to age related stages of dental development of South African children and the aim of this study was to develop dental age related tables for South African children of differing population origins.

Materials and methods

The first sample consisted of children treated at the Tygerberg Dental Faculty. These Tygerberg children were of mixed ancestry. Some of the children had both parents of

European origin; the Coloured[1] children had either one European parent or both parents of mixed ethnic origin. This group was designated the Tygerberg sample. Data were obtained from the archival records of 916 children treated at the Tygerberg Dental Hospital from 1975 to 2000 and contained their Pantomographic radiographs. Of this sample 835 Pantomographs were chosen which showed all the teeth and no pathological lesions. The age range was from 3 to 16 years and consisted of 455 females and 380 males.

Pantomographic radiographs of 91 Black (Zulu) children were obtained from a private Orthodontic dental practice in Durban, Kwa-Zulu Natal. This sample contained 47 males and 44 females with an age range of 7 to 16 years. A third sample of 157 Indian children was obtained from 2 Orthodontic dental practices in Durban. The age range was from 6-16 years and there were 82 females and 75 males.

The Pantomographic images were used to visualize the stages of development of the teeth in the left mandible. Each individual developmental stage for the incisors, canines, premolars and molars was recorded for each child and correlated to their chronological age. The chronological age was obtained by subtracting the date of birth from the date on which the radiograph was taken.

Pivot tables were constructed to correlate the chronological age with the mean age at which the various development stages of the crown and root of each tooth took place for both males and females. Graphic representation of the developmental stages of each tooth was derived for both sexes.

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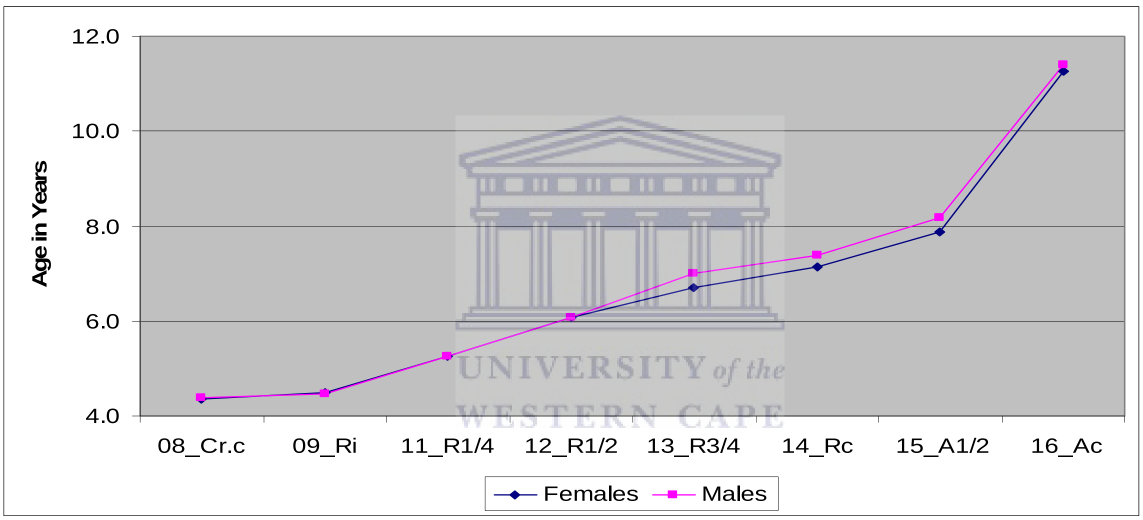
[1] **Coloured people of South Africa.** The Coloured people were descended largely from Cape slaves, the indigenous Khoisan population, and other black people who had been assimilated to Cape colonial society by the late nineteenth century. Since they are also partly descended from European settlers, Coloureds are popularly regarded as being of “mixed race” although the amount of admixture from the parental populations is highly variable (Adhikari, 2006).

Dental age related tables for each of the samples (Tygerberg, Black and Indian) were constructed including the standard deviation for each developmental stage.

Results

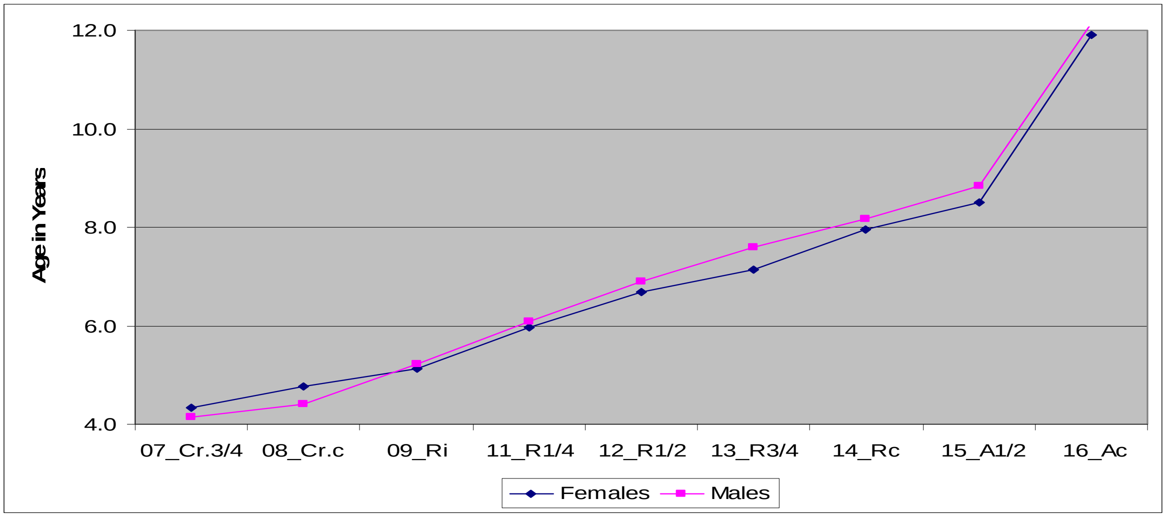
1. **The Tygerberg Sample:** The dental age estimation graphs of the Tygerberg sample of males and females are depicted below and show the mean age at which calcification occurs for each developmental stage of the individual left eight permanent mandibular teeth for males and females.

Graph 1: Tygerberg sample. The age related stages of the Central Incisor (I1) for males and females



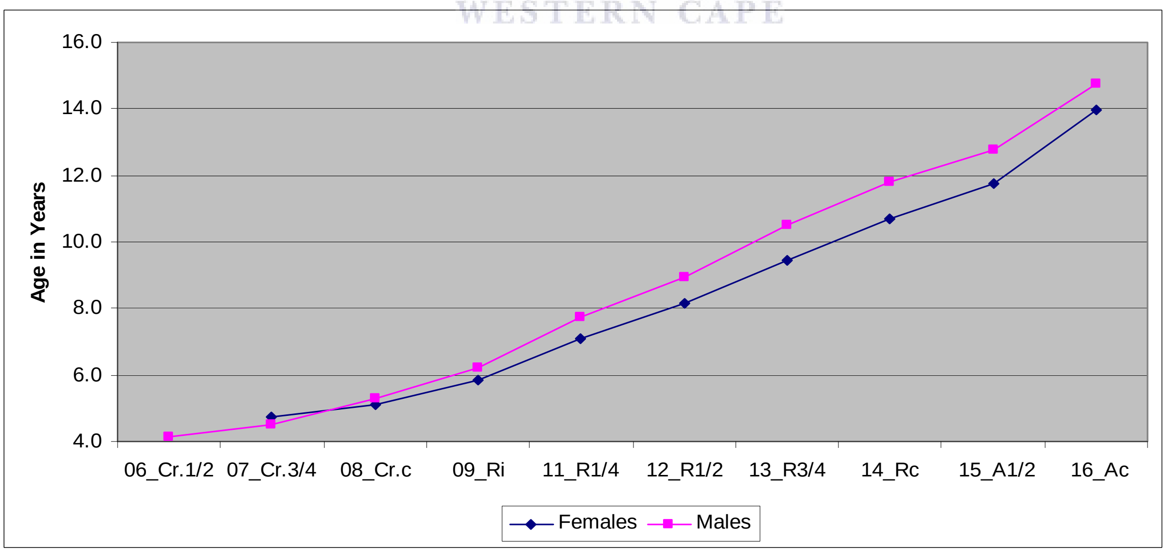
Central mandibular incisor (I1) There is no difference in the development of the I1 between boys and girls until the age of 6 years; then the root formation (R¾ to A½) in girls calcifies 3 months earlier than the boys. The apex closes at the age of 11.3 years in girls and 11.4 years in boys.

Graph 2: Tygerberg sample. The age related stages of the Lateral Incisor (I2) for males and females



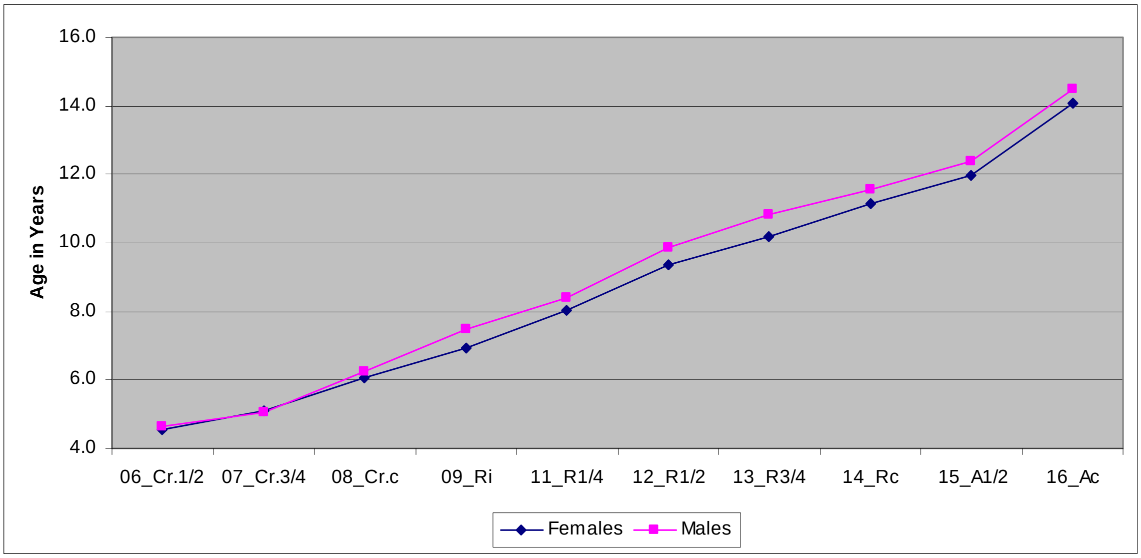
Lateral mandibular incisor (I2). The crown calcification of the I2 occurs slightly earlier in boys initially, but at age 5 years the root formation in girls is approximately 2 months ahead of the boys. The root calcification is ahead by 5 months at the R¾ stage in females. The apices close at 11.9 years in girls and 12.1 years in boys.

Graph 3: Tygerberg sample. The age related stages of the Canine (C) for males and females



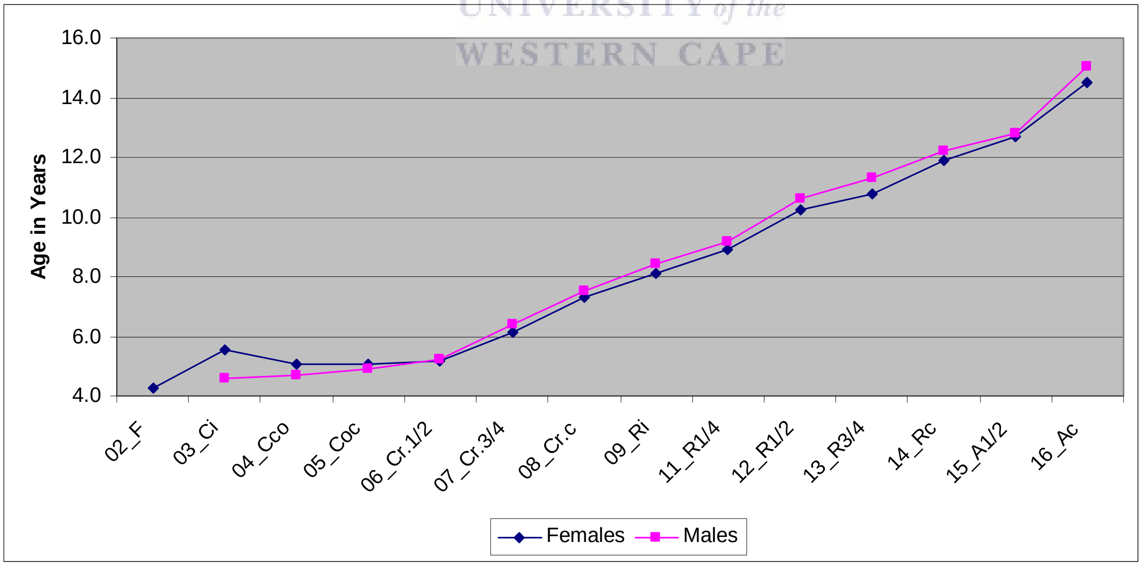
Canine (C): The crown formation in both sexes is even in the early stages up to age 6 years, then the calcification of the roots is earlier in girls from 3 months in the Ri stage to 12 months at the Rc stage (10.7 females:11.8 males). The apex closes at 14 years in girls and 14.7 years in boys.

Graph 4: Tygerberg sample. The age related stages of the 1st Premolar (Pm1) for males and females



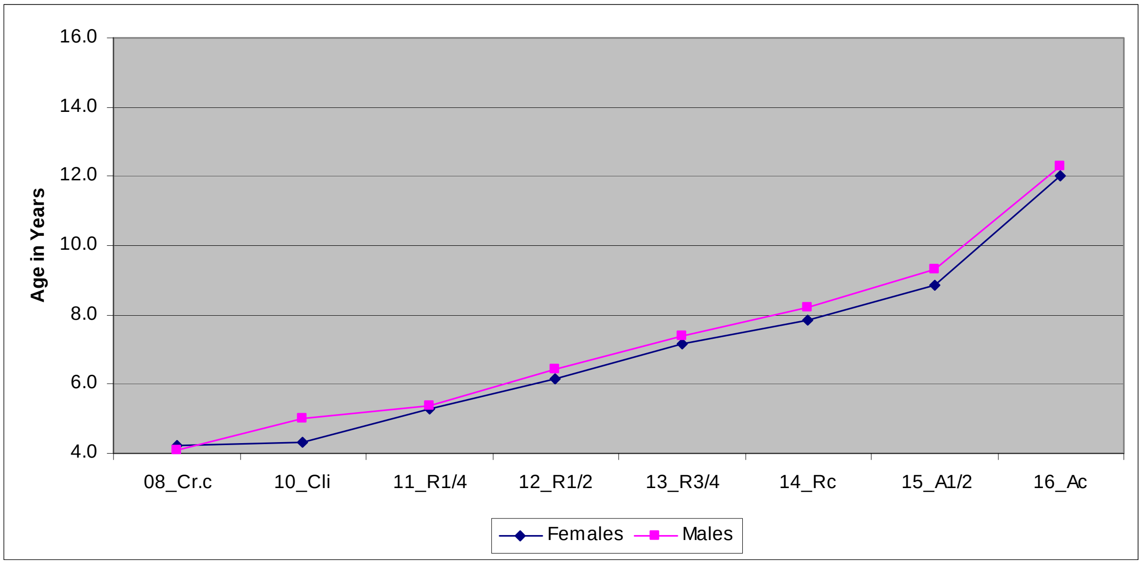
Premolar (Pm1): Initially the crown development is similar until the crown is complete (Crc), then the girls develop faster from 2 months at the (Ri) stage to 6 months at (Rc) stage. The apex closes at 14.1 years in girls and 14.5 years in boys.

Graph 5: Tygerberg sample. The age related stages of the 2nd Premolar (Pm2) for males and females



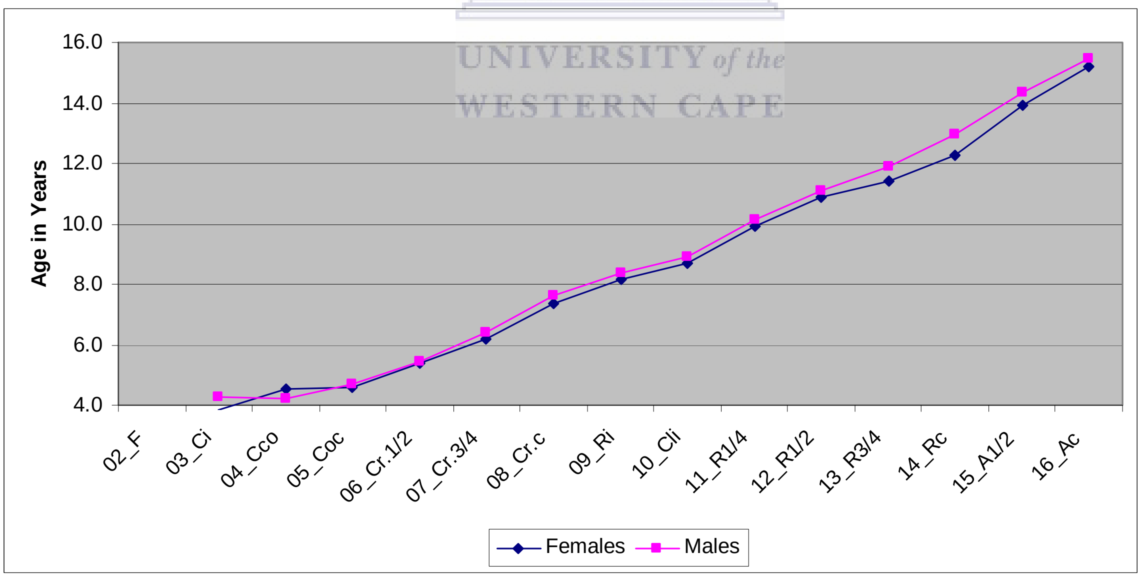
Premolar (Pm2): Initially crown formation (Ci) and calcification is ahead in boys, but the girls start developing more rapidly at the age of 5 years. The root calcification in girls is ahead of the boys by 2 to 3 months until root complete (Rc) stage. The apex closes at 14.5 years in females and 15 years in males.

Graph 6: Tygerberg sample. The age related stages of the 1st Molar (M1) for males and females



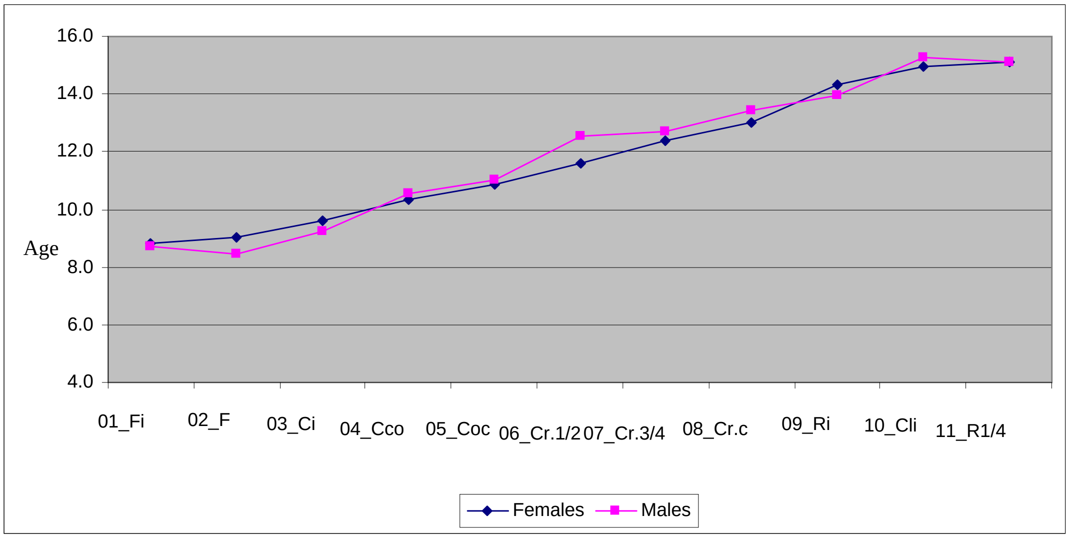
Molar (M1): There is only a 2 to 3 month difference in the development of this tooth between boys and girls; the girls being slightly earlier. The apex closes at 12 years in girls and 12.3 years in boys.

Graph 7: Tygerberg sample. The age related stages of the 2nd Molar (M2) for males and females



Molar (M2): The development of this tooth was monitored from the follicle (F) stage to the closure of the apex (Ac). There is very little difference between the boys and the girls; approximately 2 to 3 months throughout the calcification of both the crown and the root. The girls are marginally ahead in development. The apex closes at 15.2 years in girls and 15.5 years in boys.

Graph 8: Tygerberg sample. The age related stages of the 3rd Molar (M3) for males and females



Molar (M3): Initial follicle development occurs at age 8.8 years. Up to the age of 10 years the calcification of the crown is earlier in boys; then the girls develop more rapidly until the age of 15 years; the difference being no more than 4 months during root formation.

Table 1 The dental age related table for Males from the Tygerberg sample in years (SD)

	I 1	I 2	C	Pm 1	Pm 2	M 1	M 2	M 3
Fi								8.7 (1.30)
F								8.4 (1.52)
Ci					4.6 (0.40)		4.3 (0.12)	9.2 (1.33)
Cco					4.7 (0.67)		4.2 (0.54)	10.6 (1.14)
Coc					4.9 (1.16)		4.7 (0.57)	11 (0.95)
Cr.1/2			4.1 (0.5)	4.6 (0.63)	5.2 (0.71)		5.4 (0.73)	12.5 (1.21)
Cr.3/4		4.1 (0.5)	4.5 (0.60)	5.1 (0.66)	6.4 (0.54)		6.4 (0.78)	12.7 (1.40)
Cr.c	4.4 (0.35)	4.4 (0.52)	5.3 (0.75)	6.3 (0.69)	7.5 (0.84)	4.1 (0.21)	7.6 (1.03)	13.4 (1.55)
Ri	4.5 (0.57)	5.2 (0.58)	6.2 (0.63)	7.5 (1.00)	8.4 (0.95)		8.4 (0.69)	14 (1.63)
Cli						5 (1.17)	8.9 (0.92)	15.2 (0.84)
R1/4	5.3 (0.56)	6.1 (0.64)	7.7 (0.73)	8.4 (0.89)	9.2 (1.13)	5.4 (0.76)	10.1 (0.98)	15.1 (0.83)
R1/2	6.1 (0.57)	6.9 (0.67)	9 (0.98)	9.8 (1.00)	10.6 (0.97)	6.4 (0.45)	11.1 (0.98)	
R3/4	7 (0.57)	7.6 (0.74)	10.5 (1.09)	10.8 (0.81)	11.3 (0.97)	7.4 (0.63)	11.9 (0.77)	
Rc	7.4 (0.58)	8.2 (0.69)	11.8 (0.85)	11.6 (0.74)	12.2 (1.23)	8.2 (0.71)	12.9 (0.96)	
A1/2	8.2 (0.70)	8.8 (0.72)	12.8 (1.00)	12.4 (0.81)	12.8 (1.27)	9.3 (0.85)	14.4 (1.08)	
Ac	11.4 (2.19)	12.1 (1.88)	14.7 (1.25)	14.5 (1.22)	15 (0.99)	12.3 (1.88)	15.5 (0.58)	

I 1 = Central incisor; I 2 = Lateral incisor; C = Canine; Pm 1 = 1st Premolar; Pm 2 = 2nd Premolar; M 1 = 1st Molar; M 2 = 2nd Molar; M 3 = 3rd Molar.

Table 2 The dental age related table for females from the Tygerberg sample in years (SD)

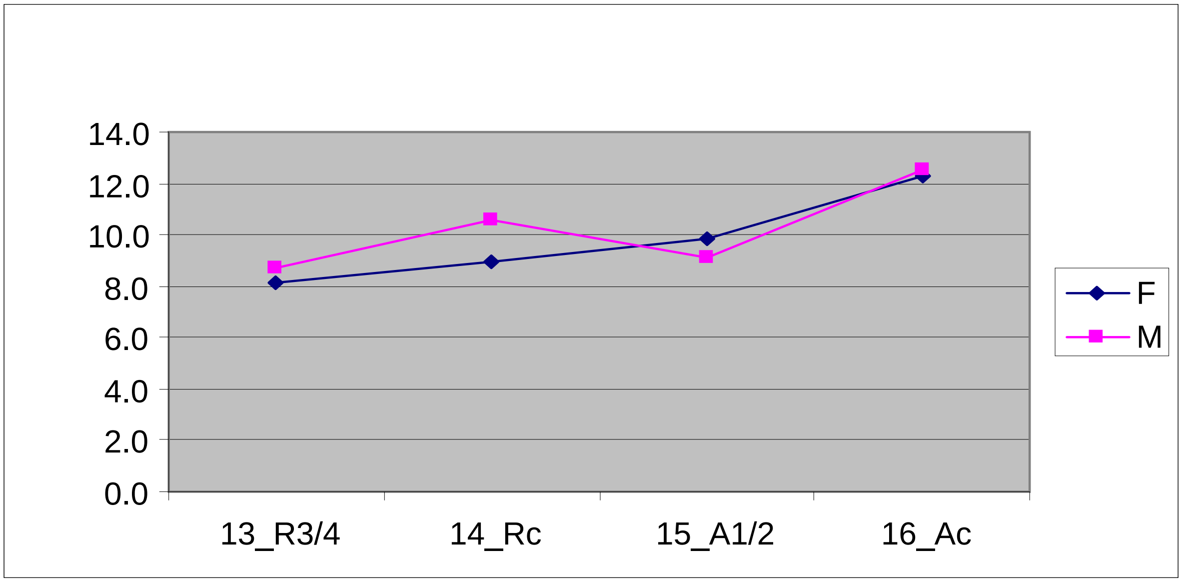
	I 1	I 2	C	Pm 1	Pm 2	M 1	M 2	M 3
Fi								8.8 (1.19)
F					4.3			9 (1.40)
Ci					5.5 (1.69)		3.9 (0.68)	9.6 (1.10)
Cco					5.1 (0.89)		4.6 (0.46)	10.3 (1.44)
Coc					5.1 (0.97)		4.6 (0.27)	10.8 (1.02)
Cr.1/2				4.5 (0.26)	5.2 (0.74)		5.4 (0.84)	11.6 (0.98)
Cr.3/4		4.3 (0.5)	4.7 (0.69)	5.1 (0.72)	6.1 (0.68)		6.2 (0.74)	12.4 (1.40)
Cr.c	4.3 (0.5)	4.8 (0.66)	5.1 (0.88)	6.1 (0.83)	7.3 (0.80)	4.2 (0.08)	7.4 (0.90)	13 (1.09)
Ri	4.5 (0.58)	5.1 (0.75)	5.9 (0.61)	6.9 (0.52)	8.1 (0.83)		8.2 (0.74)	14.3 (1.37)
Cli						4.3 (0.55)	8.7 (0.91)	15 (1.33)
R1/4	5.3 (0.63)	6 (0.56)	7.1 (0.66)	8 (0.82)	8.9 (1.13)	5.3 (0.46)	9.9 (0.90)	15.1 (1.09)
R1/2	6.1 (0.47)	6.7 (0.58)	8.2 (0.97)	9.4 (0.84)	10.2 (1.02)	6.1 (0.51)	10.9 (1.02)	
R3/4	6.7 (0.63)	7.1 (0.53)	9.5 (0.98)	10.2 (1.05)	10.8 (1.18)	7.1 (0.63)	11.4 (0.62)	
Rc	7.1 (0.48)	8 (0.70)	10.7 (1.02)	11.1 (0.85)	11.9).84)	7.9 (0.76)	12.3 (0.87)	
A1/2	7.9 (0.65)	8.5 (0.56)	11.7 (0.74)	11.9 (0.70)	12.7 (1.16)	8.8 (0.69)	13.9 (1.07)	
Ac	11.3 (2.23)	11.9 (1.97)	14 (1.65)	14.1 (1.55)	14.5 (1.35)	12 (1.97)	15.2 (1.22)	

I 1 = Central incisor; I 2 = Lateral incisor; C = Canine; Pm 1 = 1st Premolar; Pm 2 = 2nd Premolar;
M 1 = 1st Molar; M 2 = 2nd Molar; M 3 = 3rd Molar.

From the pivot tables dental age related tables were constructed for males and females (Tables 1 & 2) for the Tygerberg sample. These tables show the mean age at which the stages of crown and root calcification occur. The standard deviations for each age are indicated in parentheses.

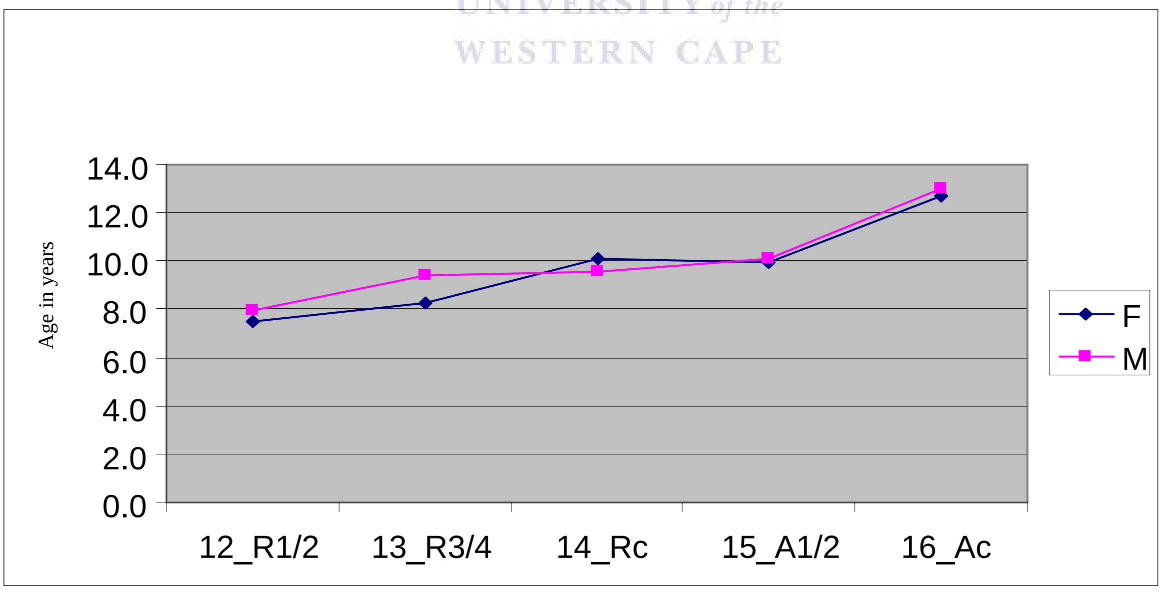
2. The Indian Sample: The dental age estimation graphs of the Indian sample of males and females are depicted below and show the mean age at which calcification occurs for each developmental stage of the eight permanent mandibular teeth.

Graph 9: Indian sample. The age related stages of the Central Incisor (I1) for males and females



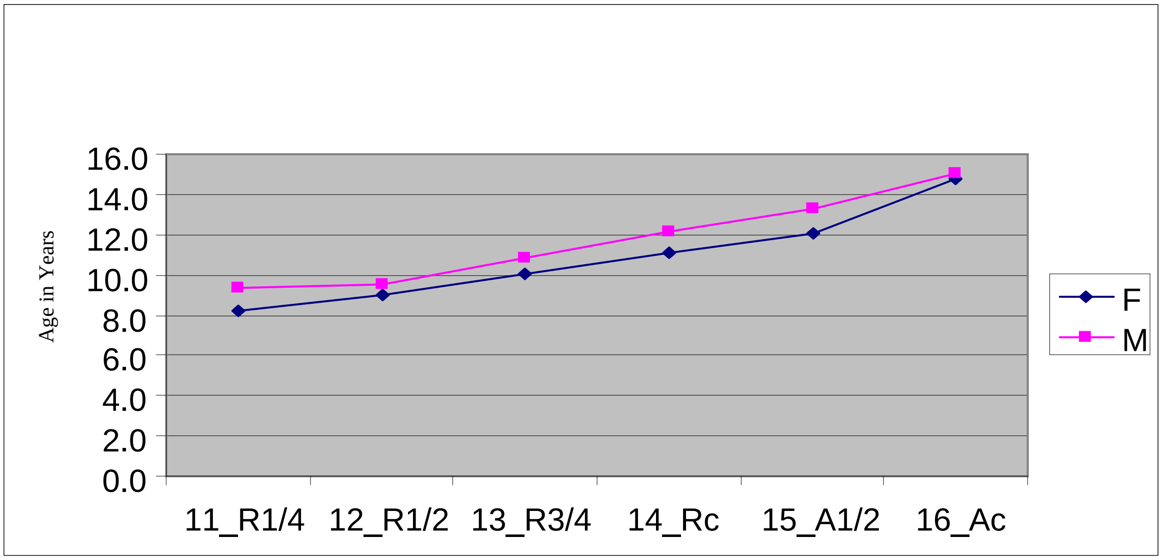
Central mandibular incisor (I1) shows a slightly earlier calcification of the root at R¾ stage in girls, but the completion stage (Rc) is 1.7 years ahead of the boys. The apices close at 12.3 and 12.5 years (F:M).

Graph 10: Indian sample. The age related stages of the Lateral Incisor (I2) for males and females



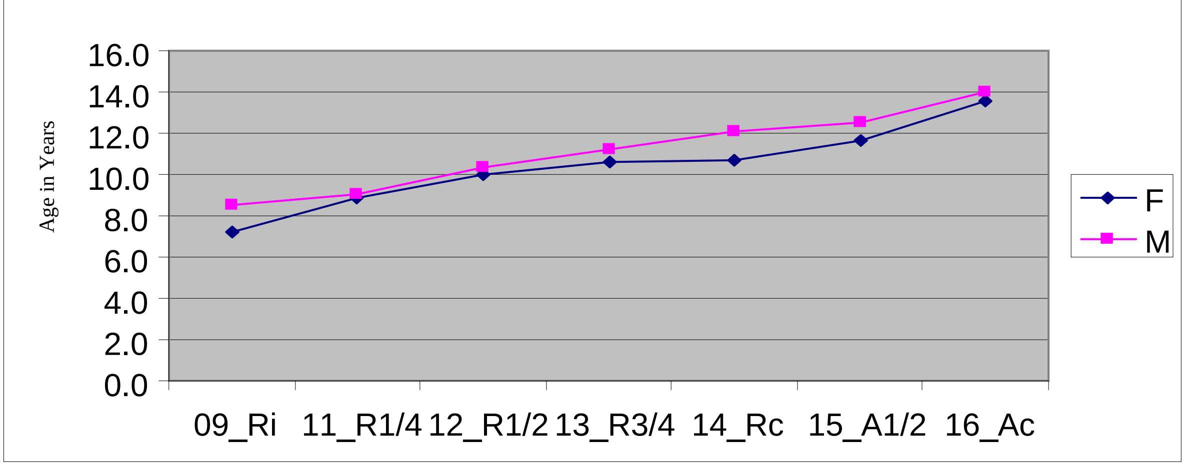
Lateral mandibular incisor (I2) shows the calcification stage R¾ of girls to be 1.1 years ahead of the boys, thereafter there is insignificant difference in the calcification times.

Graph 11: Indian sample. The age related stages of the Canine (C) for males and females



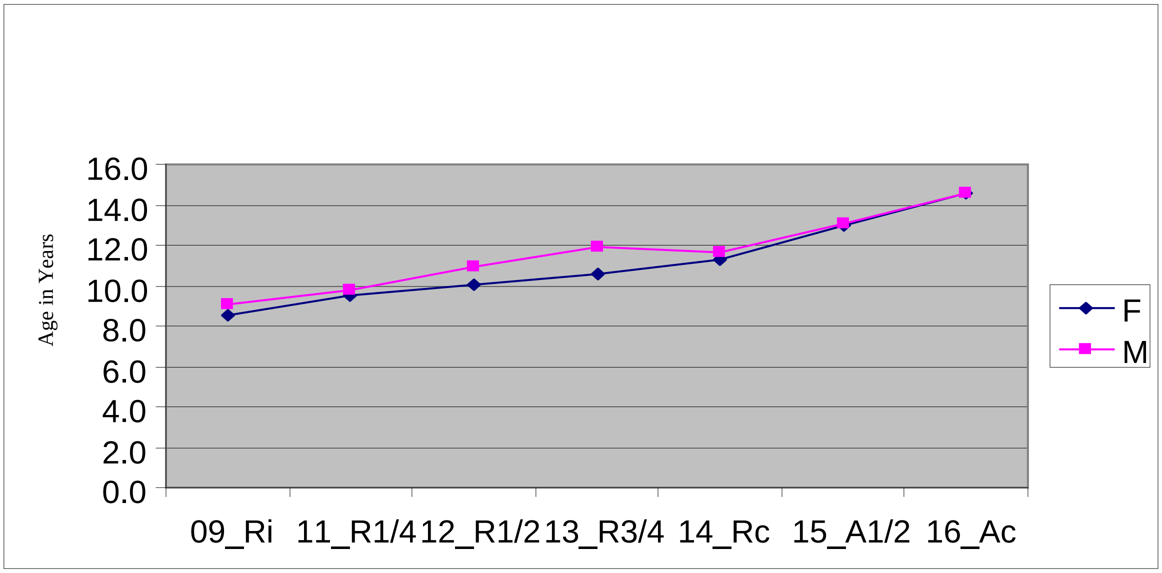
Canine (C): The calcification times for the canines is slower in the boys by approximately 1 year compared to the girls. The apices close at 14.8 and 15 years (F:M).

Graph 12: Indian sample. The age related stages of the 1st Premolar (Pm1) for males and females



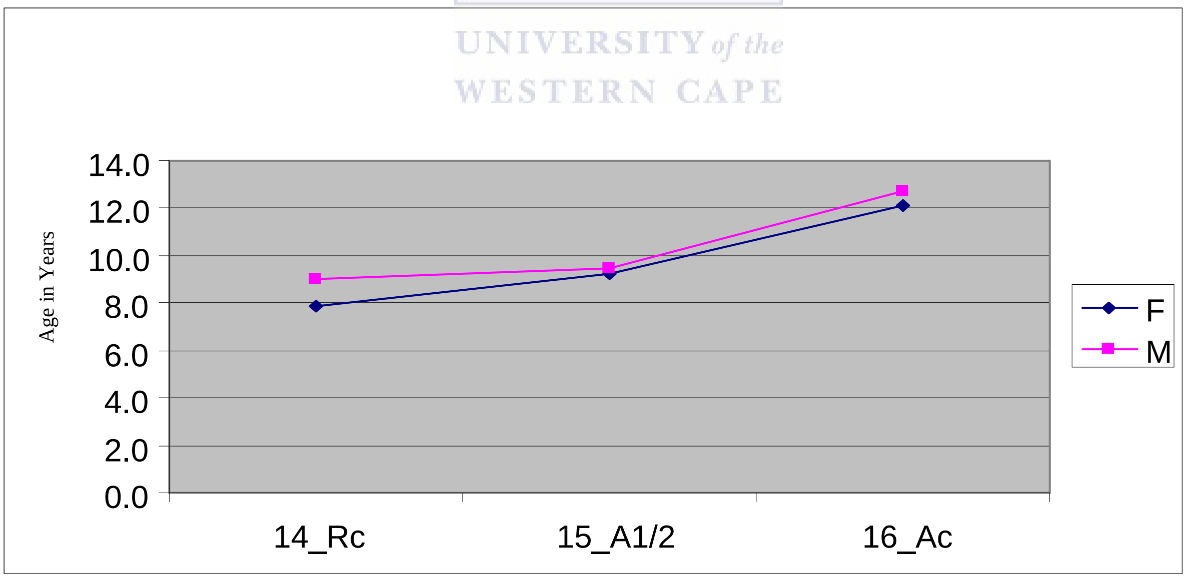
Premolar (Pm1): Initially there is a 6 months difference in the calcification times (R¼ to R¾), but at Rc stage the boys are slower by 1.4 years. The apices close 6 months earlier in girls.

Graph 13: Indian sample. The age related stages of the 2nd Premolar (Pm2) for males and females



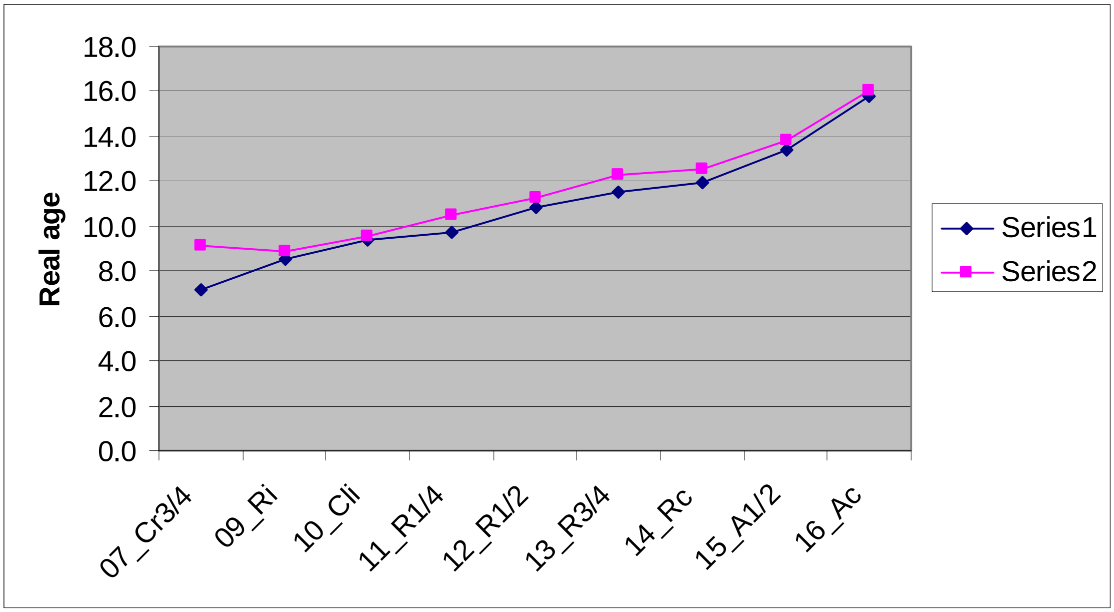
Premolar (Pm2): Initially calcification is 6 months earlier in girls, but at R¾ the girls are 1.4 years earlier. The apices close at 14.5 years.

Graph 14: Indian sample. The age related stages of the 1st Molar (M1) for males and females



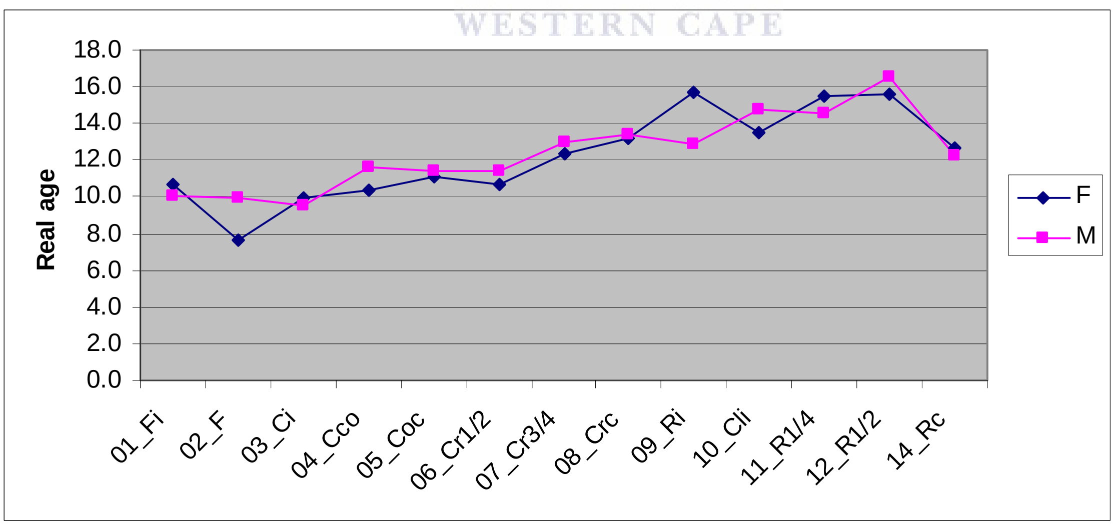
1st Molar (M1): At the Rc stage the girls are 1.1 year ahead of the boys. The apices close at 12.1 and 12.7 years (F:M).

Graph 15: Indian sample. The age related stages of the 2nd Molar (M2) for males and females



2nd Molar (M2): The differences in the calcification times for this tooth was approximately 3 months slower in boys up to the apex closure stage.

Graph 16: Indian sample. The age related stages of the 3rd Molar (M3) for males and females



3rd Molar (M3): At the crown initiation stage calcification is 10 years for both males and females. Thereafter the females are slightly ahead of the males until root initiation / cleft initiation stage where the males are earlier than the females by 2 years (between the ages of 14 and 16 years). By R¼ calcification the females are slightly ahead by 9 months.

Table 3: The dental age related table for the sample of Indian females in years (SD)

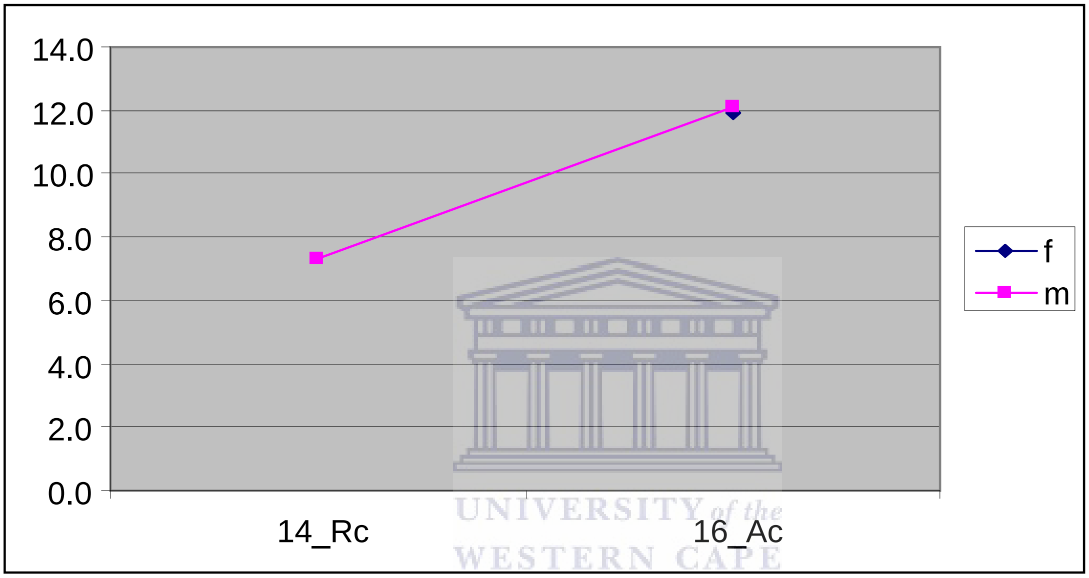
	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								7.60
Ci								9.9(0.91)
Cco								10.3(1.02)
Coc								11(1.45)
Cr1/2								10.7(0.83)
Cr3/4							7.10	12.3(1.12)
Crc								13.1(1.12)
Ri			6.90	7.2(0.36)	8.5(0.77)		8.50	
Cli							9.4(0.91)	13.5(0.33)
R1/4			8.2(0.42)	8.9(0.83)	9.5(0.73)		9.7(1.12)	15.5(0.89)
R1/2	6.90	7.5(0.88)	9(1.07)	10(0.94)	10(0.87)		10.8(0.72)	15.6(1.42)
R3/4	8.2(0.74)	8.3(0.59)	10(0.96)	10.6(1.56)	10.6(0.87)		11.5(1.18)	
Rc	8.9(0.97)	10.1(0.72)	11.1(1.34)	10.7(0.63)	11.3(2.06)	7.9(0.57)	12(2.16)	
A1/2	9.9(0.68)	10(0.77)	12(1.25)	11.7(1.52)	13(0.92)	9.3(0.95)	13.4(0.85)	
Ac	12.3(1.18)	12.7(1.69)	14.8(1.08)	13.5(1.43)	14.5(1.41)	12.1(1.87)	15.8(0.77)	

Table 4: The dental age related table for the sample of Indian males in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								10.00
Ci								9.6(1.39)
Cco								11.6(1.54)
Coc								11.4(1.30)
Cr1/2								11.4(0.61)
Cr3/4							9.2(1.08)	12.9(0.83)
Crc								13.4(0.66)
Ri			6.70	8.5(2.09)	9(0.60)		8.90	
Cli							9.5(0.64)	14.7(1.30)
R1/4			9.4(0.99)	9(0.72)	9.7(1.01)		10.5(1.22)	14.6(0.40)
R1/2	6.70	7.9(1.10)	9.5(1.05)	10.3(0.76)	10.9(1.00)		11.2(1.03)	
R3/4	8.7(0.39)	9.4(0.92)	10.9(0.96)	11.2(1.50)	11.9(0.63)		12.3(0.71)	
Rc	10.6(0.56)	9.6(1.09)	12.1(0.80)	12.1(0.73)	11.6(1.94)	9(1.06)	12.6(1.80)	
A1/2	9.1(0.84)	10.1(0.97)	13.3(0.69)	12.5(1.07)	13.1(0.70)	9.4(0.80)	13.8(0.74)	
Ac	12.5(1.6)	13(1.28)	15(1.14)	14(1.28)	14.6(1.38)	12.7(1.46)	16.1(0.90)	

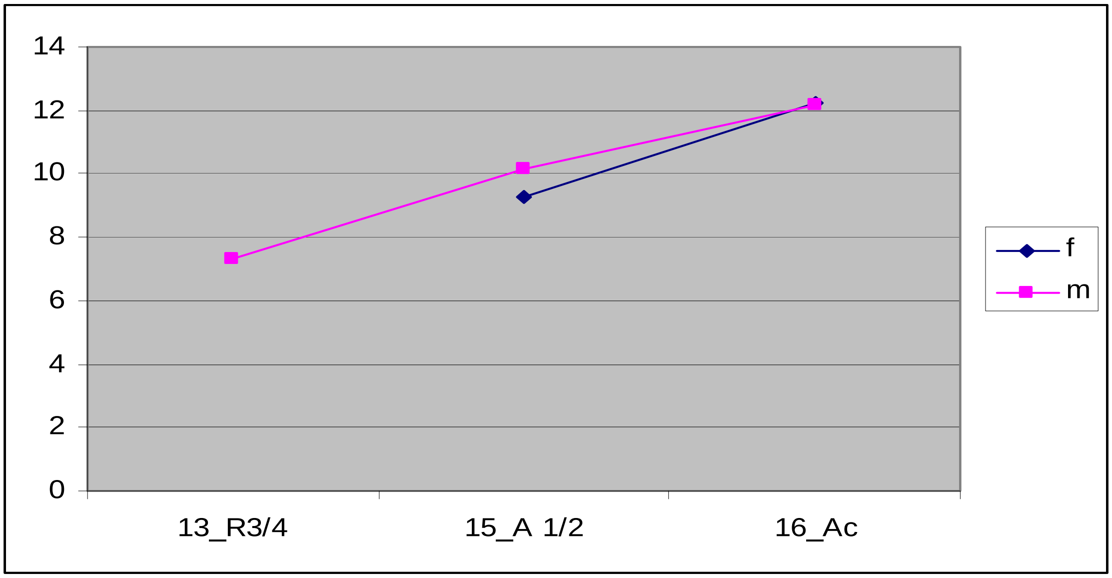
3. **The Zulu Sample:** The dental age estimation graphs of the sample of Black male and female children from Kwa-Zulu Natal are depicted below and show the mean age at which calcification occurs for each developmental stage of the eight permanent mandibular teeth. The age range was from 7 to 15 years.

Graph 17: Zulu sample. The age related stages of the central incisor (I1) for males and females



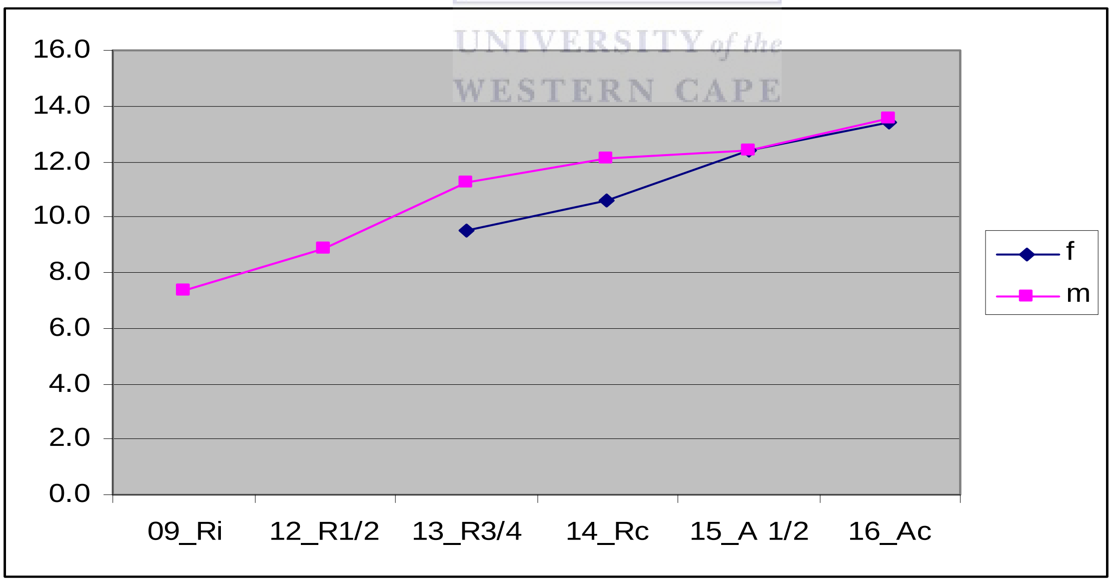
Central incisor (I1): There was only one individual at Rc stage; the apex closes at 11.9 years in females and 12.1 years in males.

Graph 18: Zulu sample. The age related stages of the lateral incisor (I2) for males and Females



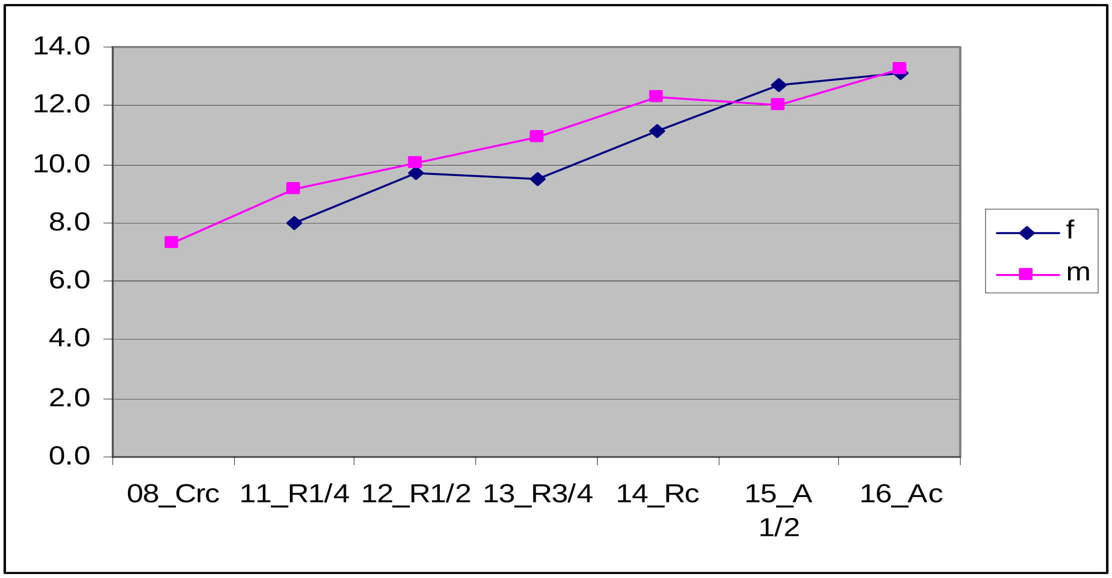
Lateral incisor (I2): There is a difference of time of the apex being half-calcified (A½), 10.2 years in males and 9.3 years in females. The apices are calcified in both sexes at 12.2 years.

Graph 19: Zulu sample. The age related stages of the canine (C) for males and females



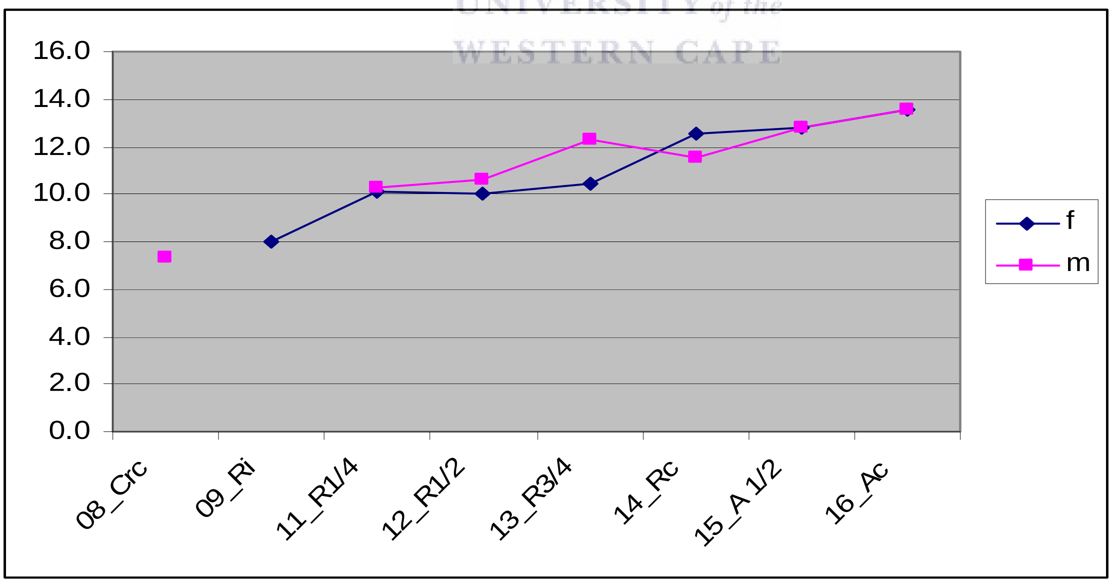
Canine (C): The root calcification in females is at the R¾ stage at 9.5 years, the males are 11.3 years old at this stage. At root complete stage the females are 10.6 years and the males are12.1 years old. The root apices are calcified (Ac) at 13.5 years in both sexes.

Graph 20: Zulu sample. The age related stages of the 1st premolar (Pm1) for males and females



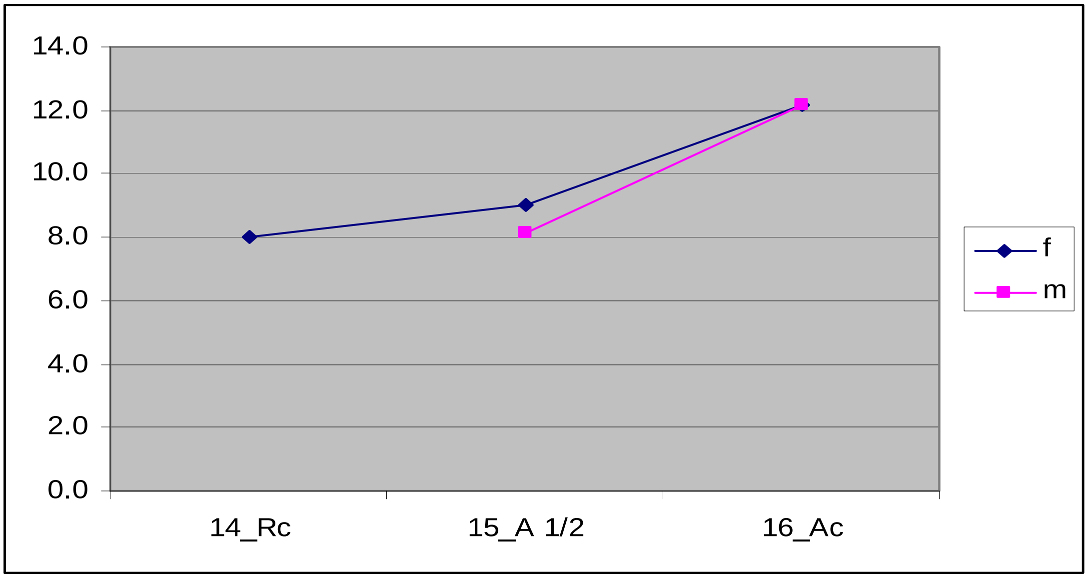
1st premolar (Pm1): The root calcification stages in males are slower than the females by approximately a year. The apex is calcified in males at 13.3 years and in females at 13.1 years.

Graph 21: Zulu sample. The age related stages of the 2nd premolar (Pm2) for males and females



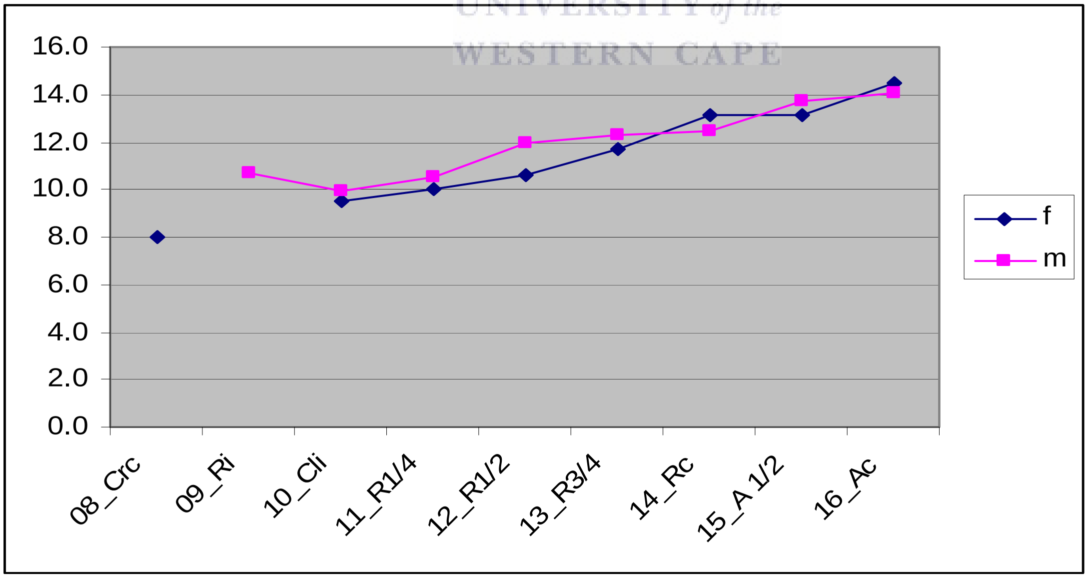
2nd premolar (Pm2): The root calcification is at the R¼ stage at 10.3 years in both sexes. At R¾ stage the girls are 1.8 years ahead of the boys. The root complete stage is reversed in males and females, the males being 1 year ahead of the females. The apices are calcified at 13.5 years in both sexes.

Graph 22: Zulu sample. The age related stages of the 1st molar (M1) for males and Females



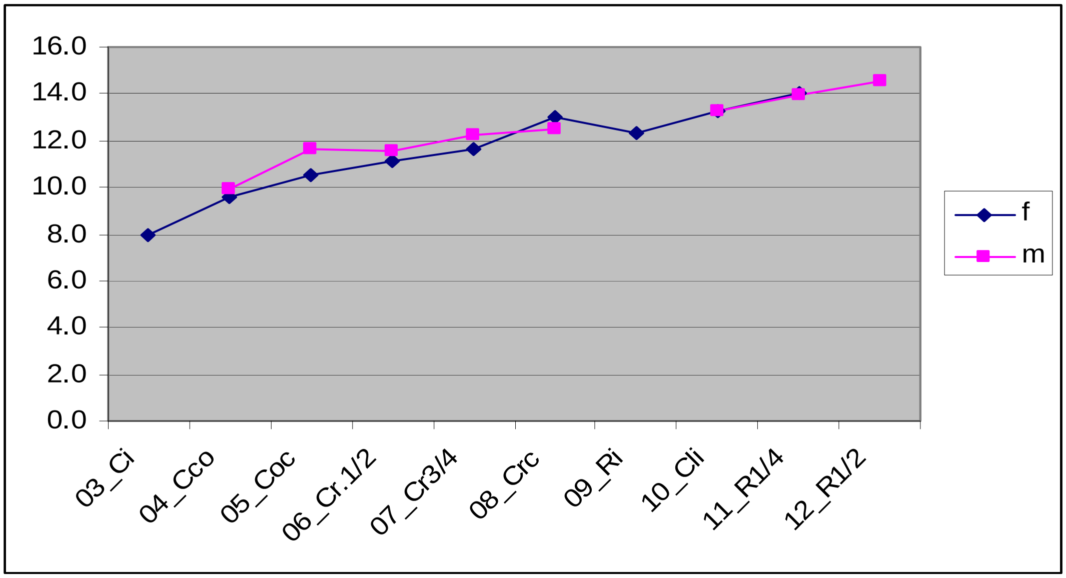
1st molar (M1): There is a difference in the A½ stage with the males being 0.9 years ahead of the females. The apex of this tooth is calcified at 12.2 years in both sexes. Most of the sample of Zulu children was above 10 years of age.

Graph 23: Zulu sample. The age related stages of the 2nd molar (M2) for males and Females



2nd molar (M2): The root calcification in males is slower than females by 0.5 years at Cli stage, at R½ stage the difference is 1.3 years, at R ¾ stage the difference is 0.6 years. The root complete (Rc) stage is reversed with the males being earlier than females by 0.7 years. The apices are calcified (Ac) at 14 years in males and 14.5 years in females.

Graph 24: Zulu sample. The age related stages of the 3rd molar (M3) for males and females



3rd molar (M3): The crowns calcify earlier in females by 6 months; the roots calcify in the same time frame in both sexes, R¼ is at 13.9 years.

Table 5: Age Related Tables for Zulu male children - Ages in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								
Cco								9.9(1.69)
Coc								11.7(0.97)
Cr.1/2								11.6(3.39)
Cr.3/4								12.3(1.23)
Cr.c				7.30	7.30			12.5(1.25)
Ri			7.30				10.7(2.49)	
Cli							10(2.07)	13.2(0.99)
R1/4				9.20	10.3(1.06)		10.6(1.04)	13.9(0.66)
R1/2			8.90	10.1(1.26)	10.6(1.39)		11.9(1.47)	14.60
R3/4			11.3(1.35)	10.9(1.11)	12.3(0.95)		12.3(0.57)	
Rc			12.1(1.64)	12.3(1.19)	11.6(1.23)		12.4(1.12)	
A1/2		10.20	12.4(1.09)	12(1.18)	12.8(1.04)	8.1(1.10)	13.7(0.63)	
Ac	12.1(1.52)	12.2(1.51)	13.5(0.92)	13.3(0.96)	13.5(1.05)	12.2(1.46)	14(0.90)	

Table 6 Age Related Tables for Zulu female children - Ages in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								8.00
Cco								9.6(1.24)
Coc								10.5(1.19)
Cr.1/2								11.10
Cr.3/4								11.6(1.39)
Cr.c							8.00	13(1.09)
Ri					8.00			
Cli							9.5(1.11)	13.2(1.17)
R1/4				8.00	10.1(1.11)		10.1(1.28)	14(0.54)
R1/2				9.7(0.75)	10.6(1.97)		10.6(1.52)	
R3/4			9.5(1.18)	9.5(1.21)	10.5(1.30)		11.7(0.89)	
Rc			10.6(0.54)	11.1(1.03)	12.6(1.53)		13.1(1.26)	
A1/2		9.3(1.80)	12.4(1.26)	12.7(1.17)	12.8(1.12)	9.0(1.80)	13.1(0.80)	
Ac	11.9(1.84)	12.2(1.51)	13.4(1.04)	13.1(1.10)	13.6(0.82)	12.2(1.65)	14.5(0.11)	

Discussion

The Tygerberg sample of children was mainly of White and Coloured origin. The age related tables for this group showed there was a slight difference in the ages at which crown and root calcification took place for males and females. The population origin of each child was not available in numerous cases, therefore the Tygerberg children were regarded a heterogeneous sample group. The sample of Zulu children ranged from 7 to 15 years, but had few young children; this limited the data on crown and root formation of the incisors and 1st molar. The development of the canine to the 3rd molar was, however, comparable to the Tygerberg and Indian samples.

Most of the data of calcification stages of the teeth within the left mandible were limited by the sizes of the samples except for the 2nd molar. The comparable data for this tooth in all three sample groups is from the crown complete (Crc) to the root apex closure (Ac) stages. This tooth appears to show greater stability in its development in both females and male in its relation to the chronological age.

Conclusion

The dental age related tables of the 3 sample groups show that there is relatively little difference in the ages at which the various teeth calcify between the males and females in each sample group. This suggests that when estimating of the age of skeletal remains of a juvenile the sex of the individual may influence the result by 2 to 8 months. Knowing the population origin of the individual will improve the age estimation.

CHAPTER 5

DENTAL AGE ESTIMATION: TESTING STANDARD METHODS OF DENTAL AGE ESTIMATION BY MOORREES, FANNING AND HUNT AND DEMIRJIAN, GOLDSTEIN AND TANNER ON THREE SOUTH AFRICAN CHILDREN SAMPLES.

Charts prepared from population surveys have been used to determine the age of individuals for orthodontic and forensic purposes for many years and have been regarded as sufficiently accurate to estimate chronological age of a juvenile. Standard charts show the bone age, dental age, height and weight, sexual development and secondary growth patterns of children and juveniles. These charts have become the standard references for age assessment used throughout the world (Tanner, 1962). Subsequent studies have used radiographs of the jaws to determine the state of development of the entire mandibular dentition; the maxillary teeth are not easily seen on Pantomographic radiographs and little data is available for these teeth. These charts are based on dental surveys of cross sections of various populations and show the progressive states of dental development for each year of age (Cameron & Sims, 1974). Tanner (1962) suggested that the rate of skeletal growth had increased over the first half of the 20th century therefore creating the difference between the earlier age estimation charts and the recent ones.

Moorrees, Fanning and Hunt (1963) published charts based on a radiographic survey of the development of both the deciduous and permanent dentition. These charts indicate the average age and two standard deviations for the various developmental stages of the teeth. The range between ± two standard deviations represents an age range in which 95% of the population would be expected to reach the appropriate developmental landmark. These charts have proved useful for the assessment of a child's dental development with regard to the skeletal developmental stage and for planning orthodontic treatment. They have also been used for age estimation of skeletal remains.

A study of dental maturity by Demirjian, Goldstein and Tanner (1973) using the Pantomographic radiographs of 2928 boys and girls of French-Canadian ancestry between the ages of 2 and 20 was undertaken. The progressive developmental stages of the 7 left mandibular teeth were allocated labels A to H. The various stages of dental development were recorded for each of the age groups. Maturity scores, based on the work of Tanner, Whitehouse and Healy (1962) were developed and allotted to each tooth during its developmental stages. The total of the maturity scores of the 7 teeth was then converted to tables for both boys and girls to obtain an estimated chronological age.

Several authors have tested the Demirjian *et al* method against their child population groups with varying success.(Hägg & Matson (1985); Davis PJ & Hägg U (1994); Farah CS, Booth DR, Knott SC(1999); Willems G, Van Olman A, Spiessens B Carels C (2001); Maber M, Liversidge HM, Hector MP (2006); Rózylo-Kalinowska, Kiworkowa-Raczkowska and Kalinowski (2007).

The aim of this study was to test the accuracy of the dental age estimation methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) against population samples of children of known chronological age from the Western Cape (Tygerberg sample), Black (Zulu) and Indian from Kwa-Zulu Natal.

Materials and methods

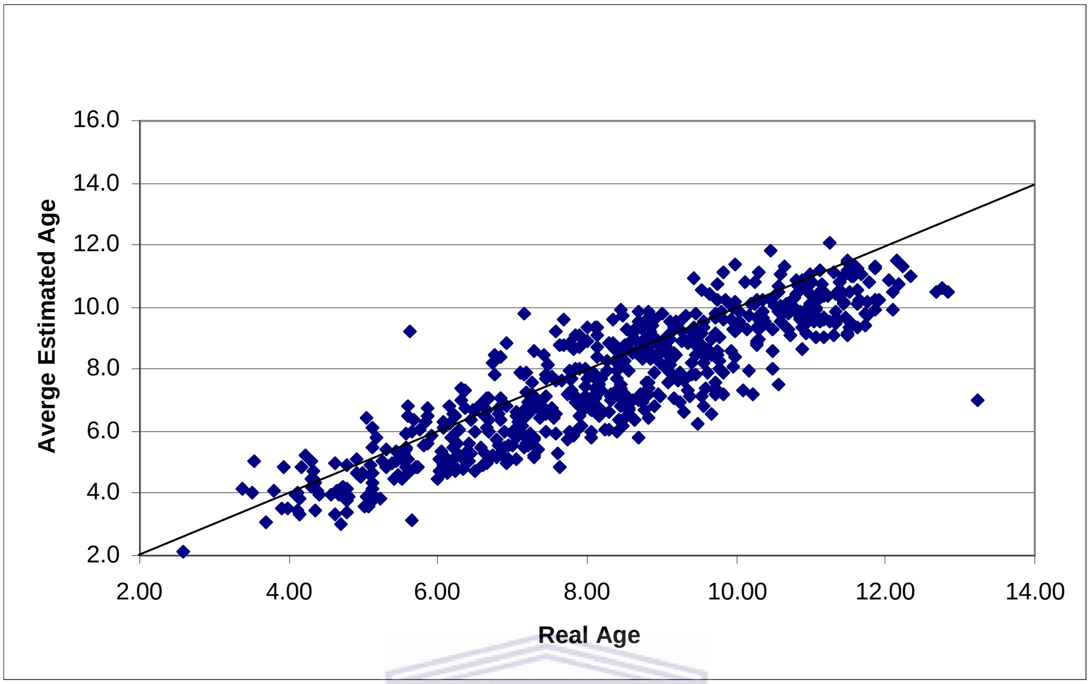
The data used for this study consisted of 916 Pantomographic radiographs of children between the ages of 3 years to 16 years that had routine dental treatment at the Dental

Faculty at Tygerberg. These were recorded as the Tygerberg sample. The Pantomographic radiographs of 90 Black (Zulu) children (43 females and 47 males) with an age range of between 7 and 15 years were obtained from an orthodontic practice in Durban. A sample of 157 Indian children (82 females and 75 males) with an age range of 6 to 16 years was obtained from 2 orthodontic practices in Durban. Only radiographs showing normal development and no pathological lesions were used. Each radiograph was numbered for further reference together with the name, sex, date of birth and the date on which the radiograph was taken. The chronological age of each individual was calculated by subtracting the date of birth from the date when the radiograph was taken. Each radiograph was then examined and the stages of development of each of the permanent mandibular teeth in the left mandibular quadrant were recorded. The age of each child was estimated firstly using the method of MFH (1963) and then that of DGT (1973). The estimated ages of the Tygerberg sample were then compared to their chronological ages. The data from the Indian and Zulu samples were analyzed in a similar manner. The data from each of the sample groups was used to analyze the error between the chronological age (real age) of each child with the age estimations of MFH and DGT methods respectively.

Results

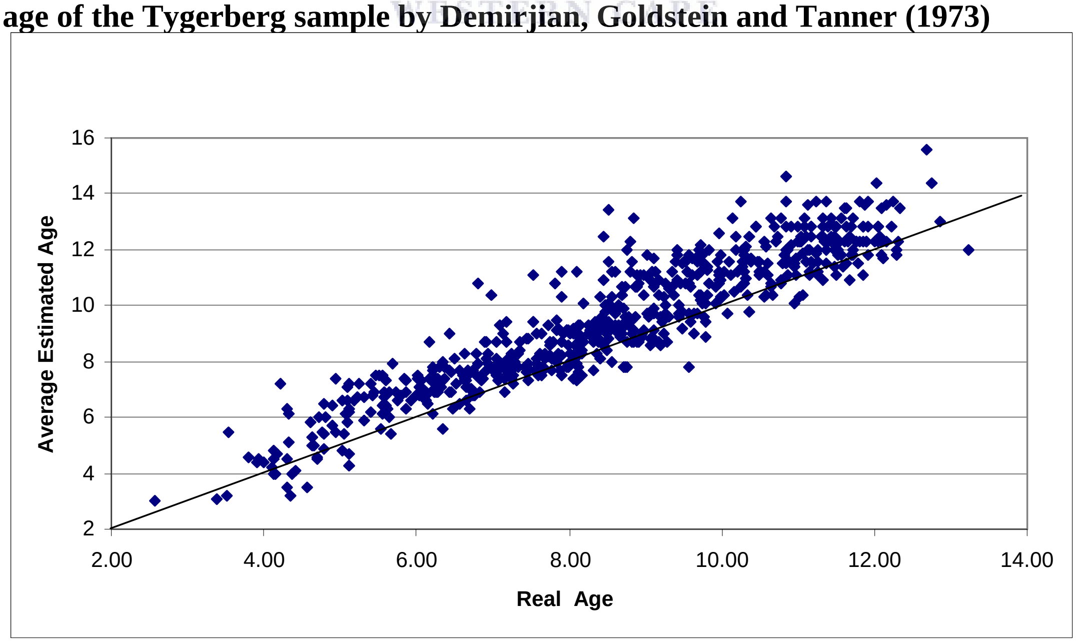
The data from the Tygerberg sample was used to compare the real age (chronological age) to the estimated age by both MFH (1963) and DGT (1973) methods. Graph 1 shows a scatter diagram of the estimated ages using MFH method and compared to the real age; it was found that in the Tygerberg sample, this method under-estimated the ages in 89.2% of the sample on average by 0.91 years; the DGT method over-estimated the ages of these children on average by 0.89 years in 85.7% of the sample (Graph 2).

Graph 1: Comparison between chronological age and the average estimated age of the Tygerberg sample by Moorrees, Fanning and Hunt (1963)



Graph 1 shows the comparison between the real age and the average estimated age by Moorrees *et al* of the Tygerberg sample. There is under-estimation of the chronological ages in 89.2% of the sample

Graph 2: Comparison between the chronological age and the average estimated age of the Tygerberg sample by Demirjian, Goldstein and Tanner (1973)



Graph 2 shows the comparison between the real age and the average estimated age of the Tygerberg sample by Demirjian *et al*. There is over-estimation of the chronological ages in 85.7% of the sample.

The data for each of the 3 sample groups i.e. Tygerberg, Indian and Zulu, were used to test the degree of error between the estimated age and the chronological age. The estimation error was calculated in the following manner; the real age was compared to the difference between the estimated age minus the real age for both MFH and DGT methods (Graphs 3, 4, 6, 7, 8 & 9).

Table 1 shows that the average age under-estimation of the Tygerberg sample by the MFH method was 0.91 years in 89.2% of the sample; the average age over-estimation by the DGT method of this sample was 0.89 years in 85.7% of the sample.

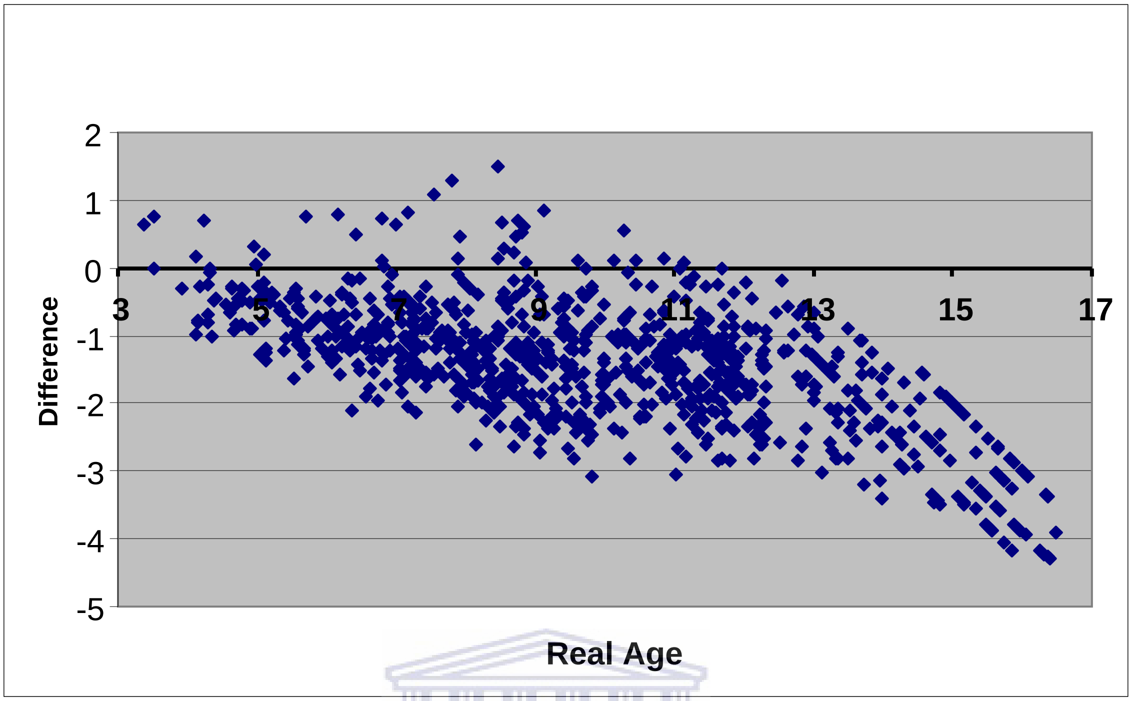
Table 1: Average age estimation of the Tygerberg sample in years

Moorrees *et al*	**Demirjian *et al***
-0.91 (in 89.2%)	**0.89 (in 85.7%)**

In the Tygerberg sample the Moorrees *et al* method under-estimated the chronological age of 89.2% of the sample by 0.91 years. The Demirjian *et al* method over-estimated the chronological age of 85.7% of the sample by 0.89 years.

Graph 3 shows the estimation error compared to the chronological age of the Tygerberg sample of children by the MFH method. This graph shows that 96% of the sample lies below the chronological age. The error increases with age from 13 to 16 years.

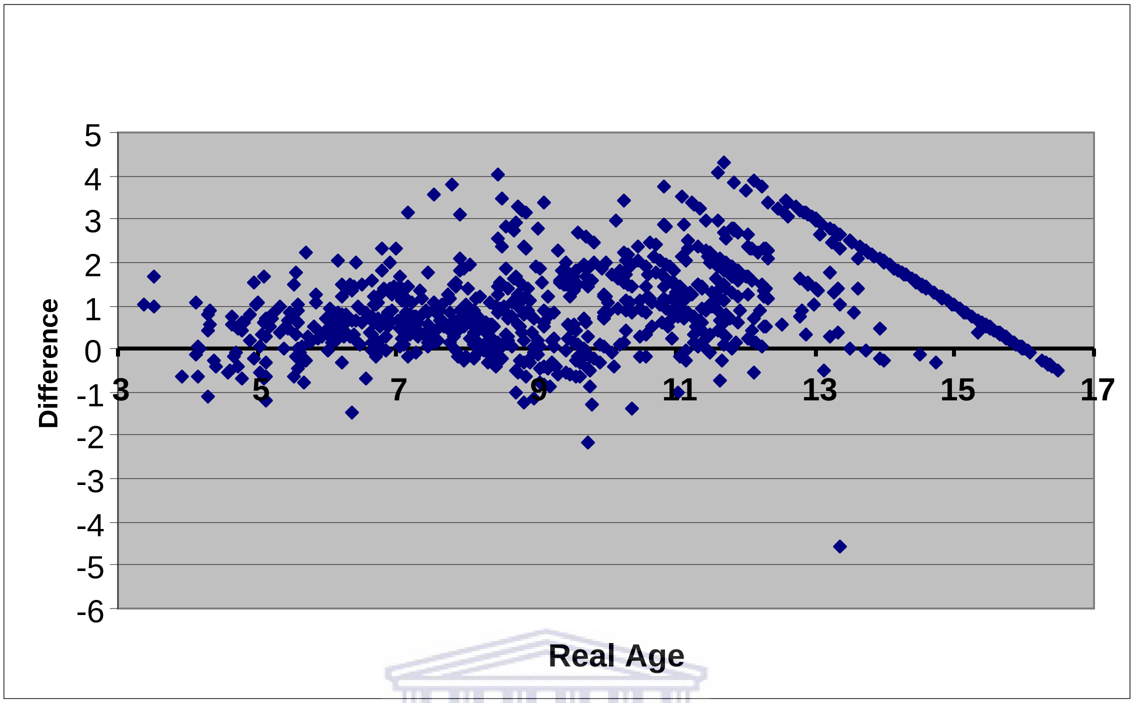
Graph 3: Tygerberg children. Age estimation error using the MFH method



Graph 3 shows the *estimation error* by the Moorrees *et al* method of the chronological ages of the Tygerberg children; 96% of the sample lies below the chronological age.

Graph 4 shows the estimation error compared to the chronological age of the Tygerberg sample by the DGT method. This graph shows that 86.3% of the sample lies above the chronological age.

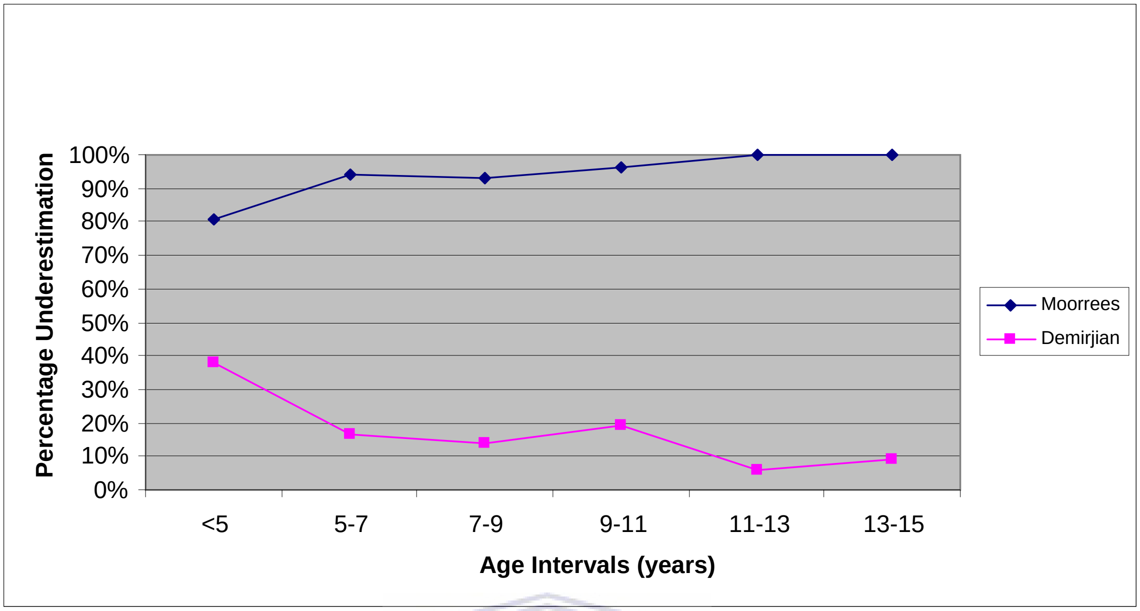
Graph 4: Tygerberg children. Age estimation error using the DGT method



Graph 4 shows the *estimation error* by the Demirjian *et al* method of the chronological ages of the Tygerberg sample. 86.3% of the sample lies above the chronological age.

Graph 5 shows the degree of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals. This graph indicates that the MFH method under-estimates 81% of individuals who are under 5 years of age; 94% between 5 and 7 years; 93% between 7 and 9 years; 97% between 9 and 11 years and 100% between 11 and 15 years. The DGT method therefore over-estimates 62% of individuals under the age of 5 years; 83% between 5 and 7 years; 86% between 7 and 9 years; 81% between 9 and 11 years; 94% between 11 and 13 years and 91% between 13 and 15 years (Table 2).

Graph 5: The percentage of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals



Graph 5 shows the percentage of under-estimation of the ages of the Tygerberg sample in age intervals using the Moorrees *et al* method; the over-estimation of the ages by Demirjian *et al* is the complement to the figures. [See Table 2.]

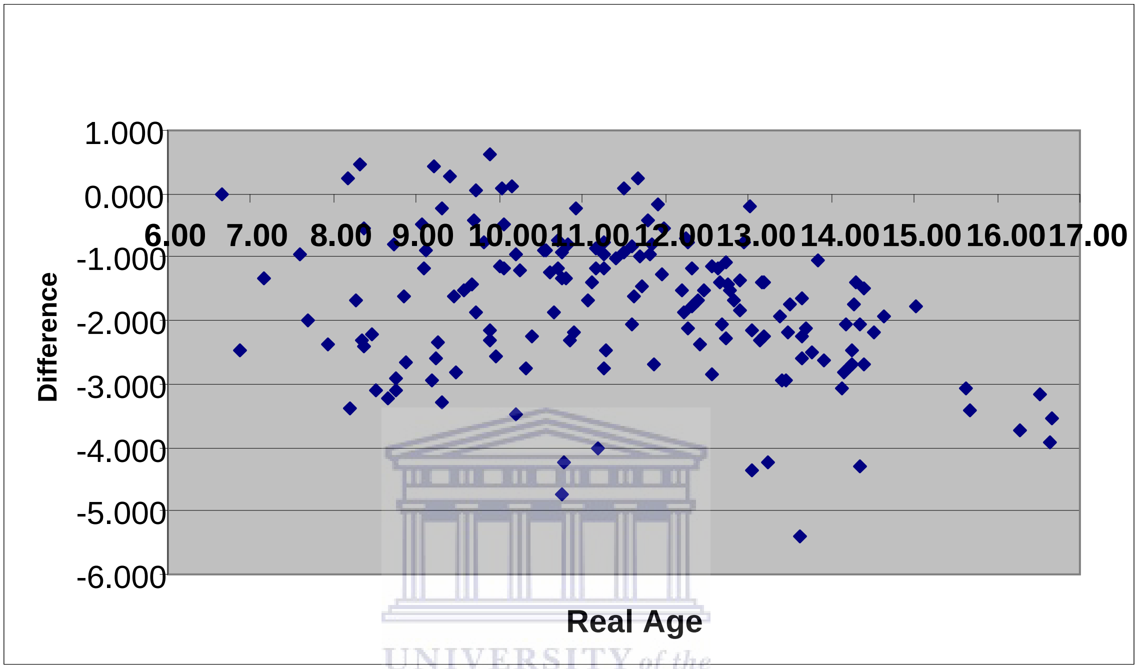
Table 2: The percentage under-estimation of the ages of the Tygerberg sample in age intervals by Moorrees *et al* and over-estimation by Demirjian *et al*

Demirjian						
Age Interval	**<5**	**5-7**	**7-9**	**9-11**	**11-13**	**13-15**
% Over Est.	62%	83%	86%	81%	94%	91%
Moorrees						
Age Interval	**<5**	**5-7**	**7-9**	**9-11**	**11-13**	**13-15**
% Under Est.	81%	94%	93%	97%	100%	100%

Table 2 shows the percentage of the Tygerberg sample in which the ages have been under-estimated by the Moorrees *et al* method and the percentage that have been over-estimated by the Demirjian *et al* method in age intervals.

Graph 6 shows the under-estimation of the ages of the Indian children by the MFH method; 93.7% of the sample lies below the chronological age.

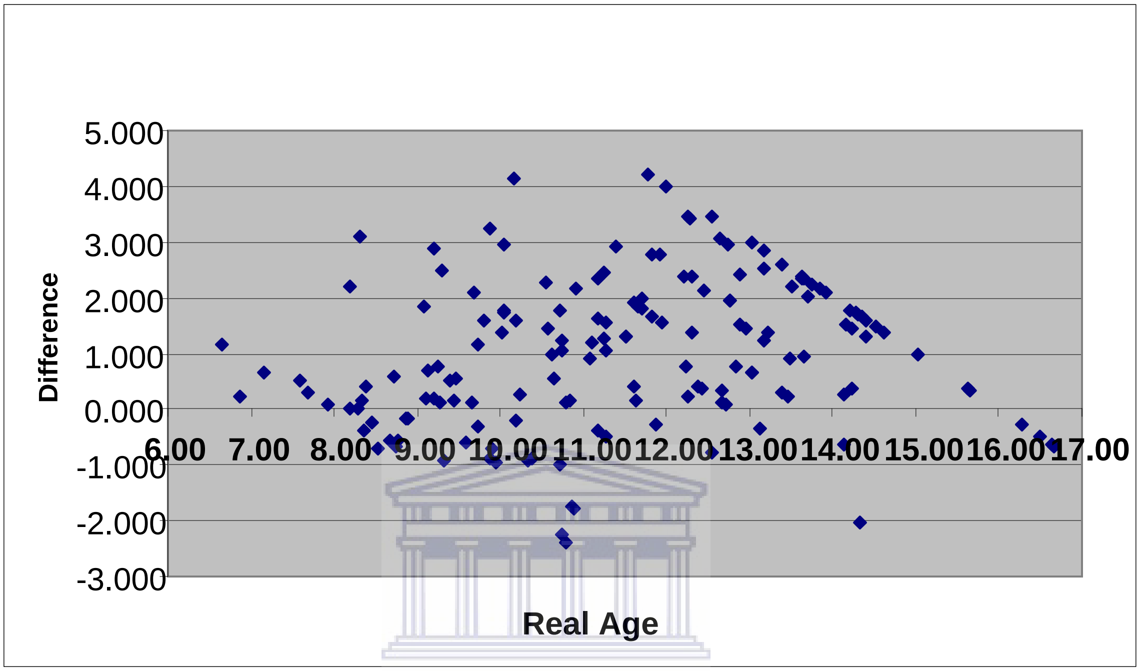
Graph 6: Indian children. Age estimation error using the MFH method



Graph 6 shows the *estimation error* by the Moorrees *et al* method of the chronological age of the Indian sample. 93.7% of the sample lies below the chronological age.

Graph 7 shows the over-estimation of the ages of 79.2% of the Indian children by the DGT method.

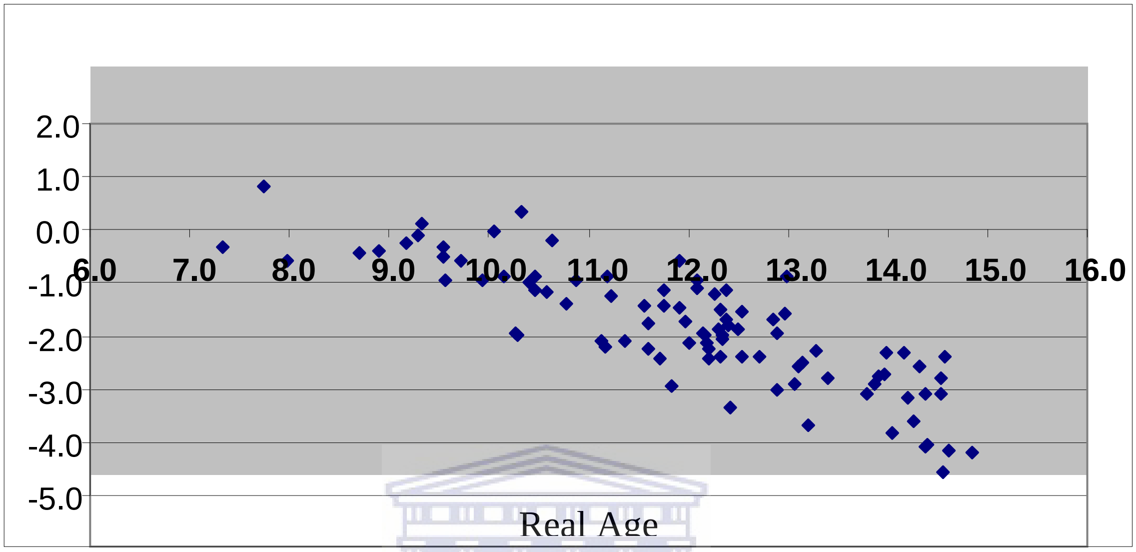
Graph 7: Indian children. Age estimation error using the DGT method



Graph 7 shows the *estimation error* by Demirjian *et al* of the chronological age of the Indian sample. 79.2% of the sample lies above the chronological age.

Graph 8 shows the under-estimation of the ages of 96.7% of the Zulu children by the MFH method.

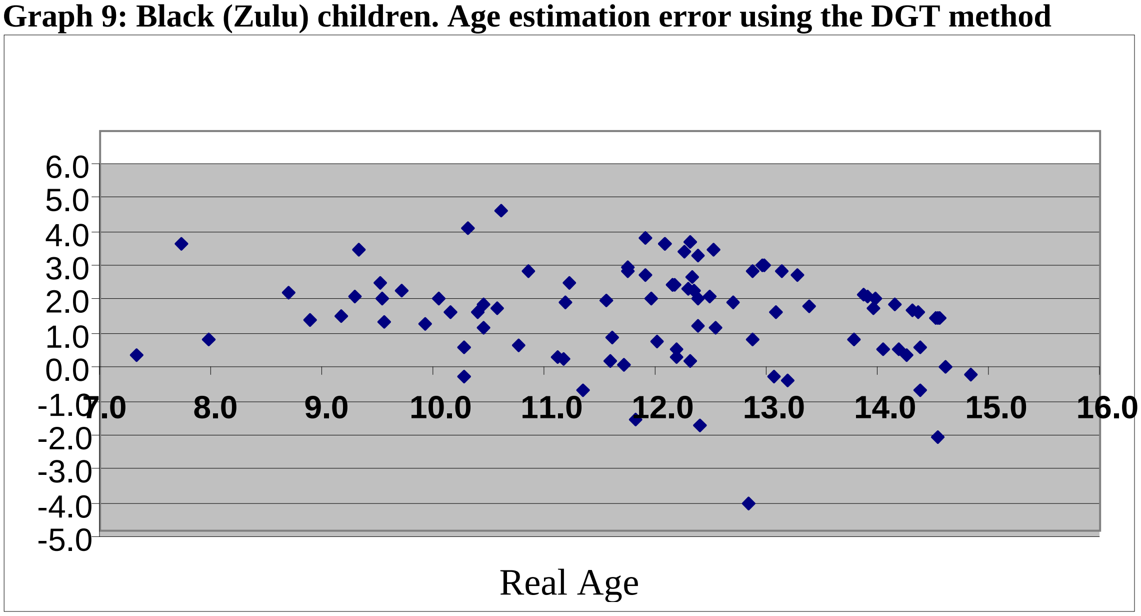
Graph 8: Black (Zulu) children. Age estimation error using the MFH method



Graph 8 shows the *estimation error* by Moorrees *et al* of the chronological age of the Zulu sample. 96.7% of the sample lies below the chronological age.

Graph 9 shows the over-estimation of the ages of 90% of the Zulu children by the DGT method.

Graph 9: Black (Zulu) children. Age estimation error using the DGT method



Graph 9 shows the *estimation error* by Demirjian *et al* of the chronological age of the Zulu sample. 90% of the sample lies above the chronological age.

Table 3 shows the percentage of the 3 samples in which there was under-estimation and over-estimation of the chronological ages by the methods of MFH and DGT respectively. The method of MFH under-estimated the ages of 96% of the Tygerberg sample, 93.7% of the Indian sample and 96.7% of the Zulu sample. The DGT method over-estimated the ages of 86.3% of the Tygerberg sample, 79.2% of the Indian sample and 90% of the Zulu sample.

Table 3: The percentage of samples where age is over-estimated and under-estimated

	Under-estimation by Moorrees *et al*	Over-estimation by Demirjian *et al*
Tygerberg (n = 814)	96%	86.3%
Indian (n = 153)	93.7%	79.2%
Zulu (n = 91)	96.7%	90.0%

This table shows the percentage under-estimation of the chronological ages of all 3 sample groups by Moorrees *et al* and the percentage over-estimation by Demirjian *et al* for the Tygerberg, Indian and Zulu children.

Discussion

The method of Moorrees, Fanning and Hunt (1963) was used extensively for dental age estimation until Demirjian, Goldstein and Tanner (1973) published their new dental age estimation method. The MFH method was used to predict the stage of development of the teeth at a certain age whereas the DGT method was originally regarded as a better method of dental age estimation. Several authors have however shown that the use of DGT method was not accurate when applied to their population sample. (Hägg and Matsson, 1985; Davis and Hägg, 1994; Farah, Booth and Knott, 1999; Willems *et al* 2001).

This study limited the age range of the samples to individuals between the ages of 6 and 16 years. The study showed that the method of MFH under-estimated the ages of the three South African sample groups and the method of DGT over-estimated the ages of these groups. The under-estimation of the ages of all 3 samples by MFH was over 90% in each sample group. The over-estimation of the ages of the samples varied from 79.2% for Indians, 86.3% for the Tygerberg children and 90% for the Black children. The isolated individuals in the graphs where the age estimation by MFH (Graph 3) and that of DGT (Graph 4) are severely under-estimated or over-estimated respectively are either due to incorrect documentation of the date of birth on the radiograph or individuals that are genetically very advanced or retarded in their growth patterns. An increase in error with age is also noted especially with the DGT method. This could be due to the construction of the weighted tables in which a small change in weighted value is applied to the ages between 13 and 16 years.

Conclusion

The Moorrees, Fanning and Hunt method consistently under-estimates the ages of the three samples of South African children. The Demirjian *et al* method over-estimates the ages of these samples. These methods are not applicable to accurately estimate the ages of South African juveniles. It therefore follows that dental age related tables for the different ethnic groups in South Africa are necessary for age estimation of these children.

CHAPTER 6

DEVELOPMENT OF CORRECTION TABLES FOR THE MOORREES AND DEMIRJIAN METHODS WHEN USED TO ESTIMATE THE AGES OF SOUTH AFRICAN CHILDREN

In Chapter 5 the age estimation of the three samples of South African children using the Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) methods was described. These methods were inaccurate in estimating the chronological ages of the Tygerberg, Indian and Zulu children by either under-estimating the age in the case of MFH method or over-estimating the age using the DGT method. The average margin of error was approximately 1 year in each case. This indicated that these methods were not suitable for accurately estimating the ages of the South African sample groups of this study.

The aim was therefore to derive correction tables for the MFH and the DGT methods to compensate for the margin of error of each method when applied to South African children.

Materials and methods

The raw data of the Tygerberg, Indian and Zulu sample groups were used (Chapter 5). The interquartile ranges of the errors of each of the age estimation methods of MFH and DGT were calculated for each age midpoint in the Tygerberg, Indian and Zulu samples. The age range was between 7 and 16 years for all three sample groups. The interquartile ranges were used to calculate the median error of the age estimation for each age midpoint between 7 and 16 years for each sample group. Graphs and tables were developed using this data. The median age estimation error was used to develop a table of correction factors from 7 to 16 years for the age estimation methods of MFH and DGT respectively for the 3 sample groups i.e. Tygerberg, Indian and Zulu children.

Results

The age estimation data of the Tygerberg sample utilizing the MFH and the DGT methods were used to calculate the interquartile ranges of the respective age estimation errors. The 1st to 3rd quartiles of the age estimation errors of the MFH method on the Tygerberg sample showed that the median error increases as the age increases from 7 to 16 years (Graph 1, Table 1). At the age of 7 years the median under-estimation of the age is 1 year; this median increases to 3.4 years at the age of 16 years.

Graph 1: The quartiles for the MFH method compared to the age mid-points (Tygerberg)

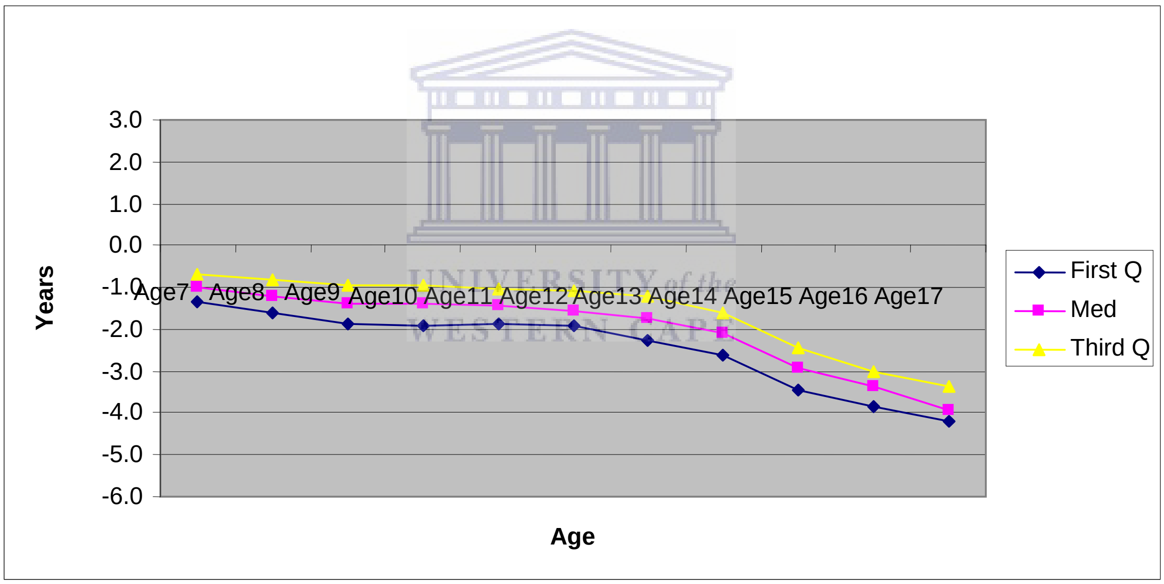


Table 1: Interquartile ranges of age estimation errors using the MFH method (Tygerberg)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-2.1	-2.6	-3.1	-3.1	-3.0	-3.0	-3.4	-3.5	-4.2	-4.3
First Q	-1.3	-1.6	-1.9	-1.9	-1.9	-1.9	-2.3	-2.6	-3.5	-3.8
Med	-1.0	-1.2	-1.4	-1.4	-1.5	-1.6	-1.7	-2.1	-2.9	-3.4
Third Q	-0.7	-0.8	-0.9	-1.0	-1.0	-1.1	-1.2	-1.6	-2.4	-3.0
Max	1.3	1.5	1.5	0.8	0.5	0.1	-0.2	-0.7	-1.5	-2.1

Table 1 and Graph 1 show the interquartile ranges of the age estimation errors on the Tygerberg sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

The DGT method of age estimation on the Tygerberg sample resulted in median quartiles that varied as the age increased to the age of 14 years, the error decreased to the age of 16 years. The errors were large between the ages of 10 and 15 years (Graph 2, Table 2).

Graph 2: The quartiles for the DGT method compared to the age mid-points (Tygerberg)

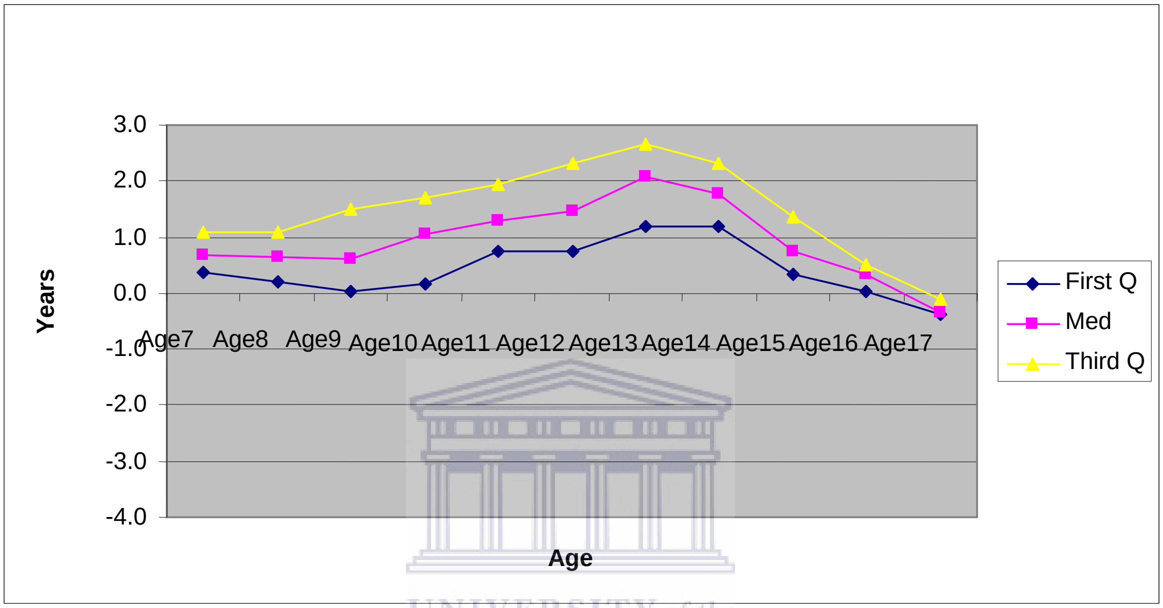


Table 2: Interquartile ranges of age estimation errors using the DGT method (Tygerberg)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-1.5	-1.2	-2.1	-2.1	-1.4	-1.0	-4.6	-4.6	-0.3	-0.5
First Q	0.4	0.2	0.0	0.2	0.8	0.7	1.2	1.2	0.3	0.0
Med	0.7	0.6	0.6	1.0	1.3	1.5	2.1	1.8	0.7	0.3
Third Q	1.1	1.1	1.5	1.7	1.9	2.3	2.7	2.3	1.4	0.5
Max	3.8	4.0	4.0	3.8	4.3	4.3	3.9	3.0	1.9	0.9

Table 2 and Graph 2 show the interquartile ranges of the age estimation errors on the Tygerberg sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Similar interquartile ranges were calculated for the Indian and Zulu samples. In the Indian sample, using the MFH method, the median error varies as the age increases. The error is small from age 10 to 12, but then increases up to 16 years. (Graph 3, Table 3).

Graph 3: The quartiles for the MFH method compared to the age mid-points (Indian)

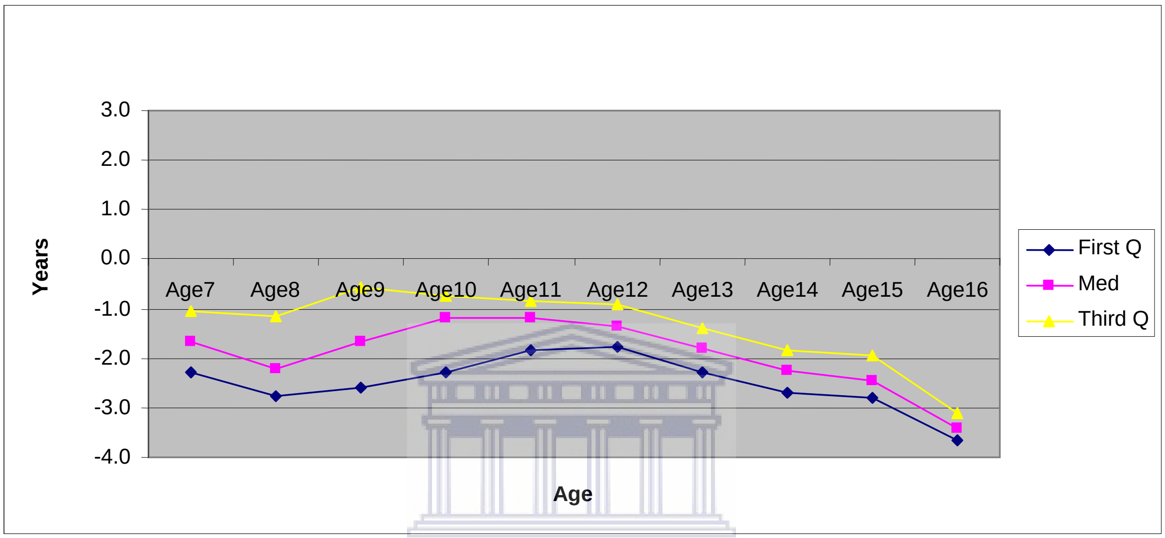


Table 3: Interquartile ranges of age estimation errors using the MFH method (Indian)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-2.5	-3.4	-3.4	-4.7	-4.7	-4.0	-5.4	-5.4	-4.3	-3.9
First Q	-2.3	-2.8	-2.6	-2.3	-1.8	-1.8	-2.3	-2.7	-2.8	-3.6
Med	-1.7	-2.2	-1.7	-1.2	-1.2	-1.4	-1.8	-2.2	-2.5	-3.4
Third Q	-1.0	-1.1	-0.6	-0.7	-0.8	-0.9	-1.4	-1.8	-1.9	-3.1
Max	0.0	0.5	0.6	0.6	0.3	0.3	-0.2	-0.2	-1.4	-1.8

Table 3 and Graph 3 show the interquartile ranges of the age estimation errors on the Indian sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Using the DGT method, the Indian sample showed the median error increases as the age increases to the age of 14 years. The error is small from age 7 to 9 years; the error is progressively larger from 10 to 14 years then decreases towards the age of 16 years (Graph 4, Table 4).

Graph 4: The quartiles for the DGT method compared to the age mid-points (Indian)

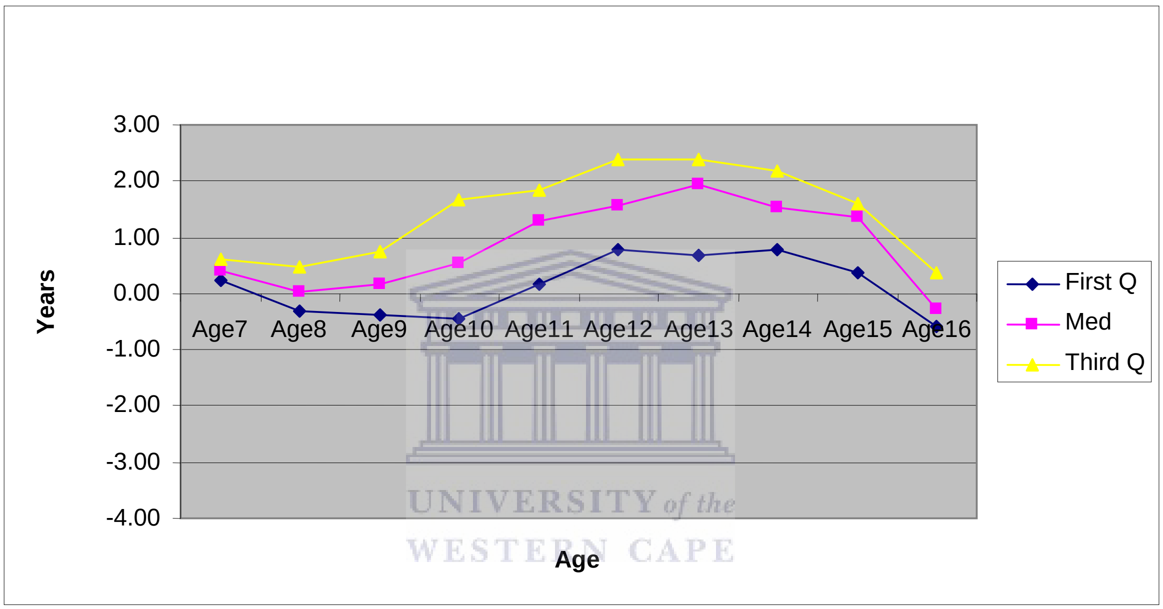


Table 4: Interquartile ranges of age estimation errors using the DGT method (Indian)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	0.07	-0.72	-0.95	-2.38	-2.38	-0.76	-0.76	-2.04	-2.04	-0.67
First Q	0.25	-0.31	-0.37	-0.45	0.17	0.76	0.67	0.80	0.36	-0.57
Med	0.41	0.02	0.15	0.54	1.30	1.55	1.94	1.53	1.37	-0.28
Third Q	0.61	0.47	0.76	1.67	1.82	2.39	2.39	2.18	1.59	0.36
Max	1.14	3.09	3.22	4.14	4.22	4.22	3.45	2.98	1.78	0.97

Table 4 and Graph 4 show the interquartile ranges of the age estimation errors on the Indian sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

The Zulu sample, using the MFH method, showed the median error decreases from 7 to 10 years. The error increases as the age increases from 11 to 16 years (Graph 5, Table 5).

Graph 5: The quartiles for the MFH method compared to the age mid-points (Zulu)

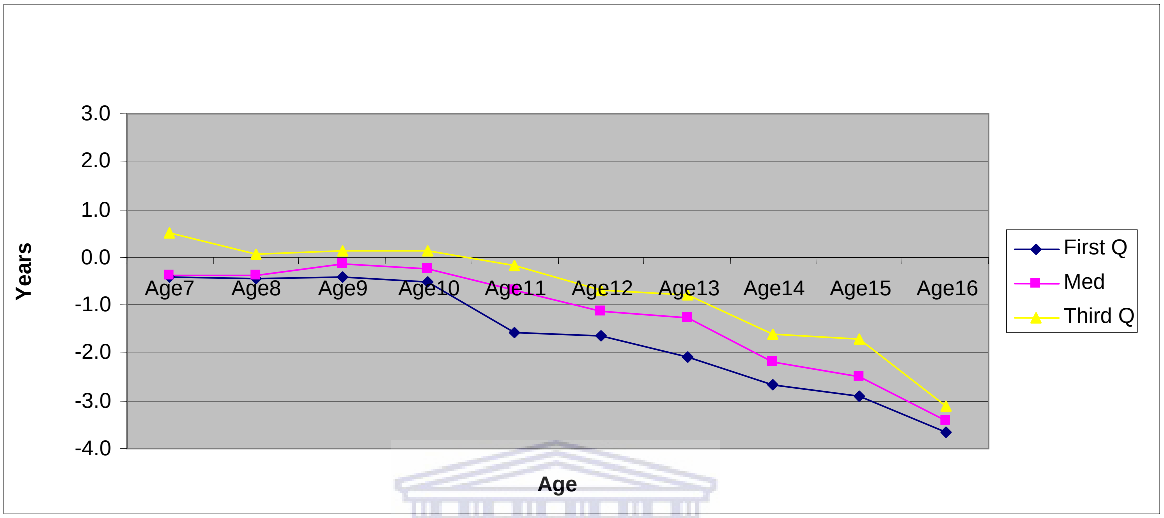


Table 5: Interquartile ranges of age estimation errors using the MFH method (Zulu)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-0.5	-0.6	-0.9	-1.6	-2.9	-3.3	-3.3	-4.4	-4.4	-3.9
First Q	-0.4	-0.5	-0.4	-0.5	-1.6	-1.6	-2.1	-2.7	-2.9	-3.6
Med	-0.4	-0.4	-0.1	-0.2	-0.7	-1.1	-1.3	-2.2	-2.5	-3.4
Third Q	0.5	0.1	0.1	0.1	-0.2	-0.7	-0.8	-1.6	-1.7	-3.1
Max	1.4	1.4	0.9	0.9	0.7	0.0	-0.1	-0.9	-1.5	-1.8

Table 5 and Graph 5 show the interquartile ranges of the age estimation errors on the Zulu sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

This sample of Zulu children, using the DGT method, showed the median error increases as the age increases to the age of 13 years, then decreases to the age of 16 years. The error is largest between the ages of 10 and 15 years (Graph 6, Table 6).

Graph 6: The quartiles for the Demirjian *et al* method compared to the age mid-points (Zulu)

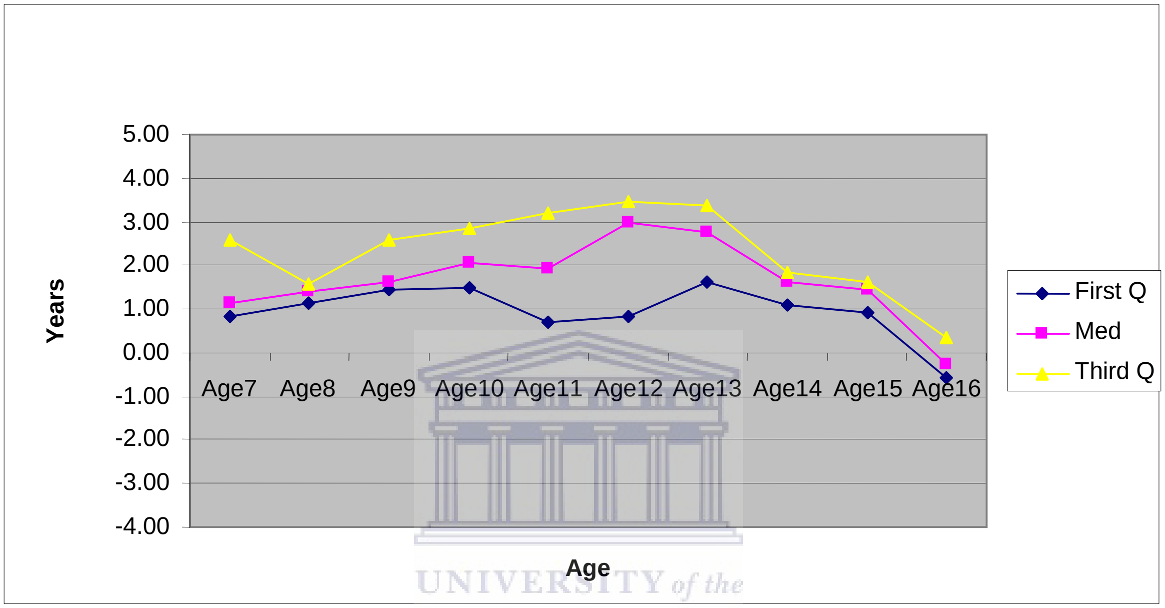


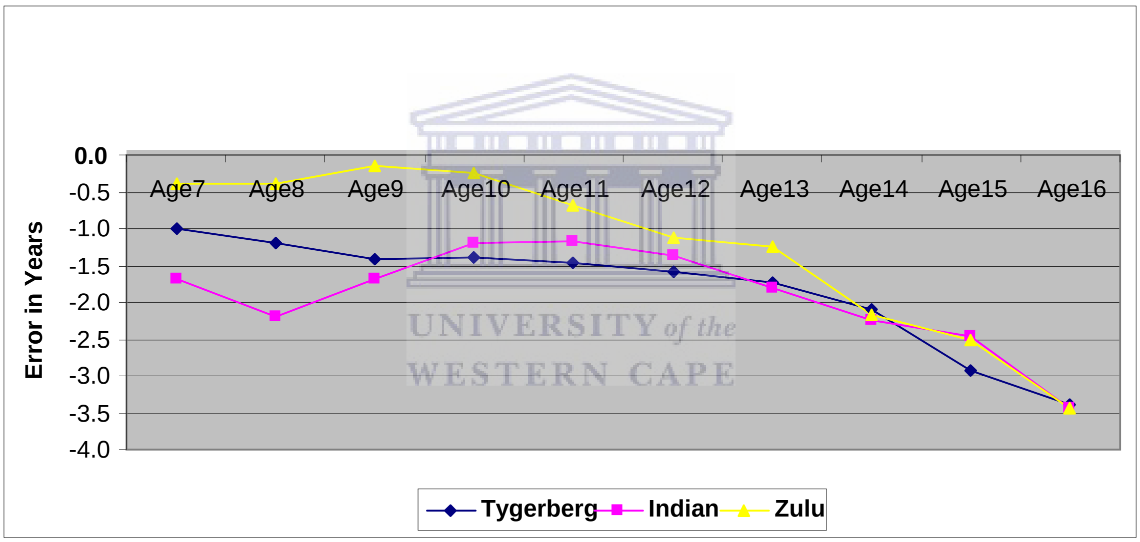
Table 6: Interquartile ranges of age estimation errors using the Demirjian *et al* method (Zulu)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	0.57	0.57	1.27	0.03	-1.53	-1.71	-1.71	-2.05	-2.05	-0.67
First Q	0.84	1.12	1.44	1.50	0.68	0.81	1.64	1.09	0.92	-0.57
Med	1.12	1.40	1.62	2.05	1.94	2.97	2.77	1.61	1.45	-0.28
Third Q	2.59	1.59	2.60	2.83	3.21	3.47	3.39	1.84	1.62	0.36
Max	4.06	4.06	3.87	4.59	4.59	3.95	3.69	2.86	1.84	0.97

Table 6 and Graph 6 show the interquartile ranges of the age estimation errors on the Zulu sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Graph 7 shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups together, using the Moorrees *et al* age determination method. The errors vary in magnitude in the 3 samples in the younger ages; at age 8 years the error is 2.2 years for Indians, 1.2 years for the Tygerberg group and 0.4 years for Zulu children. From 12 to 16 years the errors increase, but are of similar magnitude for the 3 sample groups. This method has a small degree of error for Zulu children between 7 and 11 years of age.

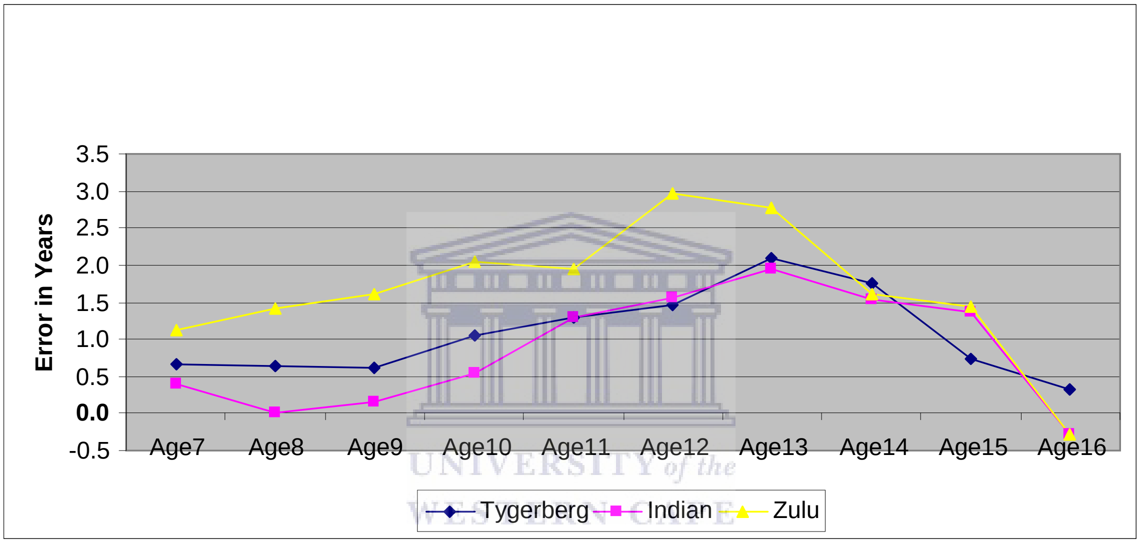
Graph 7: Median Errors made by the MFH method compared to the Real Age



This graph shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the MFH age determination method. The errors vary in magnitude between the 3 samples. At age 8 years the error is 2.2 years for Indians, 1.2 years for the Tygerberg group and 0.4 years for Zulu children. At age 12 to 16 years the errors increase from 1.5 to 3.5 years, but are of similar magnitude for the 3 sample groups.

Graph 8 shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the Demirjian *et al* age determination method. The errors vary in magnitude between the three samples. There is a large error in the 10 to 14 year old Zulu children, which is similar, but not as great in the Tygerberg and Indian groups. The error decreases towards the older ages.

Graph 8: Median Errors made by the Demirjian Method compared to the Real Age



This graph shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the DGT method. The errors vary in magnitude between the three samples. There is a large error in the 10 to 14 year old Zulu children compared to the Tygerberg and Indian children.

The median errors were used to construct a table of correction factors for each of the age estimation methods of MFH and DGT for the children of the Tygerberg, Indian and Zulu sample groups (Table 7).

Table 7: CORRECTION TABLES FOR DENTAL AGE ESTIMATION ON SOUTH AFRICAN CHILDREN

Moorrees	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Tygerberg	1	1.2	1.4	1.4	1.5	1.6	1.7	2.1	2.9	3.4
Indian	1.7	2.2	1.7	1.2	1.2	1.4	1.8	2.2	2.5	3.4
Black	0.4	0.4	0.1	0.2	0.7	1.1	1.3	2.2	2.5	3.4

Age estimation of lower teeth of left or right quadrant (Canine to 3rd molar). Estimate average age by adding the estimated ages of each tooth and divide by the number of teeth. Add the compensation factor (years)

Demirjian	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Tygerberg	-0.7	-0.6	-0.6	-1	-1.3	-1.5	-2.1	-1.8	-0.7	-0.3
Indian	-0.4	0.0	-0.2	-0.5	-1.3	-1.6	-1.9	-1.5	-1.4	0.3
Black	-1.1	-1.4	-1.6	-2.1	-1.9	-3.0	-2.8	-1.6	-1.5	0.3

Age estimation of lower teeth of left or right quadrant (Central incisor to 2nd molar). Estimated age from weighted tables of Demirjian *et al*. Add the compensation figure (years)

Table 7 shows the age correction factors applicable to the Tygerberg, Indian and Zulu age midpoints from 7 to 16 years of age when using the MFH and DGT methods.

Discussion

The Moorrees, Fanning and Hunt (1963) method under-estimates the dental age of the three sample groups, but by different amounts over the age range of 7 to 16 years (Tables 1, 3 & 5). The Demirjian, Goldstein and Tanner (1973) method over-estimates the ages of the sample groups in similar patterns, but by dissimilar amounts of over-estimation for the same age range (Tables 2, 4 & 6). The data from the calculation of the errors of the age estimations from the interquartile ranges were used to calculate the median error for each of the age estimation methods (Tables 1 to 6). The median error from each of these tables was used to construct a correction factor table for both the MFH and the DGT methods respectively (Table 7). This correction table supplies a correction factor in years for each age midpoint from 7 to 16 years for the Tygerberg, Indian and Zulu samples.

The accuracy of these age correction factors are dependant on knowing the ethnic origin of the individual on whom the age estimation is being exercised using either the MFH or the DGT method.

At either end of the age range for each group, i.e. at age 7 and 16, the dispersion of the errors of age estimation appear smaller than within the central area; this is probably due to the small number of young and older children in the sample groups. If the age of a child is estimated by using either the MFH method or the DGT method, then the correction factor for that age group is added to the estimated age. No distinction is made between males and females as their dental developmental stages related to the real age are very similar.

CHAPTER 7

TESTING OF THE CORRECTION TABLES FOR THE MOORREES *ET AL* & DEMIRJIAN *ET AL* METHODS OF AGE ESTIMATION ON THE TYGERBERG, INDIAN AND ZULU SAMPLES.

Due to the consistent age estimation errors using the methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) on South African children of different population origins, correction factors were derived for both these methods of age estimation. In the calculation of these correction figures it was necessary to derive a correction factor for each age midpoint from 7 to 16 years for the Tygerberg, Indian and Zulu sample groups. These correction figures were specific for each age mid-point of the sample groups (Chapter 8).

The aim was to use the estimated ages of the Tygerberg, Indian and Zulu sample groups using the MFH and DGT methods, then add the correction factors, and compare the results with the chronological ages of the samples.

Materials and methods

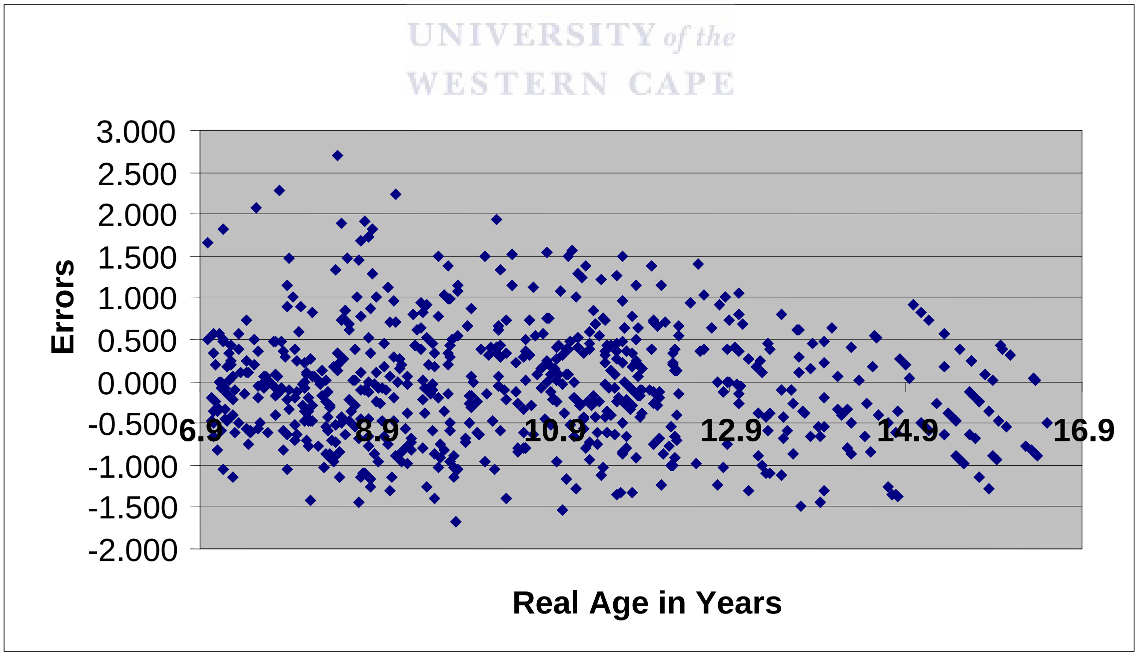
The dental developmental age data from the Tygerberg, Indian and Zulu samples were used to calculate age correction figures for each age group from 7 to 16 years for the age estimation methods of MFH and DGT (Chapter 8, Table 7). The correction figures were positive in the case of the MFH method where there was constant under-estimation of the age. The correction figures were negative in the case of the DGT method as this method over-estimated the ages. The correction figure was added to the estimated age of each individual to produce corrected age estimation. The error of the corrected age was calculated by subtracting the corrected age from the real age (chronological age) and testing it against the real age [Real Age vs Real Age – Corrected Age]. These errors were depicted graphically for each age estimation method on the three sample groups (Graphs 1 to 6).

The percentage of each sample group in which the age was estimated to be within ± 1 year of the real age was calculated for both the MFH and DGT methods. The differences between the uncorrected and corrected age estimations were then tabulated (Tables 1 & 2).

Results

The testing of the Tygerberg sample using the MFH method showed that the ages of 85.86% of the sample, between the ages of 7 to 17 years, were estimated to within 1 year of the chronological age after the application of the correction figures (Graph 1).

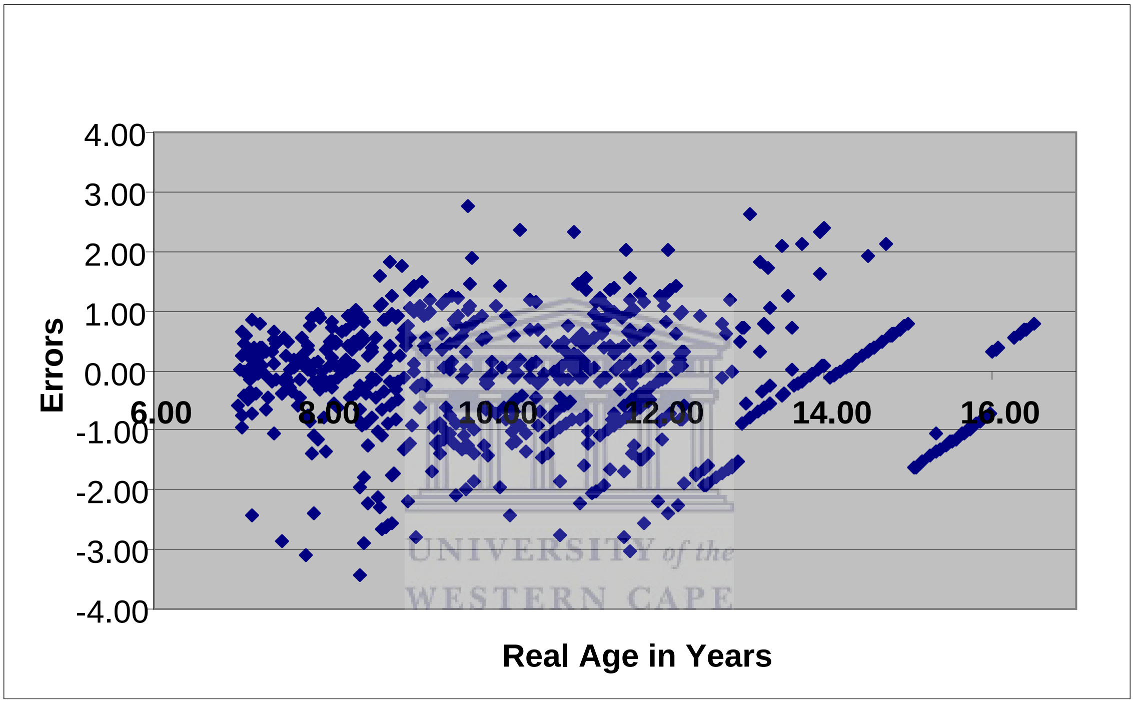
Graph 1: The errors of the corrected age using the MFH method on the Tygerberg sample



Graph 1 shows 85.86% of the Tygerberg sample, between the ages of 7 to 17 years, lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

The testing of the Tygerberg sample using the DGT method showed that 71.88% of the sample, between the ages of 7 to 17 years, was estimated to within 1 year of the chronological age after the application of the correction figures (Graph 2).

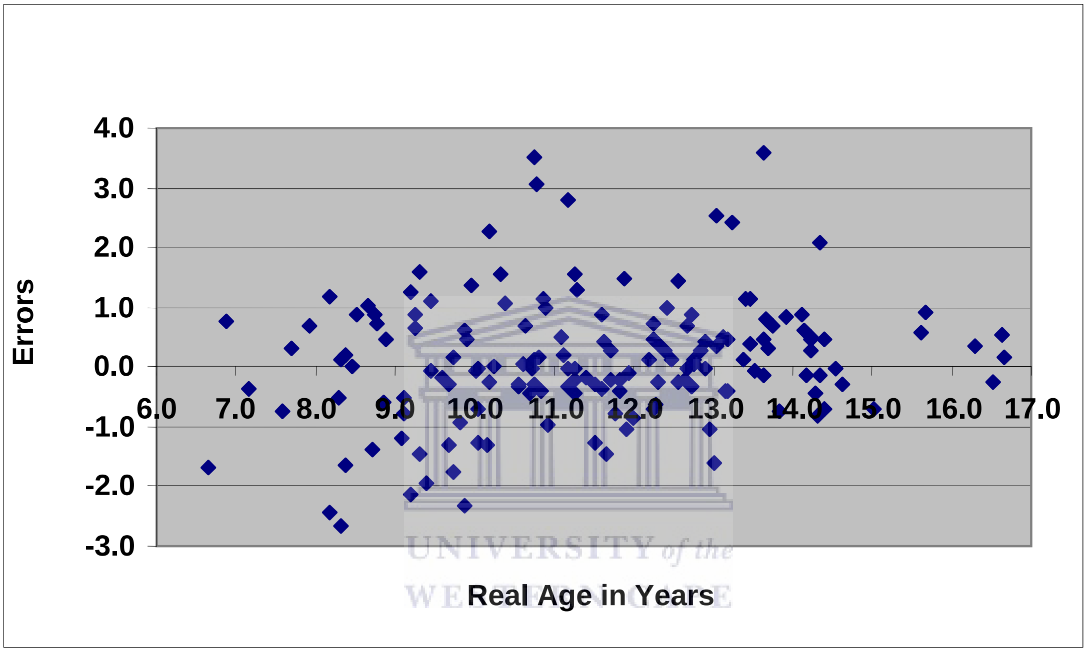
Graph 2: The errors of the corrected age using the DGT method on the Tygerberg sample



Graph 2 shows 71.88% of the Tygerberg sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the DGT method.

The Indian sample, applying the correction figures to the MFH method, showed that 73.88% of the individuals, between the ages of 7 to 17 years, were within 1 year of the chronological age (Graph 3).

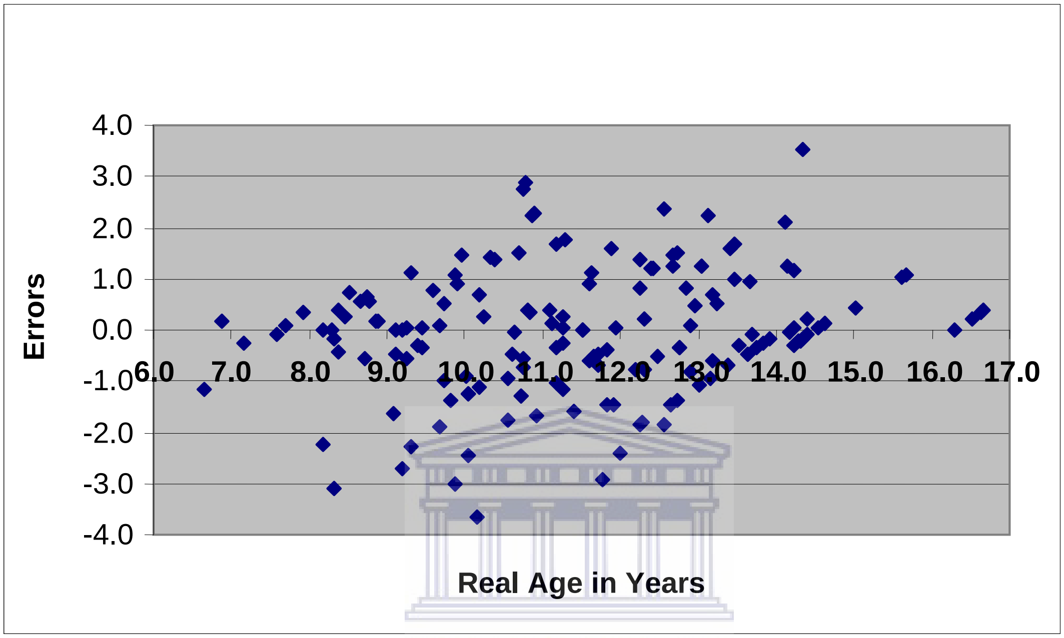
Graph 3: The errors of the corrected age using the MFH method on the Indian sample



Graph 3 shows 73.88% of the Indian sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

After the correction figures for the DGT method were applied to the Indian sample, it showed that 61.14% of the sample was within 1 year of the chronological age (Graph 4).

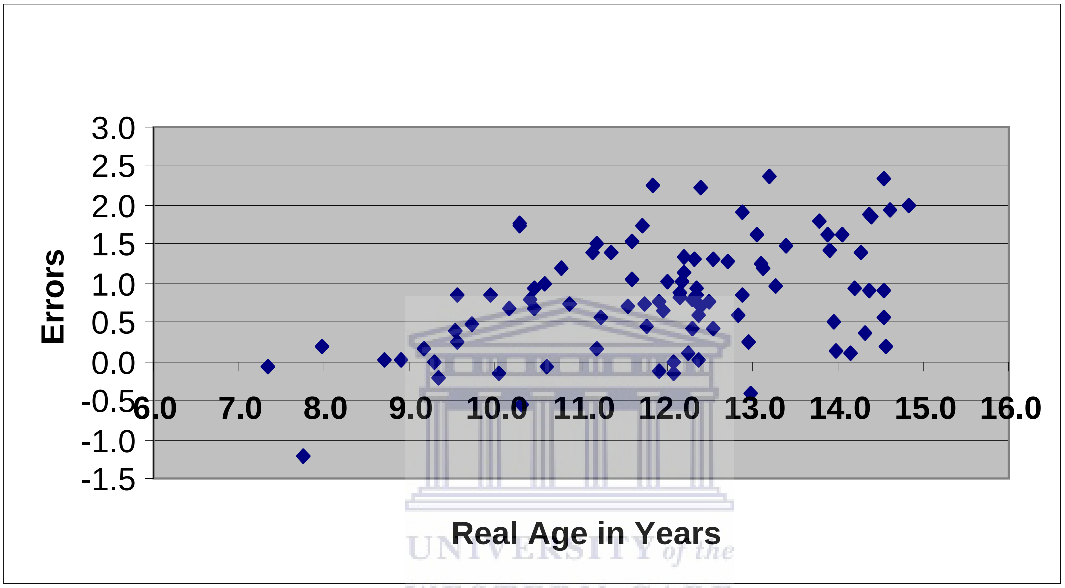
Graph 4: The errors of the corrected age using the DGT method on the Indian sample



Graph 4 shows that 61.14% of the Indian sample between the ages of 7 to 17 years is within ±1 year of the chronological age after the application of the correction factors to the DGT method.

Applying the correction figures to the MFH method on the Zulu sample showed that 61.95% of the individuals, between the ages of 7 to 17 years, were within 1 year of the chronological age (Graph 5).

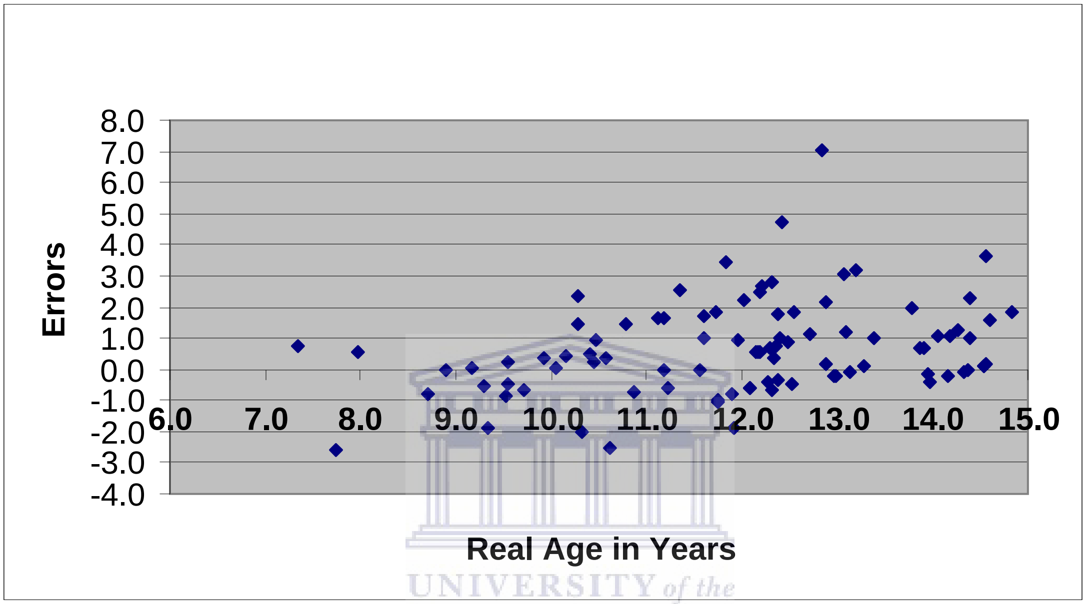
Graph 5: The errors of the corrected age using the MFHl method on the Zulu sample



Graph 5 shows that 61.95% of the Zulu sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

The application of the correction figures to the DGT method on the Zulu sample resulted in 59.78% of the children being within 1 year of their chronological age (Graph 6).

Graph 6: The errors of the corrected age using the DGT method on the Zulu Sample



Graph 6 shows the error between the real age and the corrected age. 59.78% of the Zulu sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the DGT method.

The percentage of the Tygerberg, Indian and Zulu samples where the age is estimated to within 1 year of the chronological age *using the Correction Tables* for the MFH and DGT methods is shown in Table 1. The Tygerberg sample, using the corrected MFH method, resulted in 85.86% of the group lying within 1 year of the real age; using the DGT corrected method, 71.88% were within 1 year of the real age. The Indian sample, using the corrected MFH method, showed 73.88% of the group within 1 year of the real age; the DGT corrected method resulted in 61.14% within 1 year of the real age. The Zulu sample showed 61.95% of the group within 1 year of the real age for the MFH corrected method and 59.78% for the DGT corrected method. (Table 1)

Table 1: The percentage of the Tygerberg, Indian and Zulu samples that were estimated to within 1 year of the chronological age using the Correction Tables for the MFH and DGT methods

	MFH	DGT
Tygerberg	**85.86%**	**71.88%**
Indian	**73.88%**	**61.14%**
Zulu	**61.95%**	**59.78%**

Table 2: The percentage of the Tygerberg, Indian and Zulu samples that were estimated to within 1 year of the chronological age using the un-corrected methods of MFH and DGT.

	Moorrees *et al*	Demirjian *et al*
Tygerberg	**32.7%**	**55.3%**
Indian	**26.4%**	**45.9%**
Zulu	**45.6%**	**20.6%**

Table 2 shows the results of the age estimation of the Tygerberg, Indian and Zulu samples without the correction factors. The percentage of the samples estimated to within 1 year of the real age showed that the MFH method had 32.7% and the DGT method 55.3% for the Tygerberg group. The Indian sample resulted in 26.4% for the MFH method and 45.9% for the DGT method. The Zulu sample resulted in 45.6% for the MFH method and 20.6% for the DGT method.

Conclusion

The correction factor improved the age estimation to within ± 1 year of the real age of the Moorrees, Fanning and Hunt [MFH] (1963) method from 32.7% to 85.9% for the Tygerberg sample. Similarly the improvement between the uncorrected and corrected age estimation on the Indian sample was from 26.4% to 73.88%. The Zulu sample improved the age estimation from 45.6% to 61.95% of the sample.

The age estimation of the Tygerberg sample by the Demirjian, Goldstein and Tanner [DGT] (1973) method improved the age estimation to within ±1 year from 55.3% to 71.88% by using the correction factors. In the Indian sample the improvement was from 45.9% of the group to 61.14% of the individuals being estimated to within ±1 year of their real age. The Zulu sample group improved from 20.6% to 59.78%.

From these results it is seen that the corrected age estimation methods of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) improved the age estimation markedly for each of the South African sample groups.

CHAPTER 8

TESTING THE CORRECTION FACTORS FOR THE MOORREES *ET AL* AND DEMIRJIAN *ET AL* METHODS ON NEW SAMPLES OF TYGERBERG, INDIAN AND ZULU CHILDREN.

The correction figures that were derived for the age estimation methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) were tested on the original samples of Tygerberg, Indian and Zulu children (Chapter 9). The results showed that the correction factor improved the age estimation of these children significantly. The question was whether this corrected method was accurate when applied to new samples of these children.

The aim was to test the accuracy of the correction figures for the MFH and DGT methods on new samples of children from the Tygerberg records, Indian and Zulu children from the Orthodontic practice in Durban.

Materials and Methods

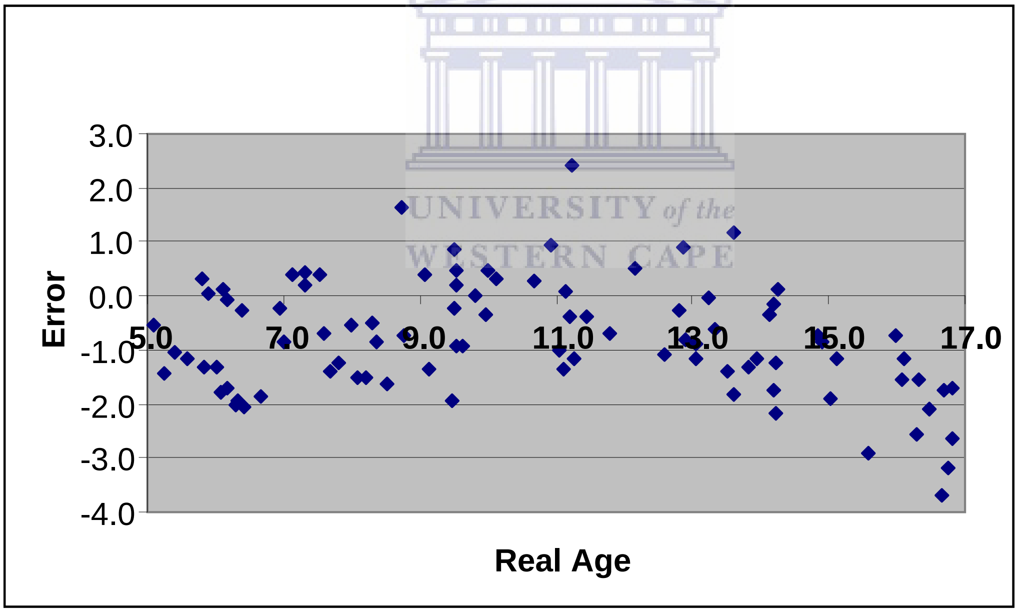
The Pantomographic radiographs from the archived records of children treated at Tygerberg Dental Faculty were accessed and an additional 97 radiographs not used in the original sample were selected for age estimation. An orthodontic practice in Durban was used to acquire Pantomographs of Indian and Zulu children who had undergone recent treatment. The Indian sample consisted of 73 boys and girls; the Zulu sample consisted of 90 individuals. Each of the three samples had an age range of 7 to 16 years.

The age of each individual was estimated using the MFH and DGT methods and the appropriate correction figure was added to the result. The age estimation error was compared to the real age of each individual and represented graphically. The error of the age estimation was recorded to within 1 year of the real age. These results were compared to the results of the previous corrected age estimation by MFH and DGT methods on the original samples of children. These new samples were labelled Tygerberg II, Indian II and Zulu II respectively. There was no separation into sexes.

Results

The age estimation of the Tygerberg II sample using the corrected MFH method resulted in 52.6% of the sample being within ± 1 year of the real age (Graph 1).

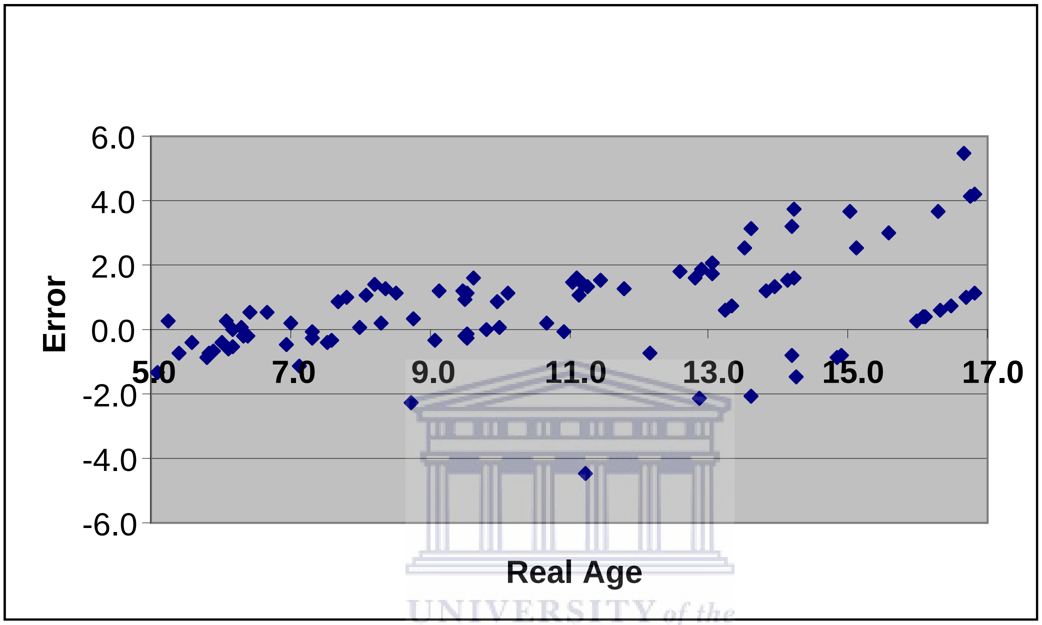
Graph 1: Tygerberg II sample: Age estimation using the corrected MFH method



This graph shows 52.6% of the Tygerberg sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT resulted in 53.68% of the ages of the Tygerberg II sample being estimated to within ± 1 year of the real age (Graph 2).

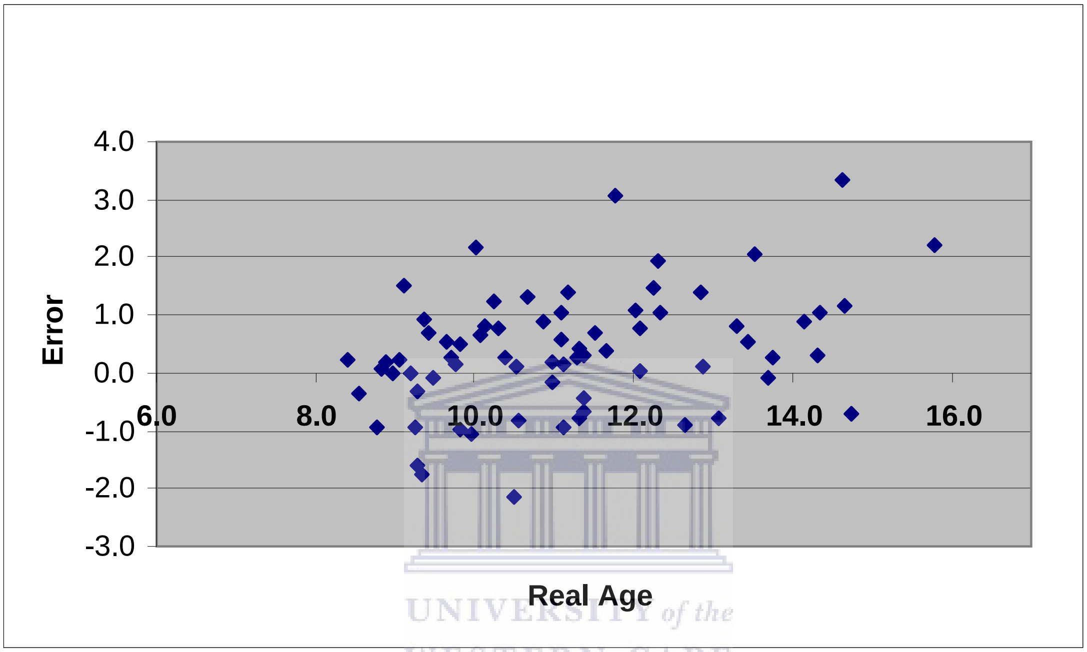
Graph 2 Tygerberg II sample: Age estimation using corrected DGT method



This graph shows 53.68% of the Tygerberg sample was within 1 year of the real age using the corrected DGT method.

The Indian II sample using the corrected MFH method resulted in the ages of 70.8% of the sample being estimated to within ± 1 year of the real age (Graph 3).

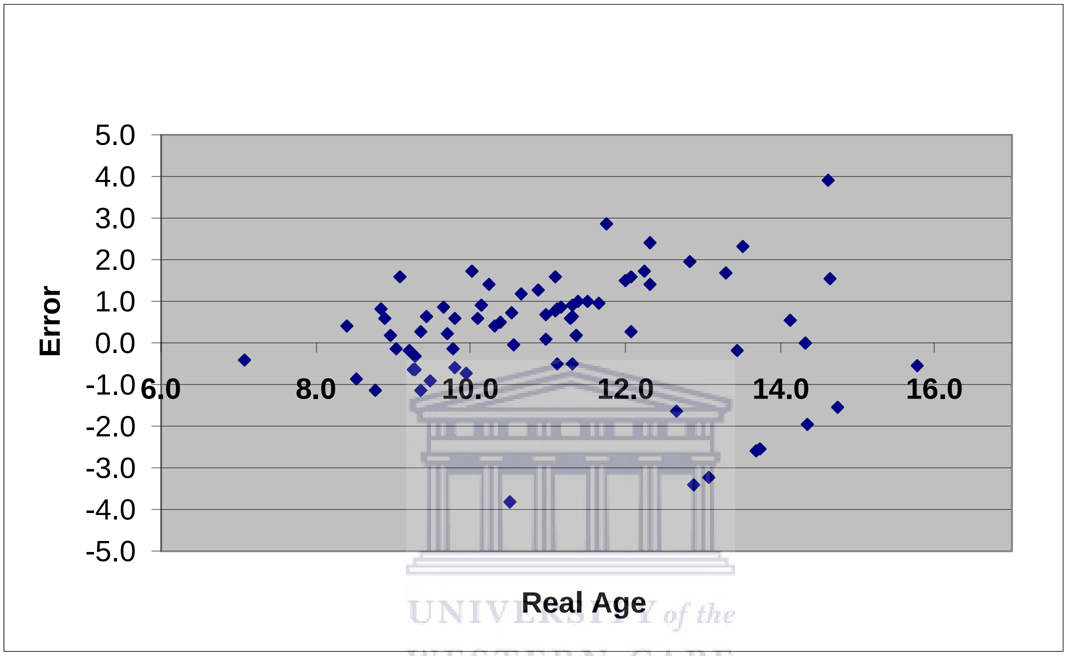
Graph 3 Indian II sample: Age estimation using corrected MFH method



This graph shows 70.8% of the Indian sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT method on the Indian II sample resulted in 61.6% being estimated to within ± 1 year of the real age (Graph 4).

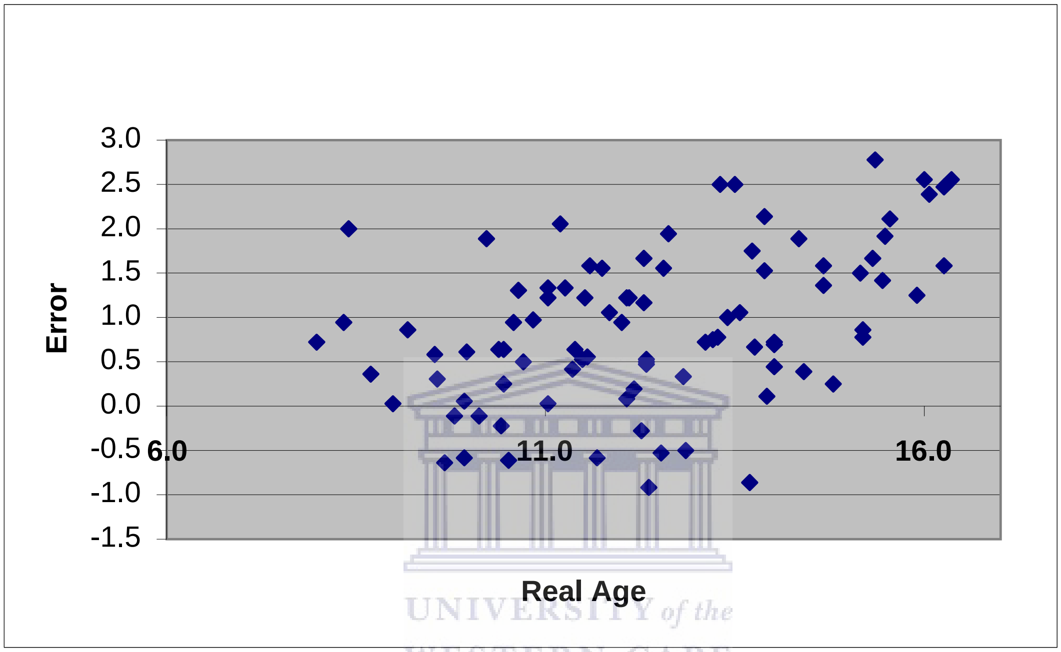
Graph 4 Indian II sample: Age estimation using corrected DGT method



This graph shows 61.6% of the Indian sample was within 1 year of the real age using the corrected DGT method.

The Zulu II sample using the corrected MFH method resulted in 58% being estimated to within ± 1 year of the real age (Graph 5)

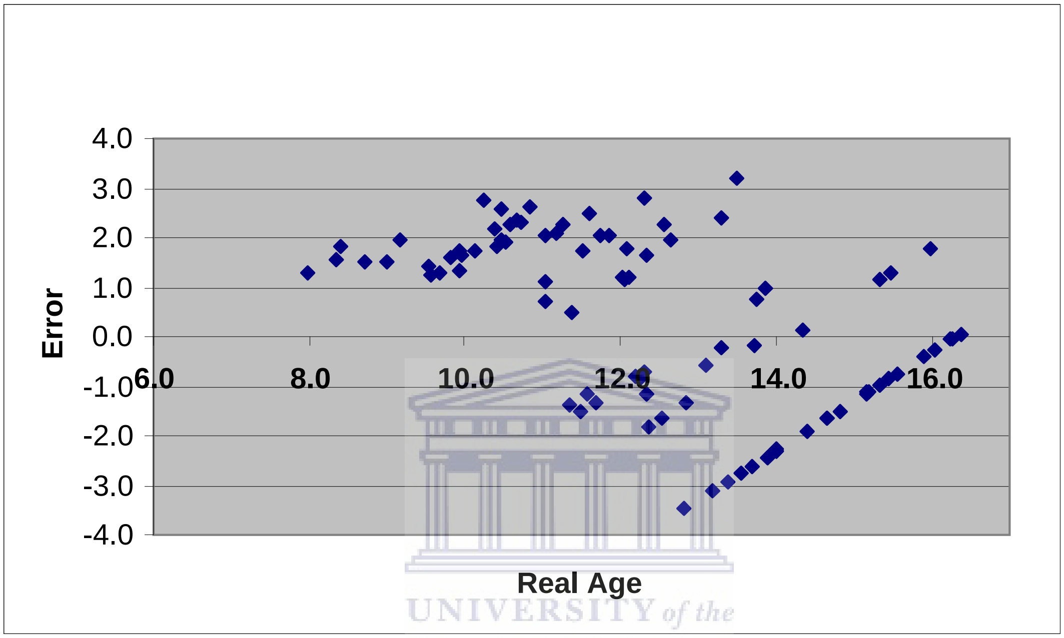
Graph 5: Zulu II sample: Age estimation using corrected MFH method



This graph shows 58% of the Zulu sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT method of the Zulu II sample resulted in 21% being estimated to within ± 1 year of the real age (Graph 6).

Graph 6: Zulu II sample: Age estimation using corrected DGT method



This graph shows 21.0% of the Zulu sample was within 1 year of the real age using the corrected Demirjian *et al* method.

The comparison of the results of the application of the correction factor for age estimation of the 1st and 2nd samples of Tygerberg, Indian and Zulu children by the MFH and DGT methods are shown in Table 1.

Table 1: Comparison between the corrected MFH and DGT methods on samples I and II of Tygerberg, Indian and Zulu children

Samples	Corrected MFH method	Corrected DGT method
Tygerberg I	**85.86%**	**71.88%**
Indian I	**73.88%**	**61.14%**
Zulu I	**61.95%**	**59.78%**
Tygerberg II	**52.6%**	**53.68%**
Indian II	**70.8%**	**61.6%**
Zulu II	**58%**	**21%**

The correction factor for MFH method on the Tygerberg I sample resulted in an age estimation of 85.86% of the sample to within 1 year of the real age. In the Tygerberg II sample the correction factor resulted in 52.6% of the sample being estimated to within 1 year of the real age. The correction of the MFH method in the Indian I and Indian II samples showed a slight change in the age estimation from 73.88% to 70.8% respectively. The Zulu samples, the age estimation using the MFH correction, changed from 61.95% for the 1st sample to 58% for the 2nd sample.

The correction factor for the DGT method on the Tygerberg I sample resulted in age estimation of 71.88% to within 1 year of the real age and 53.68% of the Tygerberg II sample. The Indian samples using the DGT correction showed very little difference between the two samples, changing from 61.14% in sample I to 61.6% in sample II. The Zulu samples, however, showed marked differences between the two samples; the DGT corrected method on the Zulu I sample resulted in 59.78% being estimated to within 1 year of the real age; the Zulu II sample resulted in 21% being within 1 year of the real age.

Discussion

The results show that the correction factor using both the MFH and DGT methods are equally applicable to the Indian children and the age estimation improved markedly. The dramatic decrease from 85.86% for the Tygerberg I to 52.6% of the Tygerberg II children using the corrected MFH method may be due to 2 factors. The Tygerberg II sample was much smaller than the Tygerberg I sample and the error may be due to the sample size discrepancy. Alternately the Tygerberg I sample consisted of mainly 'White' children whereas the Tygerberg II sample, due to the demographic change in patient intake at the Dental School, consisted mainly of 'Coloured' children. This decrease in the percentage of children estimated to within 1 year of their real age was also seen in the Tygerberg samples when using the DGT corrected method; the Tygerberg I sample showed 71.88% and the Tygerberg II sample 53.68%.

The MFH corrected method on the Zulu group remained relatively the same for both samples; 61.95% for the first sample and 58% for the second sample, but the corrected DGT method failed significantly in the second sample with only 21% of the estimated ages being within 1 year of the real age. The explanation for this could be due to the second sample of Zulu children being of a different socio-economic background to the Zulu I group and the correction factor that was derived from the first group was not applicable to the second group. The Zulu I group of children were from records obtained from the archives of the orthodontic practice and were all patients treated prior to 1990. These children were from a socio-economic background where their parents could afford private orthodontic treatment. The Zulu II group were from recent cases still undergoing treatment and from a different socio-economic background and whose parents were working class people covered by medical aid insurance.

Conclusion

The dental age estimation method of Moorrees, Fanning and Hunt (1963) using the correction factor, when applied to White-Coloured, Indian and Black South African children, will improve the accuracy of this method as shown in both the samples of children. The corrected Demirjian, Goldstein and Tanner (1973) method is applicable but less accurate than the MFH method when applied to the same samples of South African children. The correction factor, however, when used with the DGT method on Black children is inaccurate.

CHAPTER 9

CONSTRUCTION OF AGE RELATED TABLES FOR TYGERBERG, INDIAN AND NGUNI CHILDREN OF SOUTH AFRICA

This research has shown that the standard tables of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) for age estimation on the South African children is not as accurate as the results that were obtained by applying these methods on European samples. The correction factors that were derived for each of these methods improved the age estimation ability of these methods, but the accuracy of these methods still remain questionable when applied to South African children.

Materials and methods

To create more meaningful dental age related tables for the South African children of different population groups, it was decided to utilise all the data of the samples that were tested. Therefore the two samples in each group i.e. Tygerberg I and II, Indian I and II and Zulu I and II were combined to obtain larger and more meaningful sample sizes for analysis. A sample of 65 Xhosa children from the Western Cape informal settlement area were obtained from the dental records of recently treated children at the Tygerberg Dental School. These data were added to the Zulu sample and named the Nguni sample. The Tygerberg sample consisted of 1006 children of White and Coloured origin, the Indian sample consisted of 234 children and the Black sample (Nguni), which consisted of both Zulu and Xhosa children, had 236 individuals.

Pivot tables were used to derive the average age at which tooth development had taken place and dental age related tables were constructed for Tygerberg (Table 1), Indian (Table 2) and Nguni (Table 3) children. The samples were not separated into males and females due to the small differences in the developmental ages.

The 'Ac' stage in the dental age related tables was omitted because no age can be assigned in age estimation when complete maturity of a tooth has been reached, because the individual has passed this transition by an unknown amount of time, as recommended by Smith (1991). Age estimation is therefore established by assessing the developing teeth that have not attained apex closure and calculating the mean age using only these teeth.

Results

The dental age related tables, derived from pivot tables, show that there are differences in the developmental stages of the teeth in the left mandible for each of the population sample groups.

Table 1 shows the various ages at which the calcification stages of the incisors, canine, premolars and molars of Tygerberg children are visible on Pantomographic radiographs. The median age at which the various stages of calcification are visible are shown in years with the standard deviation.

Table 1: Dental Age Related Table for Tygerberg Children (SD in years) (n = 1006) [Phillips 1]

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F					4.44 (0.85)			8.85 (1.39)
Ci					4.74 (1.06)		4.13 (0.64)	9.29 (1.16)
Cco					4.97 (0.74)		4.74 (1.47)	10.40 (1.34)
Coc				3.26	4.78 (1.00)		4.75 (0.53)	10.98 (1.05)
Cr1/2			4.14	4.65 (0.65)	5.30 (0.80)		5.42 (0.82)	12.08 (1.12)
Cr3/4		3.96 (0.27)	4.70 (0.75)	5.16 (0.72)	6.21 (0.74)	3.26	6.28 (0.81)	12.62 (1.38)
Crc	4.06 (0.36)	4.74 (0.78)	5.30 (0.94)	6.29 (0.95)	7.39 (0.88)	4.04 (0.24)	7.56 (1.00)	13.38 (1.24)
Ri	4.53 (0.61)	5.27 (0.70)	6.11 (0.81)	7.13 (0.87)	8.23 (0.90)		8.29 (0.76)	14.18 (1.44)
Cli						4.70 (0.92)	8.77 (0.95)	15.09 (1.09)
R1/4	5.37 (0.65)	6.02 (0.60)	7.42 (0.94)	8.26 (0.90)	9.14 (1.17)	5.45 (0.86)	10.04 (1.00)	15.24 (0.96)
R1/2	6.07 (0.54)	6.78 (0.88)	8.52 (1.03)	9.63 (1.06)	10.45 (1.04)	6.25 (0.55)	11.05 (1.01)	
R3/4	6.89 (0.93)	7.35 (0.66)	10.00 (1.17)	10.50 (1.01)	11.09 (1.15)	7.25 (0.77)	11.73 (0.77)	
Rc	7.25 (0.58)	8.08 (0.70)	11.23 (1.10)	11.41 (0.83)	12.06 (1.02)	8.05 (0.76)	12.60 (0.91)	
A1/2	8.02 (0.68)	8.76 (0.78)	12.14 (0.96)	12.14 (0.77)	12.72 (1.16)	9.10 (0.85)	14.04 (1.06)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets. [See Appendix p.161 for number of individuals per age group]

Table 2 shows the various ages at which the calcification stages of the incisors, canine, premolars and molars of the Indian children are visible on Pantomographic radiographs. The median age at which calcification is visible is shown in years with the standard deviation.

Table 2: Dental Age Related Table for Indian Children (SD in years) (n = 234) [Phillips 2]

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								9.71
Ci								9.78 (1.06)
Cco								10.81 (1.33)
Coc								11.32 (1.10)
Cr1/2							6.87	10.86 (0.84)
Cr3/4					6.97 (0.14)		8.75 (1.30)	12.40 (1.26)
Crc				7.07	9.19 (0.92)		8.64 (1.10)	13.36 (1.18)
Ri				8.41 (1.30)	9.33 (1.01)		8.34 (0.86)	
Cli							9.59 (0.84)	14.09 (0.97)
R1/4			9.11 (0.87)	9.20 (0.87)	9.85 (1.00)		10.28 (1.15)	14.95 (0.68)
R1/2	6.76 (0.15)	7.72 (0.92)	9.64 (1.14)	10.36 (0.82)	10.40 (0.92)		11.04 (0.83)	15.30 (1.54)
R3/4	8.39 (0.66)	8.71 (0.88)	10.37 (1.08)	10.96 (1.52)	11.40 (1.22)	8.29 (1.93)	12.05 (1.12)	
Rc	9.58 (1.15)	9.57 (1.10)	11.62 (1.30)	11.53 (1.05)	11.60 (1.81)	8.62 (0.99)	12.66 (1.56)	
A1/2	9.41 (0.96)	9.57 (0.80)	12.47 (1.18)	12.15 (1.28)	13.04 (0.92)	9.65 (1.04)	13.89 (0.91)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets. [See Appendix p.161 for number of individuals per age group]

Table 3 shows the various ages at which the calcification stages of the incisors, canine, premolars and molars of the Nguni children are visible on Pantomographic radiograph. The median age for each stage and the standard deviation are shown.

Table 3: Dental Age Related Table for Nguni Children (SD in years) (n = 236) [Phillips 3]

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								8.50 (0.96)
Cco								9.64 (1.18)
Coc					5.94		5.94	10.91 (1.30)
Cr1/2				6.03 (0.12)	6.45 (0.64)		6.50 (0.67)	11.30 (1.47)
Cr3/4			6.12 (0.01)	6.57 (0.73)	7.32 (1.54)		6.94 (1.04)	11.93 (1.43)
Crc		6.12	6.35 (0.71)	7.72 (1.83)	8.07 (1.64)		7.87 (0.90)	12.54 (1.02)
Ri	6.12 (0.01)	6.03 (0.12)	6,74 (0.40)	7.80 (1.30)	8.46 (0.92)		10.03 (1.65)	12.76 (0.98)
Cli							9.45 (1.31)	13.82 (1.55)
R1/4	6.14 (0.40)	6.52 (0.66)	8.44 (1.25)	8.97 (0.81)	9.93 (0.96)		10.27 (0.89)	14.45 (0.97)
R1/2	6.79 (0.87)	7.01 (0.97)	9.29 (0.58)	9.82 (0.82)	10.48 (1.18)	6.22 (0.34)	11.43 (1.39)	15.64 (0.91)
R3/4	7.24 (1.26)	6.94 (0.44)	10.71 (1.31)	10.50 (1.11)	11.22 (1.21)	7.21 (0.95)	12.24 (0.87)	15.78
Rc	8.91 (1.14)	9.07 (0.86)	11.73 (1.42)	11.65 (1.32)	12.33 (1.29)	8.35 (0.97)	12.99 (1.29)	
A1/2	8.98 (1.01)	10.13 (1.21)	12.49 (1.26)	12.34 (1.07)	13.06 (1.37)	9.60 (1.05)	13.72 (1.01)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets. [See Appendix p.161 for number of individuals per age group]

Table 4 shows the median age at which the stages of crown and root calcification of the mandibular central incisor (I1) occur in the Tygerberg, Indian and Nguni children. The stage A½ is reached at 8.02 years in the Tygerberg children; this is 1.39 years earlier than the Indian and 0.96 years earlier than the Nguni children.

Table 4: Comparison of the developmental stages of the 1st Incisor (I1) in the Tygerberg, Indian & Nguni samples

	Tygerberg	Indian	Nguni
Fi			
F			
Ci			
Cco			
Coc			
Cr1/2			
Cr3/4			
Crc	4.06		
Ri	4.53		6.12
Cli			
R1/4	5.37		6.14
R1/2	6.07	6.76	6.79
R3/4	6.89	8.39	7.24
Rc	7.25	9.58	8.91
A1/2	8.02	9.41	8.98

Table 4: The median age at which the A½ stage of the root calcification of the mandibular central incisor (I1) in the Tygerberg children occurs is at 8.02 years. The median age for Indians is 9.41 years and the Nguni children at 8.98 years

Table 5 shows the median age at which the crown and root stages of calcification of the mandibular lateral incisor (I2) in the Tygerberg, Indian and Nguni children occur. The A½ stage is reached at 8.76 years in the Tygerberg children whereas this stage is reached at 9.41 years in Indians and at 8.98 years in the Nguni sample. This is 0.81 years earlier than the Indian and 1.37 years earlier than the Nguni children.

Table 5: Comparison of the developmental stages of the 2nd Incisor (I2) in the Tygerberg, Indian & Nguni samples

	Tygerberg	Indian	Nguni
Fi			
F			
Ci			
Cco			
Coc			
Cr1/2			
Cr3/4	3.96		
Crc	4.74		6.12
Ri	5.27		6.03
Cli			
R1/4	6.02		6.52
R1/2	6.78	7.72	7.01
R3/4	7.35	8.71	6.94
Rc	8.08	9.57	9.07
A1/2	8.76	9.57	10.13

Table 5: The median age at which the A½ stage of the root calcification of the mandibular lateral incisor (I2) in the Tygerberg children occurs is at 8.76 years, the Indian children at 9.57 years and the Nguni sample at 10.13 years

Table 6 shows the median age at which the crown and root stages of calcification of the mandibular canine (C) occur in the Tygerberg, Indian and Nguni samples. The A½ stage occurs at 12.14 years in the Tygerberg children, at 12.47 years in the Indian children and at 12.49 years in the Nguni sample. This is 0.33 years earlier than the Indian and 0.35 years earlier than the Nguni children.

Table 6: Comparison of the developmental stages of the Canine (C) in the Tygerberg, Indian & Nguni samples

	Tygerberg	Indian	Nguni
Fi			
F			
Ci			
Cco			
Coc			
Cr1/2	4.14		
Cr3/4	4.7		6.12
Crc	5.3		6.35
Ri	6.11		6.74
Cli			
R1/4	7.42	9.11	8.44
R1/2	8.52	9.64	9.29
R3/4	10	10.37	10.71
Rc	11.23	11.62	11.73
A1/2	12.14	12.47	12.49

Table 6: The median age at which the A½ stage of the root calcification of the mandibular canine (C) in the Tygerberg children occurs is at 12.14 years, the Indians at 12.47 years and the Nguni at 12.49 years.

Table 7 shows the median age at which the stages of crown and root calcification of the mandibular 1st premolar (Pm1) occurs in the Tygerberg, Indian and Nguni children. The A½ stage occurs at 12.14 years in the Tygerberg children, at 12.15 years in Indians and at 12.34 years in the Nguni children. There is no significant difference between the three groups.

Table 7: Comparison of the developmental stages of the 1st Premolar (Pm1) in the Tygerberg, Indian & Nguni samples

Fi	Tygerberg	Indian	Nguni
F			
Ci			
Cco			
Coc	3.26		
Cr1/2	4.65		6.03
Cr3/4	5.16		6.57
Crc	6.29	7.07	7.72
Ri	7.13	8.41	7.8
Cli			
R1/4	8.26	9.2	8.97
R1/2	9.63	10.36	9.82
R3/4	10.5	10.96	10.5
Rc	11.41	11.53	11.65
A1/2	12.14	12.15	12.34

Table 7: The median age at which the A½ stage of the root calcification of the mandibular 1st premolar (Pm1) in the Tygerberg children occurs at 12.14 and that of the Indian group at 12.15 years. The Nguni children have a mean age of 12.34 years for this stage.

Table 8 shows the median age at which the crown and root calcification of the mandibular 2nd premolar (Pm2) occurs in the Tygerberg, Indian and Nguni children. The A ½ stage occurs at 12.72 years in the Tygerberg sample, at 13.04 years in Indians and at 13.06 years in Nguni children. This is 0.32 years earlier than the Indian and 0.34 years earlier than the Nguni children.

Table 8: Comparison of the developmental stages of the 2nd Premolar (Pm2) in the Tygerberg, Indian & Nguni samples

	Tygerberg	Indian	Nguni
Fi			
F	4.44		
Ci	4.74		
Cco	4.97		
Coc	4.78		5.94
Cr1/2	5.3		6.45
Cr3/4	6.21	6.97	7.32
Crc	7.39	9.19	8.07
Ri	8.23	9.33	8.46
Cli			
R1/4	9.14	9.85	9.93
R1/2	10.45	10.4	10.48
R3/4	11.09	11.4	11.22
Rc	12.06	11.6	12.33
A1/2	12.72	13.04	13.06

Table 8: The median age at which the A½ stage of the root calcification of the mandibular 2nd premolar (Pm2) in the Tygerberg children occurs at 12.72 years, at 13.04 years in Indians and at 13.06 years in Nguni children.

Table 9 shows the median age at which the crown and root calcification of the mandibular 1st molar (M1) in the Tygerberg, Indian and Nguni children occurs. The A½ stage occurs at 9.1 years in the Tygerberg sample, at 9.65 years in Indians and at 9.6 years in Nguni children. This is 0.55 years earlier than the Indian and 0.56 years earlier than the Nguni children.

Table 9: Comparison of the developmental stages of the 1st Molar (M1) in the Tygerberg, Indian & Nguni samples

	Tygerberg	Indian	Nguni
Fi			
F			
Ci			
Cco			
Coc			
Cr1/2			
Cr3/4	3.26		
Crc	4.04		
Ri			
Cli	4.7		
R1/4	5.45		
R1/2	6.25		6.22
R3/4	7.25	8.29	7.21
Rc	8.05	8.62	8.35
A1/2	9.1	9.65	9.6

Table 9: The median age at which the A½ stage of the root calcification of the mandibular 1st molar (M1) in the Tygerberg children occurs is at 9.1 years, in the Indians at 9.65 years and in the Nguni children at 9.60 years.

Table 10 shows the median age at which the crown and root calcification of the mandibular 2nd molar (M2) in the Tygerberg, Indian and Nguni children occurs. The A½ stage for the Tygerberg sample occurs at 14.04 years, this stage is reached at 13.89 years in the Indian children and at 13.72 years in the Nguni sample. This is 0.15 years later than the Indian and 0.32 years later than the Nguni children.

Table 10: Comparison of the developmental stages of the 2nd Molar (M2) in the Tygerberg, Indian & Nguni samples

	Tyger	Indian	Nguni
Fi			
F			
Ci	4.13		
Cco	4.74		
Coc	4.75		5.94
Cr1/2	5.42	6.87	6.5
Cr3/4	6.28	8.75	6.94
Crc	7.56	8.64	7.87
Ri	8.29	8.34	10.03
Cli	8.77	9.59	9.45
R1/4	10.04	10.28	10.27
R1/2	11.05	11.04	11.43
R3/4	11.73	12.05	12.24
Rc	12.6	12.66	12.99
A1/2	14.04	13.89	13.72

Table 10: The median age at which the A½ stage of the root calcification of the mandibular 2nd molar (M2) in the Tygerberg children occurs is at 14.04 years, in the Indians it occurs at 13.89 years and in the Nguni at 13.72 years.

Table 11 shows the developmental stages of the 3rd molar to the early root calcification stages. The limitation of the age range of the samples did not extend beyond 17 years to include the apex closed stage for each of the sample groups.

Table 11: Comparison of the developmental stages of the 3rd Molar (M3) in the Tygerberg, Indian & Nguni samples

	Tyger	Indian	Nguni
Fi			
F	8.85	9.71	
Ci	9.29	9.78	8.5
Cco	10.4	10.81	9.64
Coc	10.98	11.32	10.91
Cr1/2	12.08	10.86	11.3
Cr3/4	12.62	12.4	11.93
Crc	13.38	13.36	12.54
Ri	14.18		12.76
Cli	15.09	14.09	13.82
R1/4	15.24	14.95	14.45
R1/2		15.3	15.64
R3/4			15.78
Rc			
A1/2			

Table 11: The developmental stages of the 3rd molar to the early root calcification stages. There is no data for the root apex closure due to the limitation of the age range of the samples.

Discussion

The comparison of the developmental stages of each tooth from the Tygerberg, Indian and the Nguni samples showed that the Tygerberg sample, which consisted of White and Coloured children, are slightly ahead of the Indian and Nguni children in the calcification of the apices of the incisors, canine, premolars and 1st molar. The calcification of the root apex in the 2nd and 3rd molars shows a reversal in the developmental ages. The Indian and Black children are slightly ahead of the Tygerberg children.

The differences in the calcification stages of the teeth in the sample groups is marginally different and of significance when dealing with age prediction in living children who are undergoing orthodontic treatment or in clinical evaluation of relating their skeletal maturity to their dental development. If, however, one is estimating the age of skeletal remains of children, it would appear that the slight differences in the ages at the various developmental stages of the teeth are not as critical as originally believed. In the dental age related tables (Tables 1, 2 & 3) the sex difference has been omitted and generic tables for boys and girls were derived. This study has shown that there are slight differences in the ages of the calcification stages of the teeth of boys and girls; this varies by a few months and is not significant enough to influence the age estimation of skeletal remains.

It is often impossible to decide if skeletal remains of a child are either male of female and before secondary sex characteristics develop; it is also not possible to determine the population origin of the skeletal remains of young individuals. It is therefore proposed that the tables for Tygerberg children be used if the population group is known to be of White or Coloured origin. Similarly the Indian and Nguni tables are used if the individual is of Indian or Negroid origin.

It is suggested from this study that if age estimation of South African juvenile skeletal remains is required and if the Moorrees, Fanning and Hunt method or the Demirjian, Goldstein and Tanner methods are applied, then the calculated correction factors be added to the age estimated result. Alternatively the age related tables that this study has calculated can be used for South African children between the ages of 6 and 16 years.

The method of dental age estimation using the age estimation tables for Tygerberg, Indian and Nguni children

The radiographic images of the mandibular teeth are viewed either from a Pantomograph of the jaws or from periapical radiographic images. The teeth that have closed root apices are not used to calculate age estimation as the child has passed the age at which these teeth have calcified. The teeth which show developing stages of crown or root formation are used to estimate the age. The stage of crown and root calcification is determined for each tooth by comparing its image to the equivalent image amongst the standard radiographic images in Chapter 1. When a calcification stage has been established for a tooth then the mean age is obtained from the dental age related table in Chapter 9. Once the age of each undeveloped tooth in the left or right mandible is established the age is calculated by the mean of the sum of the age of each tooth in a mandibular quadrant.

Example: Skull of a Negroid juvenile shows the following dental development;

I1 = Ac; not calculated as the age is surpassed

I2 = Ac; not calculated as the age is surpassed

C = R½; 9.29 years

Pm1 = R¾; 10.5 years

Pm2 = R½; 10.48 years

M1 = Ac; not calculated as the age is surpassed

M2 = Cli; 9.45 years

M3 = Cco 9.64 years

Utilizing the dental age related table for Nguni children (Table 3)

The mean estimated age is calculated by adding the ages of the canine, premolars and molars and calculating the mean of the sum:

$$\frac{9.29+10.5+10.48+9.45+9.64}{5} = 9.87 \text{ years}$$

Conclusion

The dental age related tables that have been derived in this study for White and Coloured children as a group, Indian and Black children of South African origin show that there are differences in the ages at which tooth calcification takes place for the teeth of the left mandibular quadrant. These differences in the ages at which the various stages of tooth development are visualized for each of the sample groups is significant enough to warrant specific dental age related tables for children of different population origins. In the forensic analysis of the skeletal remains of South African children one can choose to use the methods of MFH or DGT with the correction factors or the dental age related tables for the Tygerberg, Indian and Nguni children from this study. These tables are easy to use and will be beneficial in the age estimation of individuals. If the population origin of the individual is known this would result in accurate age estimation.

Appendix

Xhosa Children (Tygerberg)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								8.64 (1.06)
Cco								9.72 (0.94)
Coc							5.94	10.84 (1.62)
Cr1/2				6.03 (0.12)	6.45 (0.64)		6.50 (0.67)	11.23 (0.13)
Cr3/4			6.12 (0.01)	6.57 (0.73)	7.11 (1.70)		6.28 (0.16)	12.12 (1.61)
Crc			6.35 (0.71)	7.72 (2.23)	8.20 (2.26)		7.73 (1.11)	12.41 (1.02)
Ri	6.12 (0.01)	6.03 (0.12)	6.54 (0.06)	7.68 (1.42)	8.48 (0.99)			
Cli						5.89	9.18 (1.16)	14.77 (1.76)
R1/4	6.14 (0.40)	6.52 (0.66)	8.54 (1.51)	9.10 (0.83)	9.34 (0.62)	6.22 (0.34)	10.14 (0.78)	15.37 (1.00)
R1/2	6.79 (0.87)	6.45 (0.15)	9.36 (0.62)	9.74 (0.75)	10.84 (1.14)	6.14 (0.04)	12.08 (1.84)	16.18 (0.59)
R3/4		6.74 (0.39)	11.30 (1.18)	11.03 (1.23)	11.32 (0.01)	7.21 (0.95)	12.32 (0.49)	15.87
Rc	6.68 (0.29)	9.25 (1.23)	12.71 (1.93)	12.38 (1.88)	12.73 (1.13)	8.43 (1.23)	13.30 (1.47)	
A1/2	9.19 (1.09)	9.53 (0.89)	12.85 (1.68)	12.81 (0.72)	13.83 (1.87)	9.79 (0.80)	13.93 (1.90)	
Ac								

This dental age related table is of a sample of Xhosa speaking children from the informal settlement in Cape Town. These children come from a poor socio-economic background. The appendix is added as these data were combined with the Zulu samples to make up an Nguni sample.

CHAPTER 10

TESTING THE PHILLIPS AGE ESTIMATION TABLES ON SAMPLES OF TYGERBERG, INDIAN AND XHOSA CHILDREN

The previous chapter showed the derivation of dental age related tables for a Tygerberg sample of children of White and Coloured origin. Tables were also derived for Indian and African (Nguni) children. These tables will be described as Phillips Tables for this chapter. Phillips Table 1 is the table for age estimation of White and Coloured children (Tygerberg); Phillips Table 2 is the table derived for Indian children and Phillips Table 3 is for African (Nguni) children.

The aim of this study was to compare the estimated ages of the three sample groups using the MFH and DGT methods with the dental age related tables of Phillips and to analyse the results statistically.

Materials and methods

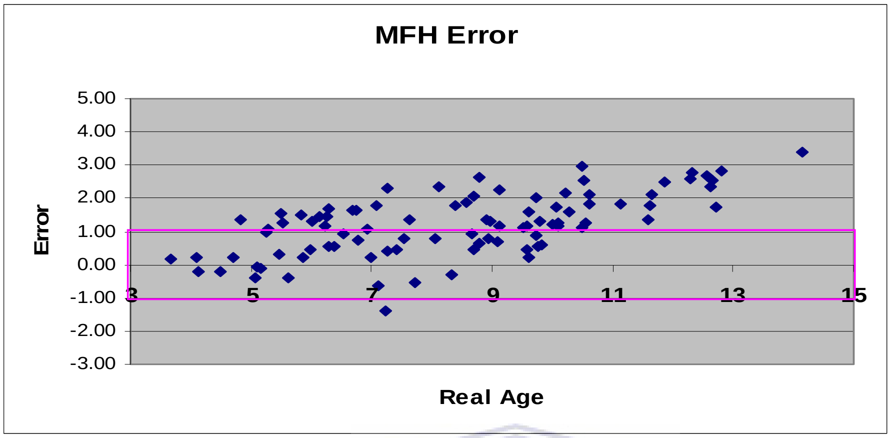
The new Tygerberg sample used for this part of the study was an additional set of individuals obtained from the files of children currently undergoing dental treatment at the Dental Faculty of the University of the Western Cape. The Tygerberg sample consisted of 91 children, 70 White, 21 Coloured. The Indian and Xhosa samples were a random selection of children from the original data bases used in this study. There were 112 Indian and 62 Xhosa children respectively. The Tygerberg, Indian and Xhosa samples were analysed in the following manner: the age of each child was estimated using the MFH, the DGT methods. Then the ages of the samples were estimated using the Phillips Tables applicable for each sample. (Phillips Table 1 was used for the Tygerberg sample, Phillips Table 2 was used for the Indian sample and Phillips Table 3 was used for the Xhosa sample). The age estimation error for each method was calculated and depicted graphically. The real ages and the errors of the estimated ages of each method were subjected to regression analysis. All r-correlation coefficients were tested for significance and in every case the p-value was significant at the $p < 0.05$ level.

Results

THE NEW TYGERBERG SAMPLE

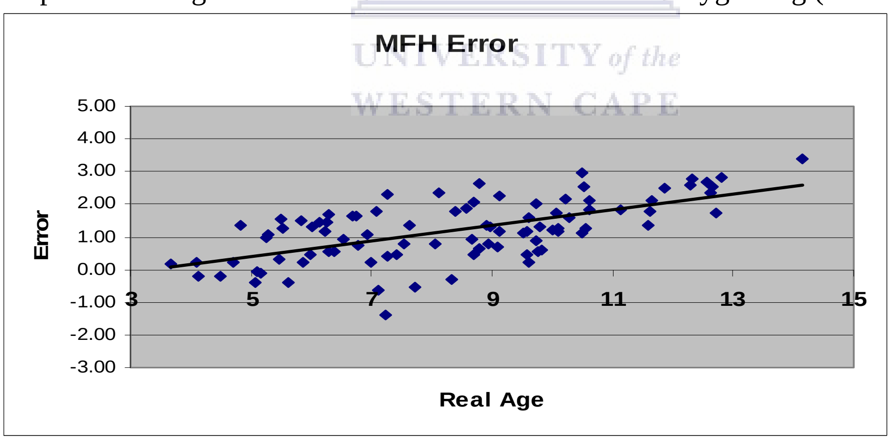
The MFH method of age estimation of the new Tygerberg sample resulted in 38.4% of the sample being estimated to within 1 year of the real age (Graph 1). Regression analysis of the MFH method showed an R-value of 0.63 with a p-value of 1.6376×10^{-11}(Table 1).

Graph 1a: The age estimation error of the MFH method. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00. *The alignment* of the sample (Graph 1a) shows that 38.4 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample. [If the error is positive then the estimated age is less than the real age]

Graph 1b: The age estimation error of the MFH method. Tygerberg (n = 91)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 1b). The R-value (R = 0.633) indicates that the MFH method is strongly predictive. The regression correlation is significant ($p<0.05$)

Table 1: Regression analysis of MFH method on the Tygerberg sample

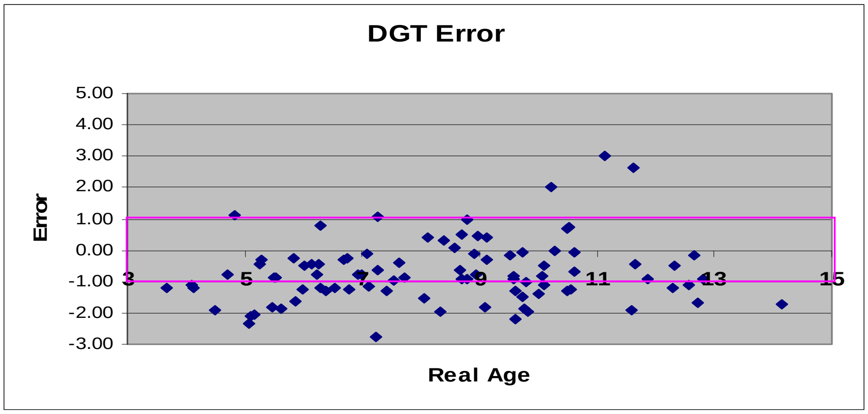
Regression Statistics	
R	0.633
R Square	0.401
Observations	91

ANOVA

	df	Significance F
Regression	1	1.6376E-11
Residual	89	
Total	90	

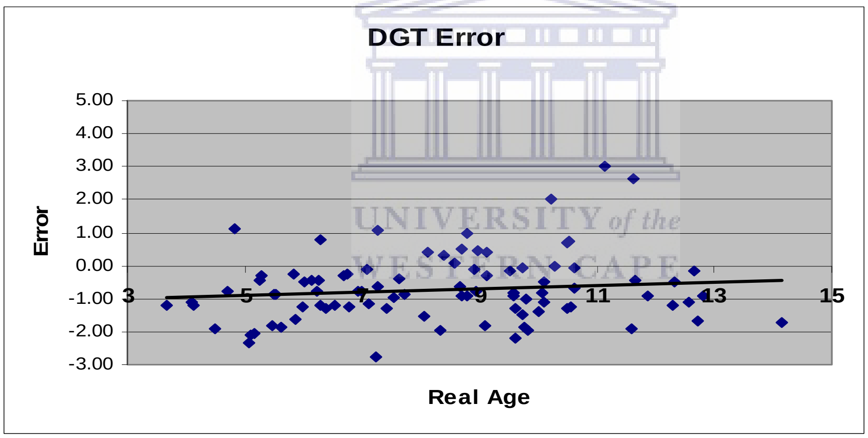
The DGT method of age estimation of the Tygerberg sample resulted in 53.8% of the sample being estimated to within 1 year of the real age (Graph 2). Regression analysis of the DGT method showed an R-value of 0.91 with a p-value of 2.40489 x 10^{-36} (Table 2).

Graph 2a: The age estimation error of the DGT method. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00.*The alignment* of the sample (Graph 2a) shows that 53.8 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 2b: The age estimation error of the DGT method. Tygerberg (n = 91)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 2b). The R-value (R = 0.913) indicates that the DGT method is strongly predictive. The regression correlation is significant (p<0.05)

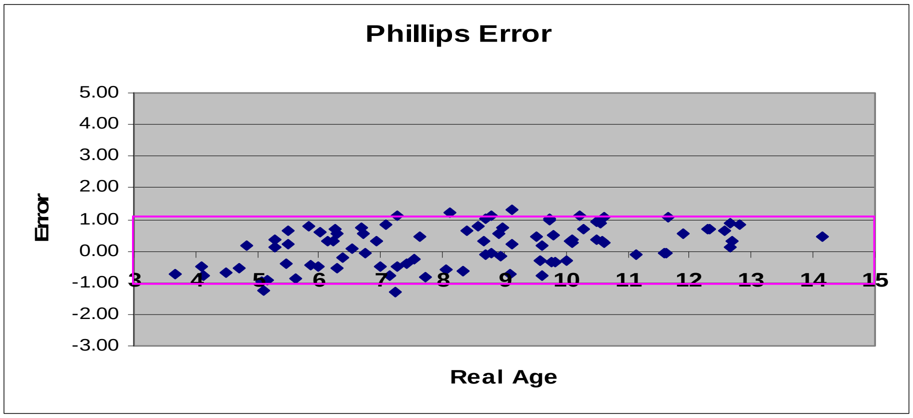
Table 2: Regression analysis of the DGT method on the Tygerberg sample

Regression Statistics		
R	0.913	
R Square	0.833	
Observations	91	
ANOVA		
	df	Significance F
Regression	1	2.40489E-36
Residual	89	
Total	90	

The R correlation is significant (p<0.05) and strongly predictive. This method is more accurate than the MFH method, but over-estimates the ages of 46.8% of the Tygerberg sample.

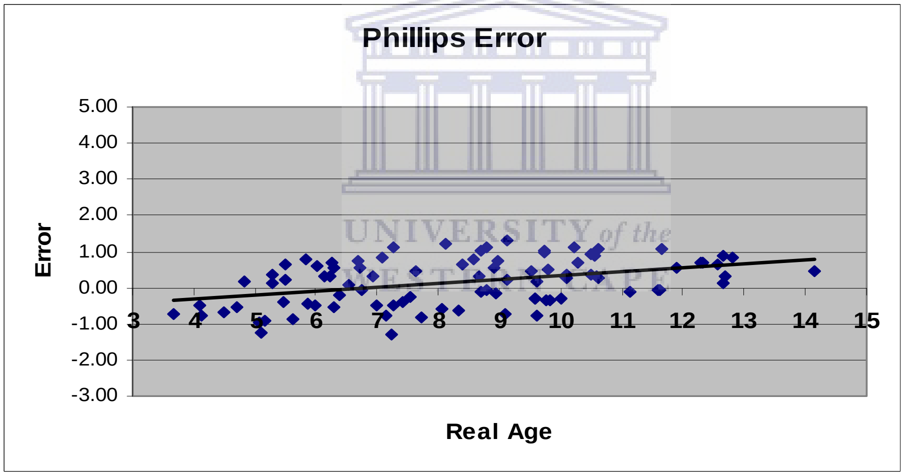
The Phillips Table 1 used for age estimation of the Tygerberg sample resulted in 88.4% of the sample being estimated to within 1 year of the real age (Graph 3). Regression analysis of the Phillips Table 1 showed an R-value of 0.966 with a p-value of 3.18422×10^{-54} (Table 3)

Graph 3a: The age estimation error of the Phillips Table 1. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00. *The alignment* of the sample shows that 88.4 % of the sample is within 1 year of Real Age.

Graph 3b: The age estimation error of the Phillips Table 1. Tygerberg (n = 91)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 3b). The R-value (R = 0.966) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 3: Regression analysis of the Phillips Table 1 on the Tygerberg sample

Regression Statistics	
R	0.966
R Square	0.934
Observations	91

ANOVA

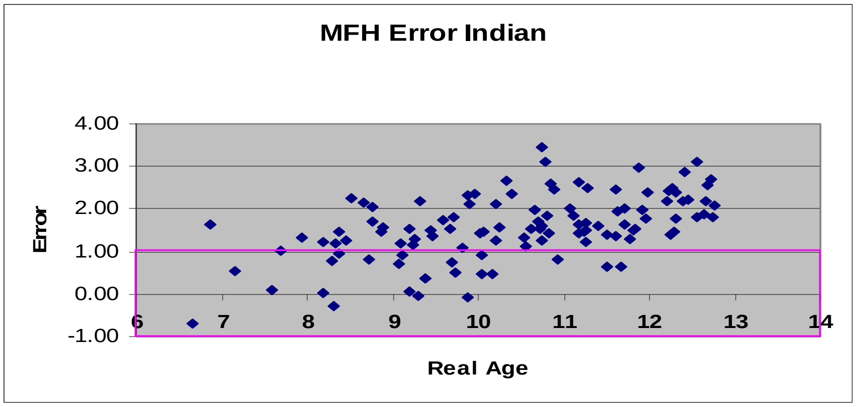
	df	Significance F
Regression	1	3.18422E-54
Residual	89	
Total	90	

The Phillips method is more accurate than the MFH and the DGT methods for ageing Tygerberg children.

THE INDIAN SAMPLE

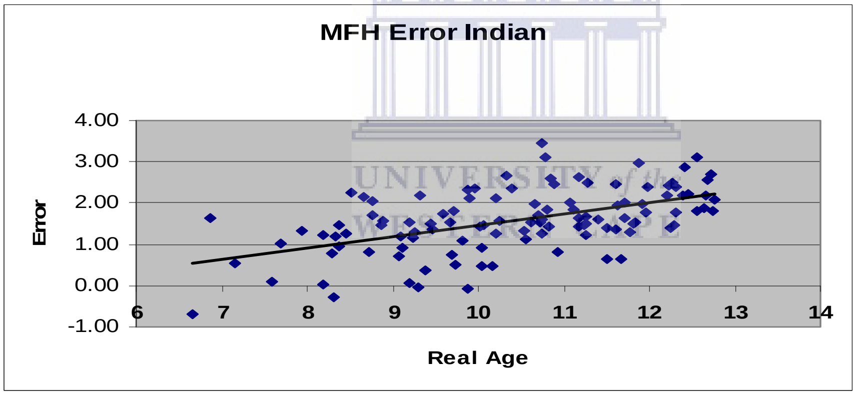
The MFH method of age estimation of the Indian sample resulted in 19.6% of the sample being estimated to within 1 year of the real age (Graph 6). Regression analysis of the MFH method showed an R-value of 0.54 with a p-value of 7.70422×10^{-10} (Table 4).

Graph 4a: The age estimation error of the MFH method. Indian (n = 112)



The scale of the error is from -1.00 to 4.00. *The alignment* of the sample (Graph 6a) shows that 19.6 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 4b: The age estimation error of the MFH method. Indian (n = 112)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 4b). The R-value (R = 0.540) indicates that the MFH method is predictive. The regression correlation is significant ($p<0.05$)

Table 4: Regression analysis of the MFH method on the Indian sample

Regression Statistics	
R	0.540
R Square	0.292
Observations	112

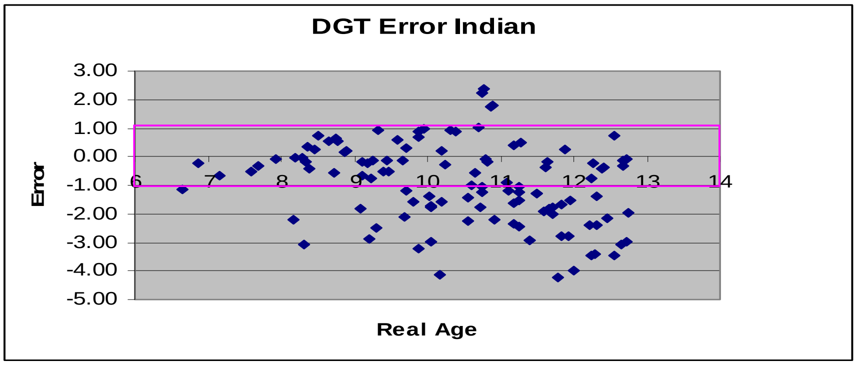
ANOVA

	df	Significance F
Regression	1	7.70422E-10
Residual	110	
Total	111	

The R correlation is significant ($p<0.05$) and predictive, but the MFH method under-estimates the ages of 80.4% of the Indian sample.

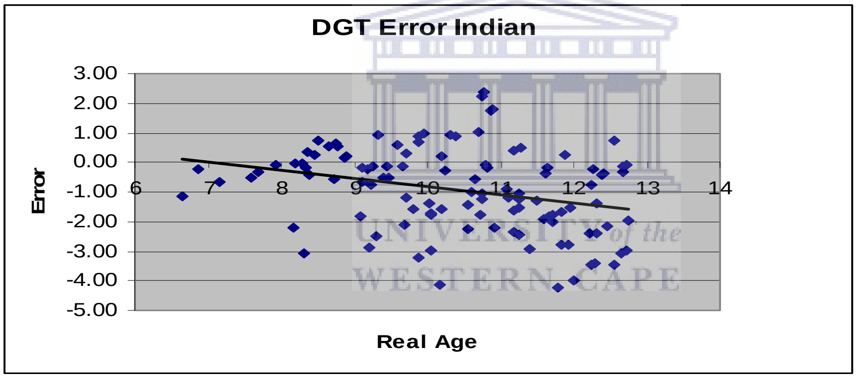
The DGT method of age estimation of the Indian sample resulted in 46.4% of the sample being estimated to within 1 year of the real age (Graph 7). Regression analysis of the DGT method showed an R-value of 0.306 with a p-value of 0.001022 (Table 5).

Graph 5a: The age estimation error of the DGT method. Indian (n = 112)



The scale of the error is from -5.00 to 3.00.*The alignment* of the sample (Graph 7a) shows that 46.4 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 5b: The age estimation error of the DGT method. Indian (n = 112)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 5b). The R-value (R = 0.306) indicates that the DGT method is predictive, but there is a significant amount of scatter around the trend line.
The regression correlation is significant ($p<0.05$)

Table 5: Regression analysis of the DGT method on the Indian sample

Regression Statistics	
R	0.306
R Square	0.094
Observations	112

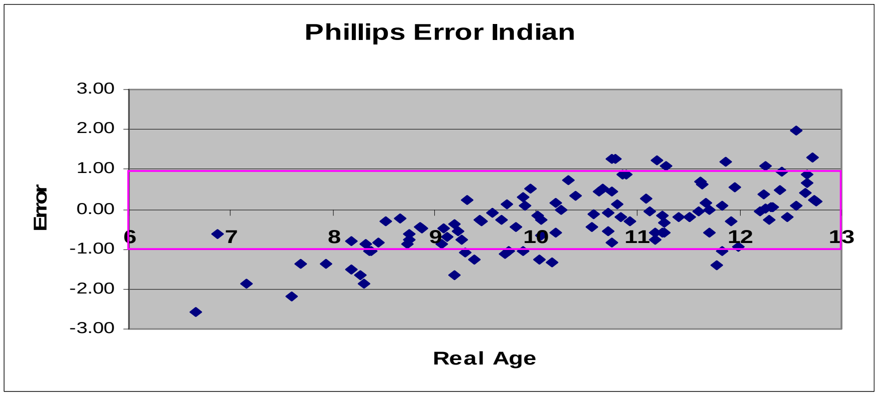
ANOVA

	df	Significance F
Regression	1	0.001022684
Residual	110	
Total	111	

The regression correlation is significant ($p<0.05$) for the DGT method. The method overestimated the ages of 53.6% of the Indian sample.

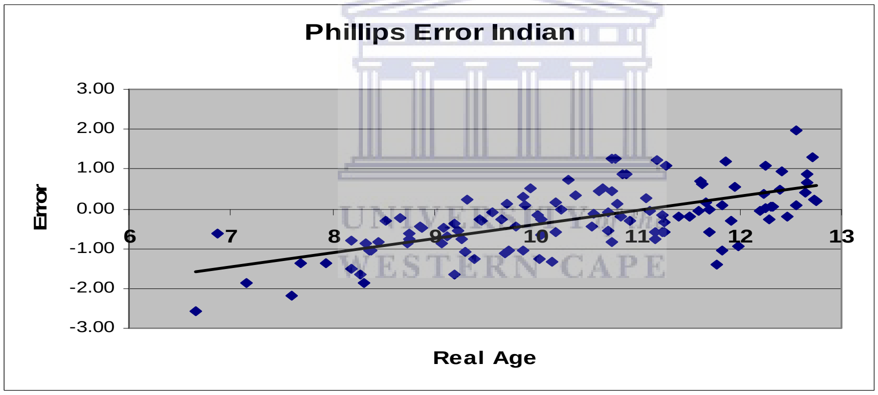
The Phillips Table 2 used for age estimation of the Indian sample resulted in 75% of the sample being estimated to within 1 year of the real age (Graph 8). Regression analysis of the Phillips Table 2 showed an R-value of 0.65 with a p-value of 8.22195 x 10^{-15} (Table 6).

Graph 6a: The age estimation error of the Phillips Table 2. Indian (n = 112)



The scale of the error is from -3.00 to 3.00. *The alignment* of the sample shows that 75 % of the sample is within 1 year of Real Age.

Graph 6b: The age estimation error of the Phillips Table 2. Indian (n = 112)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 6b). The R-value (R = 0.651) indicates that the Phillips method is strongly predictive. The R correlation is significant (p<0.05)

Table 6: Regression analysis of Phillips Table 2 on the Indian sample

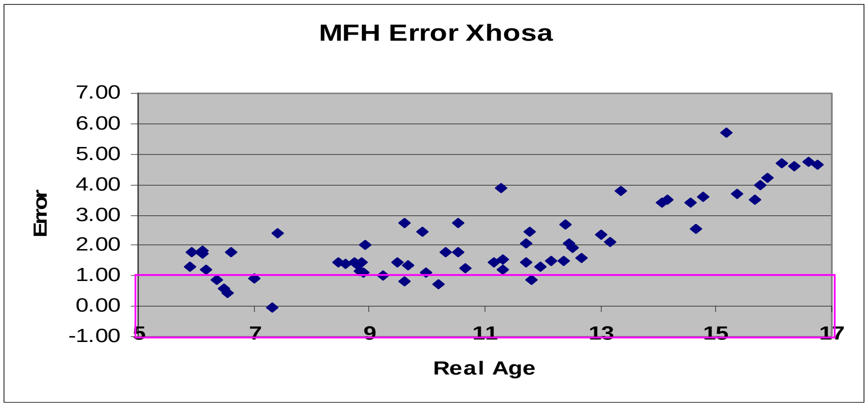
Regression Statistics		
R	0.651	
R Square	0.423	
Observations	112	
ANOVA		
	df	*Significance F*
Regression	1	8.22195E-15
Residual	110	
Total	111	

The Phillips method is more accurate than the MFH and the DGT methods for ageing Indian children.

THE XHOSA SAMPLE

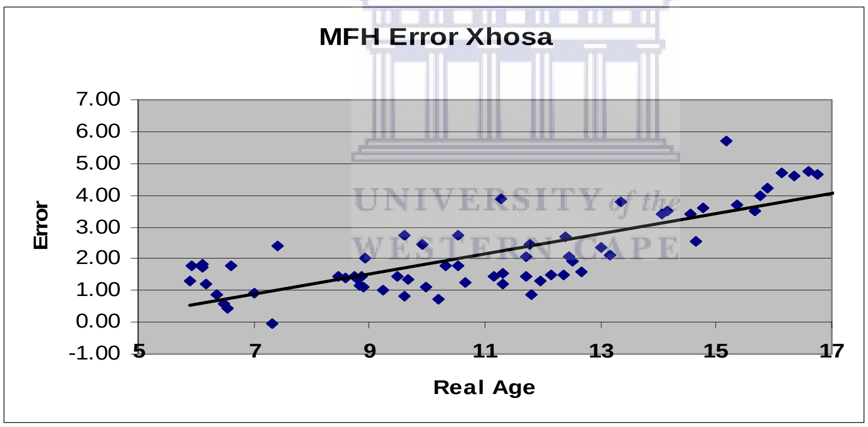
The MFH method of age estimation of the Xhosa sample resulted in 13.8% of the sample being estimated to within 1 year of the real age (Graph 11). Regression analysis of the MFH method showed an R-value of 0.784 with a p-value of 1.06964 x 10^{-14} (Table 7).

Graph 7a: The age estimation error of the MFH method. Xhosa (n = 65)



The scale of the error is from -1.00 to 7.00. *The alignment* of the sample (Graph 11a) shows that 13.8 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 7b: The age estimation error of the MFH method. Xhosa (n = 65)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 7b). The R-value (R = 0.784) indicates that the MFH method is strongly predictive. The regression correlation is significant (p<0.05)

Table 7: Regression analysis of the MFH method on the Xhosa sample

Regression Statistics	
R	0.784
R Square	0.615
Observations	65

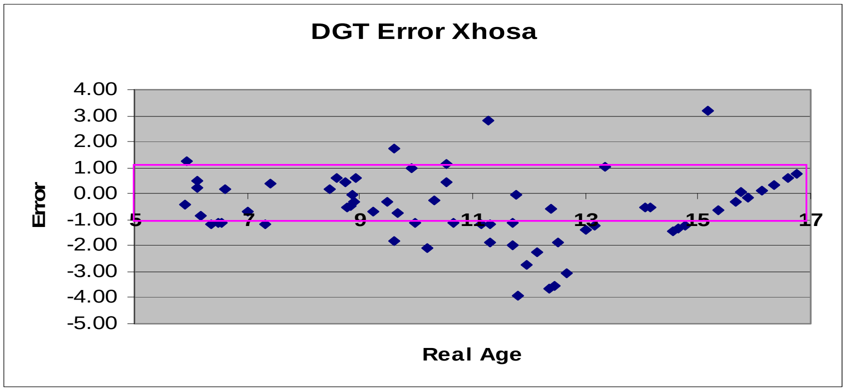
ANOVA

	df	Significance F
Regression	1	1.06964E-14
Residual	63	
Total	64	

The R correlation is significant (p<0.05) and predictive, but the MFH method under-estimates the ages of 86.2% of the Xhosa sample.

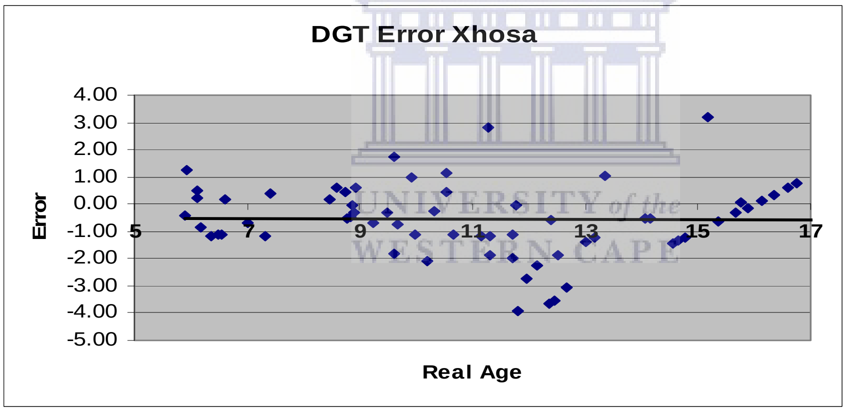
The DGT method of age estimation of the Xhosa sample resulted in 49.2% of the sample being estimated to within 1 year of the real age (Graph 12). Regression analysis of the DGT method showed an R-value of 0.013 with a p-value of 0.912053379 (Table 8).

Graph 8a: The age estimation error of the DGT method. Xhosa (n = 62)



The scale of the error is from -5.00 to 4.00.*The alignment* of the sample (Graph 12a) shows that 49.2 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 8b: The age estimation error of the DGT method. Xhosa (n = 62)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 8b). The R-value (R = 0.014) indicates that the DGT method is not predictive because there is a significant amount of scatter around the trend line even though this line is parallel to the X-axis. The regression correlation is not significant (p=0.912)

Table 8: Regression analysis of the DGT method on the Xhosa sample

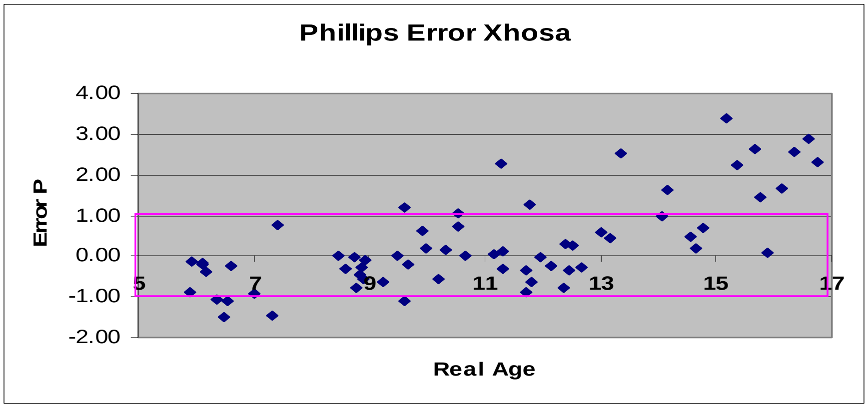
Regression Statistics	
R	0.014
R Square	0.0001
Observations	65

ANOVA		
	df	Significance F
Regression	1	0.912053379
Residual	63	
Total	64	

The DGT method is not applicable for age estimation of the Xhosa sample.

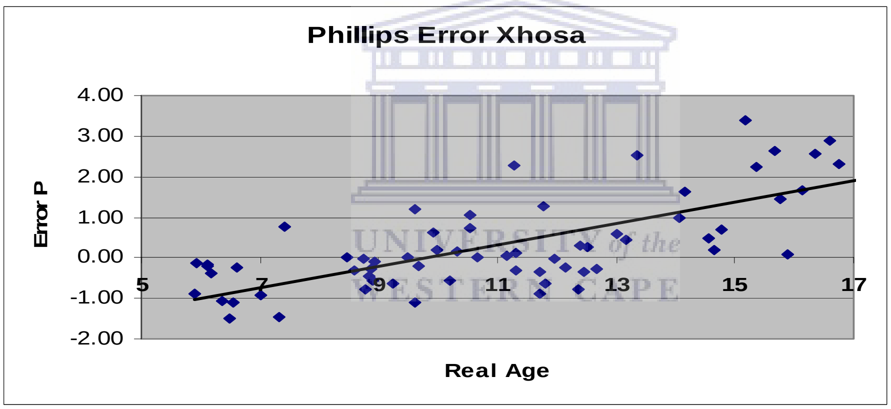
The Phillips Table used for age estimation of the Xhosa sample resulted in 69.2% of the sample being estimated to within 1 year of the real age (Graph 13). Regression analysis of the Phillips Table 3 showed an R-value of 0.71 with a p-value of 2.10552×10^{-11} (Table 9)

Graph 9a: The age estimation error of the Phillips Table 3. Xhosa (n = 62)



The scale of the error is from -2.00 to 4.00. *The alignment* of the sample shows that 69.2% of the sample is within 1 year of Real Age.

Graph 9b: The age estimation error of the Phillips Table 3. Xhosa (n = 62)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 9b). The R-value (R = 0.716) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 9: The Regression analysis of Phillips Table 3 on Xhosa sample

Regression Statistics	
R	0.716
R Square	0.512
Observations	65

ANOVA

	Significance F
Regression	2.10552E-11
Residual	
Total	

The Phillips method is more accurate for the age estimation of Xhosa children than the MFH and DGT methods.

The age estimation errors for the Tygerberg sample using the MFH, DGT and the Phillips Table 1 resulted in 38.4%, 53.8% and 88.4% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Tygerberg sample showed that the r-value of 0.966 (Table 11) and the p-value of $3.18x10^{-54}$ indicate that the Phillips Table 1 for White and Coloured children is more accurate than the methods of MFH and DGT.

The age estimation errors for the Indian sample using the MFH, DGT and the Phillips Table 2 resulted in 19.6%, 46.4% and 75% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Indian sample showed that the r-value of 0.651 (Table 11) and the p-value of $8.22x10^{-15}$ indicate that the Phillips Table 2 for Indian children is more accurate than the methods of MFH and DGT. The age estimation errors for the Xhosa sample using the MFH, DGT and the Phillips Table methods resulted in 13.8%, 49.2% and 69.2% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Xhosa sample showed that the r-value of 0.716 (Table 11) and the p-value of $2.106x10^{-11}$ indicate that the Phillips Table 3 for Xhosa children is more accurate than to the methods of MFH and DGT.

Table 10: The percentages of the Tygerberg, Indian & Xhosa samples estimated to within 1 year of the chronological age using the methods of MFH, DGT and Phillips

	Tygerberg	Indian	Xhosa
MFH	38.4	19.6	13.8
DGT	53.8	46.4	49.2
Phillips	88.4	75.0	69.2

Table 11: The regression correlation of the ageing errors for the MFH, DGT & Phillips methods on the Tygerberg, Indian and Xhosa samples

	Tygerberg	Indian	Xhosa
MFH	R = 0.633	R = 0.540	R = 0.784
DGT	R = 0.913	R = 0.306	R = 0.014
Phillips	R = 0.966	R = 0.651	R = 0.716

Discussion and Conclusion

The MFH method consistently under-estimated the age of the South African children. The performance of the MFH method for the White and Coloured children was poor as it only estimated the ages of 38% of the sample to within 1 year of the chronological age. The MFH method performed very poorly for the Indian and Xhosa children. The DGT method over-estimated the ages of the samples. The performance of the DGT method was relatively constant for all three samples, estimating the ages to within 1 year in approximately 50% in all cases. The Phillips Tables for White and Coloured, Indian and African (Nguni) children was found to be more accurate than the MFH and DGT methods when estimating the ages of South African children.

CHAPTER 11

DISCUSSION AND CONCLUSIONS

This study has encountered various problems in the estimation of age using radiographic images and the application of dental age related tables to children of different population groups by using the standard age estimation methods. This discussion will highlight these problems and suggest further investigation.

Radiographic images:

Pictorial images of the various stages of tooth development were taken to illustrate the calcification of crowns and roots of the teeth as they age. The examination of the Pantomographic images of the developing teeth highlighted some areas of difficulty in interpreting the developmental stages. Firstly it is difficult in numerous cases to visualise the root apical calcification stages of the incisors due to the superimposition of the cervical spine on the radiograph. The difference in the formation of the root apex between ‘A½’ and ‘Ac’ is not always clear in the radiographic images of all the teeth and makes this stage of calcification difficult to evaluate. The ‘A½’ stage is easier to visualise and is more reliable for age evaluation. The alternative radiographic image for apical calcification evaluation is the periapical radiograph that provides a much clearer image and would possibly facilitate the visualizing of the Ac stage.

The calcification stages of the crown are fairly easy to distinguish except for the stages of ‘crown complete’ (Crc) and ‘root initiation’ (Ri). These stages are especially difficult to determine in the molars. It is suggested that the stage of ‘root initiation’ (Ri) in molars be abandoned and that the stage of ‘cleft initiation’ (Cli) be used. This stage is much easier to visualise and depicts a definitive stage between crown and root formation.

The stages of calcification of the roots of the canine and the premolars need intermediate stages from the 'root ¼' to 'root ½' stage and between 'root ½' and 'root ¾'stages. There are images of root lengths that appear to be between these stages and suggest 'root ⅓' and 'root ⅔' stages; this was suggested by Smith (1991). These intermediate stages warrant investigation and appropriate ages determined for each tooth in the left mandibular quadrant.

Although some of the roots of the maxillary teeth are difficult to visualize on Pantomographic radiographs, the corresponding developmental stages of the maxillary teeth need to be investigated and ages derived for these stages in comparison to their mandibular counterparts.

The population groups

This study investigated the prediction of age of children and juveniles from four population groups. The Tygerberg sample which consisted of White and Coloured children was used as a group because it was not possible in most cases to derive the ethnicity of the individual from the dental records. The Tygerberg I sample consisted of mostly White children with a small number of Coloured children. The second sample (Tygerberg II) from more recent records consisted of mainly Coloured children due to the change in the demographic intake of patients at the Dental Faculty after 1994. The correction factor that was derived from the first sample of Tygerberg children attained a more accurate result in age estimation compared to the second Tygerberg sample. The components of the two samples were different and suggest that there is a dental developmental difference in the White and Coloured child populations which needs to be investigated. Dental age related tables therefore need to be derived for White and Coloured children and compared to the Tygerberg dental age related table.

The Zulu samples, however, showed a different result. The first sample was obtained from archival records of children who had orthodontic treatment during the Apartheid era and who came from an upper socio-economic background that was able to afford private dental treatment. The second Zulu sample was from current files of patients in the process of orthodontic treatment. These patients are mainly from a lower socio-economic class of Zulus who have recently had access to medical insurance and therefore could afford orthodontic treatment for their children. The two samples behaved differently when the correction factors were applied, especially when the correction factors were applied to the Demirjian *et al* (1973) method. The low percentage of children estimated to within 1 year of their real age in the Zulu II sample was possibly due to differences in the nutritional status of this sample.

Genetic vs. socio-economic status

This study has shown there are genetic differences in the development of teeth which is indicated in by the differences in the ages at which the teeth develop in the South African children within the three sample groups. There is evidence, despite the work of Lavelle (1976) who stated that nutritional factors played an insignificant role in tooth development, that socio-economic factors do affect tooth development as was seen in the difference in the two samples of Zulu children. A sample of 65 Xhosa speaking children mainly from the informal settlement (Khayelitsha) were obtained from recent records. These children come from a very poor socio-economic background. The age related table derived for this sample group showed that there was a delay in the development of the teeth in these children compared to the Zulu children. This indicates that there is an influence of nutritional status on tooth development.

Correction factors were derived for the MFH and DGT methods for South African children; these corrections can be applied if either the MFH or DGT method to estimate the age of a South African child. These correction factors improved the age estimation for the White-Coloured and Indian samples but were inaccurate for the African children when using the DGT method.

Application of this study

This study demonstrated that the ages at which the various teeth attained their developmental stages in the different sample groups were not exactly the same but never-the-less within 6 months to 1 year of each other. The Tygerberg sample consisted of approximately 1000 individuals of mixed population origin and suggests that in the estimation of the age of a juvenile skeleton of South African origin, the Phillips Table 1 could be used with relative confidence.

Dental age related tables (Phillips Tables) were created for the sample groups from Tygerberg, Indian and Nguni origin and represent the majority of South African children with regard to the estimation of ages. The further application of these age related tables need to be applied to the other population groups in South Africa.

In Chapter 10 samples of Tygerberg, Indian and Xhosa children were subjected to age estimation using the MFH, DGT and the Phillips Tables. The regression analysis of these methods indicated that the Phillips Tables for White-Coloured, Indian and African children are more accurate for age estimation compared to the MFH or the DGT methods.

Conclusion

The hypotheses of this study were firstly, that the standard dental age estimation tables of Moorrees, Fanning and Hunt (1963) and that of Demirjian, Goldstein and Tanner (1973) were not applicable to the South African child population, and secondly that specific dental age related tables were needed to estimate the ages of South African children. This study has shown that the dental age related tables developed for South African children (Phillips Tables) are more accurate and applicable for age estimation of White-Coloured, Indian and Nguni children.

In the age estimation of skeletal remains of South African juveniles of unknown population origin, it is suggested that the Phillips Table 1 could be used as this sample consisted of approximately 1000 children. This would provide a better age estimation than either MFH or DGT. If, however, the population origin of the individual is known to be White, Coloured, Indian or Negroid then the appropriate table should be used for more accurate age estimation.

Proposals for possible areas of future investigation suggested by the results of this study:

- Compare the various age related stages of tooth development of children with their nutritional / socio-economic status [There has been no study on the effect of malnutrition on the calcification of teeth and the relation to chronological age]
- Investigated and compared the corresponding age related developmental stages of the maxillary teeth to their counterparts in the mandible [There has been no extensive study of the equivalent dental age related stages of maxillary teeth compared to the mandibular teeth]

- Testing the dental age related tables derived in this study on other population groups within South Africa [The dental age related tables of this study need to be tested on other South African tribes and refugees from beyond the South African borders]
- Investigate the ages at which the roots of the mandibular teeth reach ⅓ and ⅔ of their final length when viewed radiographically as interim stages would make the age related tables more accurate.
- Investigate the rate of root development of the 2nd mandibular molar where the 1st molar is lost early due to extraction and the influence this may have on dental age estimation.

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CHAPTER 1

THE DENTAL MATURATION OF THE PERMANENT MANDIBULAR TEETH OF SOUTH AFRICAN CHILDREN AND THE RELATION TO CHRONOLOGICAL AGE

1.1 RATIONALE FOR THIS STUDY

The main reason for undertaking this study was as a result of a series of child murders that occurred in Cape Town in the 1980's. Several children were reported missing during this period. The discovery of decomposed juvenile human remains on the 'Cape Flats' over 3 years eventually resulted in the recovery of the bodies of 18 children in various stages of decomposition. Some of these were so badly decomposed that it was impossible to determine either the race or gender of the individual.

The attempts at identification included age estimation using the recognized tables of Moorrees, Fanning and Hunt, a study that was published in 1963 on the developmental stages of permanent teeth in American children from Boston Massachusetts.

These age estimation tables did not fit the age profiles of these children and was of little help in the attempted identification process. The Demirjian *et al* method (1973) was attempted and was not successful either. Most of these children were not positively identified as the age estimations from these two methods did not correspond to the age profiles of the children. The use of DNA analysis was in its infancy and not available at this stage. The clothing and footwear worn by the children was used as the only means of identification and burials took place using these items as the only identification criteria.

The murders of these children was thought to have been committed by a man described by the media as the 'Station Strangler', most of the victims having commuted by rail and the murders having taken place in the proximity of train stations. An 18 year old woman was also raped and murdered during this period and the 'Station Strangler' was arrested and subsequently convicted of this crime. The Police suspected that he was also guilty of the murders of the children, but the evidence was circumstantial and dismissed by the High Court. The 'Strangler' was sent to prison for 25 years and is about to be released soon, but the murders of these children has never been solved.

The lack of dental age related tables for South African children was a major factor in the failure to identify these children and was the motivation to undertake this study and produce dental age related tables applicable to the South African child population.

1.1.2 HYPOTHESIS

The use of the standard dental age estimation tables of Moorrees, Fanning and Hunt (1963) and that of Demirjian, Goldstein and Tanner (1973) on the murdered children associated with the 'station strangler' were inaccurate and thereby suggested that these tables were not applicable for South African children. This suggested that dental age related tables be compiled for a representative sample of South African children of appropriate ethnic groups. This is formally stated as the aim of this study.

1.2 HUMAN TOOTH FORMATION AND DENTAL AGE ASSESSMENT

The age standards for human growth and development are essential in human biology and clinical medicine. The clinical assessment of the growth of a child requires normal standards as references to assess the physiological age of a system compared with the chronological age. In forensic anthropology and forensic dentistry the age of an individual is vitally important. The age will narrow the investigative field and aid in identification of skeletal remains.

Dental age is one method of physiological age assessment and is comparable to ages based on skeletal development, height and weight or sexual maturation. It is also much less affected than other tissues by endocrinopathies and other developmental insults (Garn, Lewis and Blizzard, 1965).

It has been shown in studies of children with major abnormalities affecting sexual maturation, stature and bone age that there are comparatively small deviations in the timing of dental development (Garn, Lewis and Blizzard, 1965). Dental development has two main aspects: the formation of crowns and roots, and the eruption of teeth. Of the two, formation of teeth seems to be more robust against environmental influences; caries, tooth loss and severe malnutrition can affect tooth eruption (Alvarez and Navia, 1989). Formation of teeth and tooth size or morphology is heritable, but the stages of tooth formation have lower coefficients of variation than the stages of skeletal development (Garn *et al.*, 1973). This is not to say that the dentition shows no effects attributable to environmental influences, but that it tends to be the least affected tissue. Thus the dentition is the single best physiological indicator of chronological age in juveniles (Smith, 1991).

1.3 CHRONOLOGY OF HUMAN DENTAL DEVELOPMENT

Dental age may be based on the formation or eruption of teeth. In most studies of eruption times they are limited to timing the emergence of the teeth through the gingiva. This is a single event in time for the development of each tooth (Smith, 1991). The formation of teeth, however, is more advantageous as it offers continuous development during the juvenile years. Human teeth have a definitive growth period, the last tooth completing its development as the skeleton nears maturation.

In adults teeth undergo attrition and erosion. There is an increase in the amount of secondary dentine deposition in the pulp chamber and cementum at the root apex. The root dentine undergoes hyper-mineralization. These changes have been used to provide an estimate of the chronological age of adult teeth (Gustafson, 1950; Johansen, 1971). The accuracy for the estimation of adult age is in the order of ± 5 years in the best cases.

It is, however, possible to estimate the age of juveniles far more accurately. The development of the dentition spans a period of approximately 20 years during which formation and eruption takes place. Tooth formation includes formation of an organic matrix and its subsequent calcification or mineralization. Most of the chronological studies of mineralization of teeth have been done radiographically as this is a non-invasive procedure and easily assessed. Mineralization, however, can be demonstrated at a slightly earlier age by dissection when compared to radiography (Logan and Kronfeld, 1933). Prenatal tooth formation has been studied mainly by dissection of anatomical material whereas most postnatal development has been studied radiographically. Because of this, it is not possible to assemble a complete chronology of human tooth formation based on a single technique (Johansen, 1971).

The age of emergence of teeth is known for a great variety of human groups and socioeconomic levels within groups (Adler, 1958; Steggerda and Hill, 1942; Garn, Nagy and Sandusky, 1973). There have been several recent studies of tooth emergence (Moorrees and Kent, 1978; Gillet, 1997; Gillet, 1998). Tooth emergence is the appearance of a tooth through the gums; it is an acceptable means of estimating age and has the advantage of being a quick and fairly non-invasive procedure requiring only sufficient light and a dental mirror. By contrast less is known about chronologies of tooth formation as there have been few major studies. The explanation for this is that tooth formation requires radiography or dissection whereas the study of tooth emergence requires only looking into a child's mouth. Deciduous teeth start forming prenatally with mineralization commencing in the 2nd trimester of pregnancy between 12 and 16 weeks (Kraus, 1959). Crowns are partially completed at birth and deciduous tooth root formation is complete some 2 to 3 years after initial mineralization. Calcification of the permanent dentition is however entirely postnatal and the formation of each tooth occupies between 8 to 12 years (Garn *et al*, 1965).

The events in the formation of the human permanent dentition occur in several phases. The 1st molar (M1) and the anterior teeth (I1, I2 & C) all begin formation within the 1st year. A second phase of formation is the premolars (Pm1, Pm2) and the 2nd molar (M2) between the ages of 2 to 4 years. The 3rd molars are considerably delayed and develop some 5 to 6 years after the M2 in European populations.

1.4 RADIOGRAPHIC PICTURES OF THE DEVELOPMENTAL STAGES OF TEETH

In order to visualize the developmental stages of the permanent teeth the following images of the teeth are presented. These images show the progressive development of the crowns and roots of the teeth starting with the incisors and progressing to the canine, premolars and then the molars.

Table 1: The standard abbreviation of developmental stages of teeth

Ci	Cusp initiation
Cco	Cusp coalescence
Coc	Cusp outline complete
Cr½	Crown half formed
Cr¾	Crown three quarters formed
Crc	Crown completely formed
Ri	Root initiation
Cli	Cleft initiation (molars only)
R¼	Root one quarter formed
R½	Root half formed
R¾	Root three quarters formed
Rc	Root complete
A½	Apex one half complete
Ac	Apex complete

Moorrees, Fanning & Hunt (1963)

1.4.1 Development of the incisors and early formation of the canine

The following images show the progressive stages of the development of the first incisor I1 the second incisor I2 and the canine C. The cusp initiation of the incisors begins to calcify at or just before birth; the stage of crown development in the image (Figs.1&2) is at approximately 4 years of age. The captions under each image describe the various stages of development of the teeth with relation to the adjacent teeth.

Figure 1: Incisor I1 at the 'crown complete' (Crc) stage. I2 is almost at the 'crown complete' (Crc) stage, the canine (C) & the first premolar Pm1 are at the 'crown ¾' stage (Cr¾)

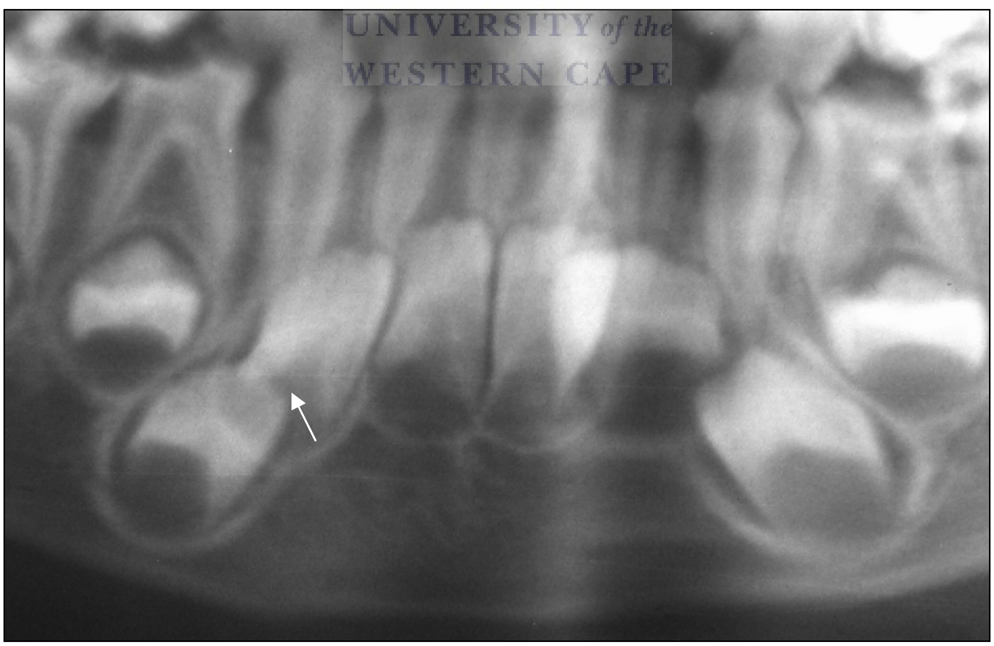


Figure 2: I1 is at the 'root initiation' stage (Ri); the I2 (arrow) is at the 'crown complete' stage (Crc), the Canine is at the 'crown ¾' stage (Cr¾), the Pm1 is at the 'crown ¾' stage (Cr¾)

The ‘crown ¾’ stage (Cr¾) shows calcification of the crown with thin elongations of enamel to the lower border of the follicle; the pulpal area has an early bell shape with a short pulp horn. As the crown develops further to the ‘crown complete’ stage (Crc), the dentine surrounding the pulp chamber calcifies and reveals a pulp chamber with a distinct bell shape and elongated pulp horn (similar to an inverted amphora vessel). The ‘root initiation’ stage (Ri) is seen as an elongation of the thin calcification lines from the crown into the underlying follicle. The pulp chamber and pulp horn have an elongated bell formation (Fig.3).

Figure 3: I1 is at the root ¼ stage (R¼), I2 is at the root initiation stage (Ri), the canine is at the root initiation stage (Ri). [Note the distinct round bell shape of the pulp chamber of the canine as the root starts to form (arrow)]

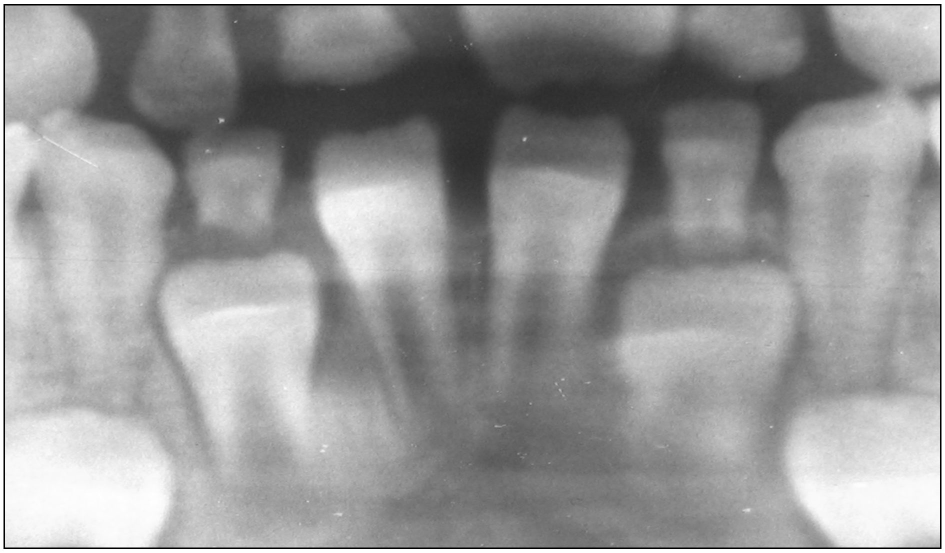


Figure 4: I1 is at the 'root ½' stage (R½),   I2 is at the 'root ¼' stage (R¼)

As the root of the incisor starts to form it reaches the 'root ¼' stage (R¼), the root walls are short and pointed at the ends; the crown and root are of equal length; the pulp chamber and initial root canal is conical in shape with the base of the cone at the apical area. The 'root ½' (R½) stage has elongated root walls with pointed ends and with a pulp chamber and root canal having parallel sides; the root is approximately twice the length of the crown. The canine at the 'root initiation' stage (Ri) has a distinct form; the pulp horn is elongated and the pulp chamber has a round bell shape (Fig 5).

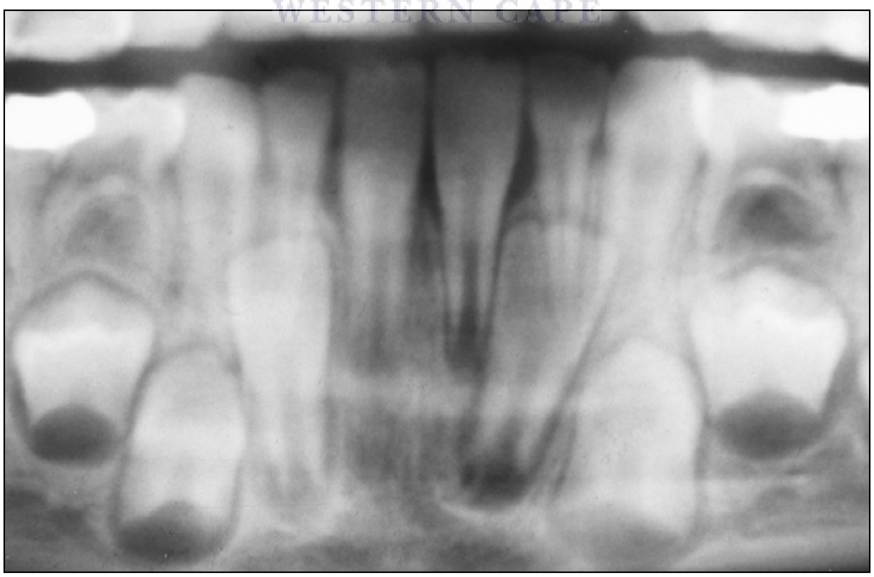


Figure 5: I1 is at the 'root ¾' stage (R¾), I2 is at the 'root ½' stage (R½), the canine (C) is at the 'root initiation' stage (Ri), the Pm1 is at the 'crown complete' stage (Crc)

Figure 6: I1 is at the 'apex ½' calcified stage (A½), I2 is at the 'root complete' stage (Rc), the canine (C) is at the 'root ¼' stage (R¼).

The 'root ¾' (R¾) stage for the incisors is attained when the root length is greater than twice the length of the crown; the tip of the root is still funnel shaped. The 'root complete'(Rc) stage is when the root is almost 3 times the length of the crown, the sides of the root canal are parallel and the width of the apical canal is the same as the width of the canal above it. As the apex of the root starts to form the walls of the root converge and narrow the root canal. This is the 'apex ½' (A½) stage; there is still a distinct radiolucent 'bulge' of the uncalcified future root apex (Figs 6 & 7). The stage at which the apex is complete (Ac) is seen when the apical calcification has converged the tip of the root to a point and the apical periodontal lamina dura of the bone surrounds the apex.

Figure 7: I1 is at the 'apex ½' calcified stage (A½), the I2 is at the 'root complete' stage (Rc), the canine is at the 'root ¼' stage (R¼), the left Pm1 is at the 'root initiation' stage (Ri), the right Pm1 is at 'root½' stage (R½) (arrow). [The roots of the permanent teeth appear to develop more rapidly when the overlying primary teeth are prematurely extracted]

1.4.2 Development of the canine and premolars

The canine and premolars go through similar developmental stages albeit at different times. Initially a radiolucent follicle appears at the apex of the overlying deciduous tooth (Fig 9); the well circumscribed radiolucency then develops points of calcification which are the cusps of the permanent tooth starting to form. Then follows the stages of cusp coalescence (Figs 8 & 10), crown formation and eventually root development (Figs 11-15).

Figure 8: The Pm1 is at the 'crown ½' stage (Cr½), the Pm2 is at the 'cusp outline Complete' stage (Coc), the M1 is at the 'cleft initiation' stage (Cli).

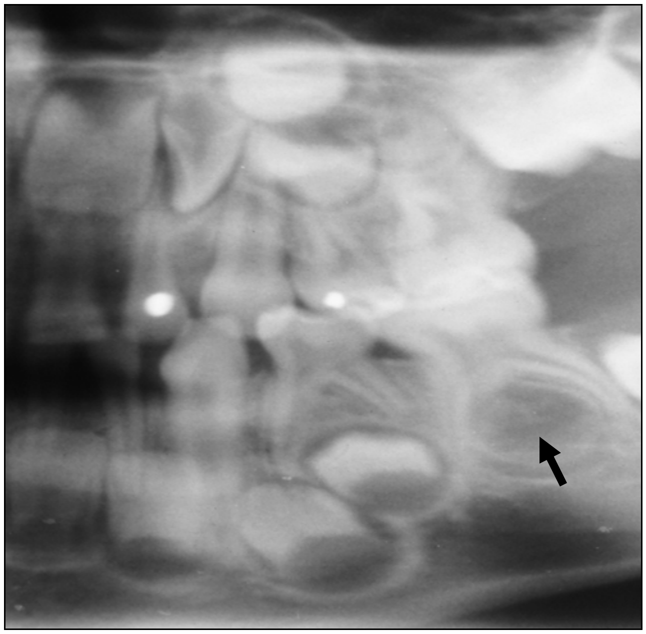


Figure 9: The canine and the Pm1 are at the ‘crown ¾’ stage (Cr¾), the Pm2 shows the ‘follicle’ stage (F) without any calcification of the cusps (arrow)

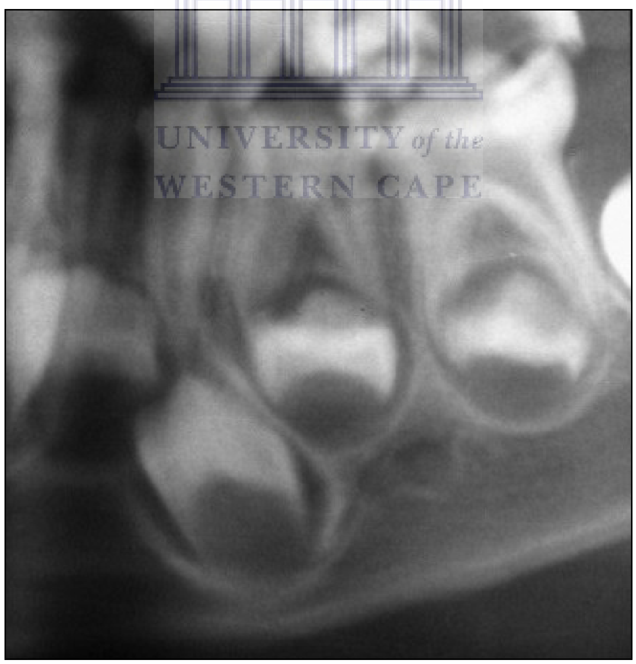


Figure 10: The canine is at the ‘crown complete’ stage (Crc), the Pm1 is at the ‘crown ¾’ stage (Cr ¾), the Pm2 is at the ‘crown ½’ stage

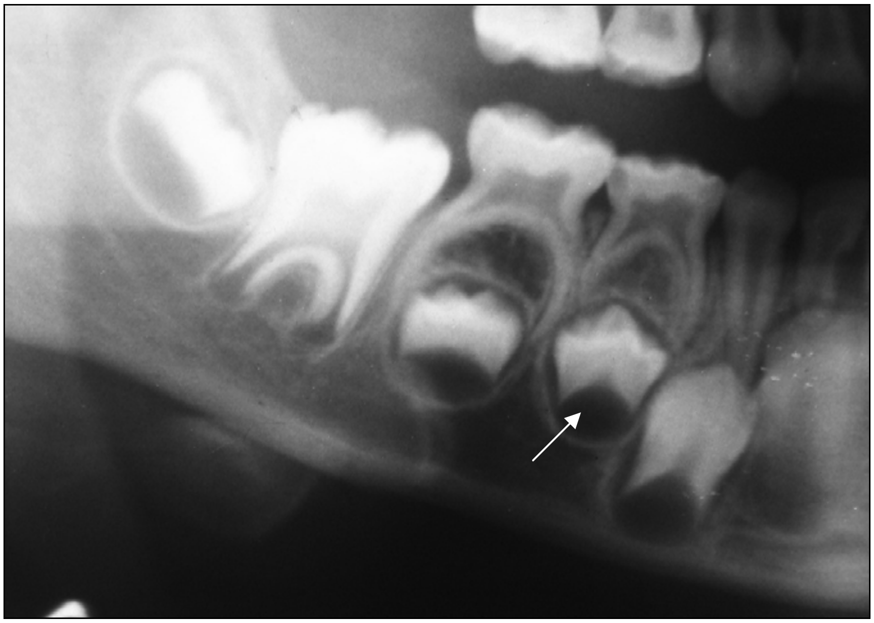


Figure 11: The canine is at a stage between root initiation and root ¼, note the elongated bell shape of the pulp extending from the crown to the root area. The Pm1 is at the 'crown complete' stage (Crc), the Pm2 is at the 'crown ¾' stage (Cr¾). The M1 is at the 'root ½' stage (R½), the M2 is at the 'crown ¾' stage (Cr ¾). Note that the Crc stage of the premolar has an early bell-shaped radiolucency in the pulp-horn / root area (Arrow).

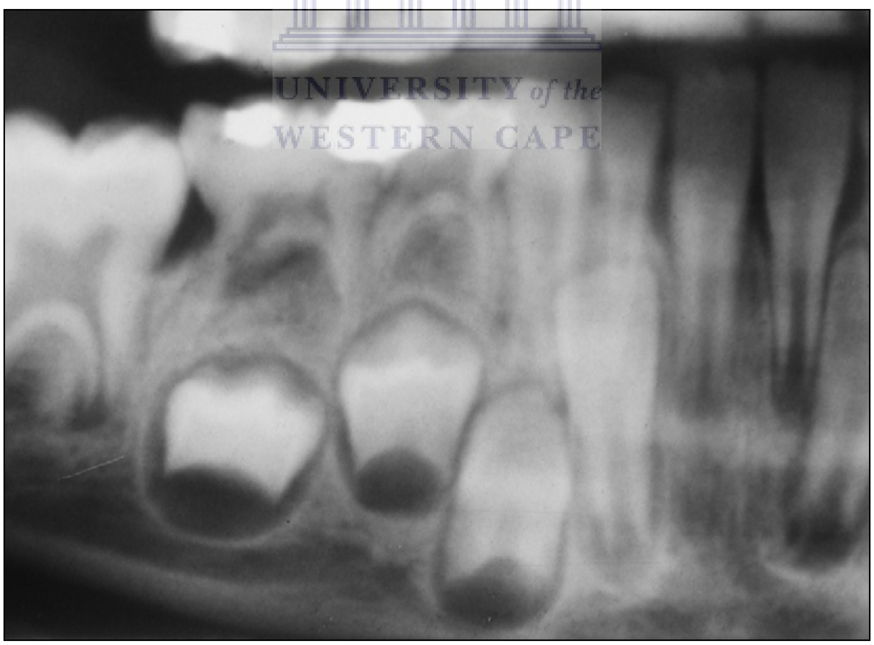


Figure 12: The I1 is at the 'root ¾' stage (R¾), the I2 is at the 'root ½' stage (R½), the canine is at the 'root ¼' stage (R¼), the Pm1 is at the 'root initiation' stage (Ri), the Pm2 is at the 'crown ¾' stage (Cr¾) [The pulp-horn is not yet visible].

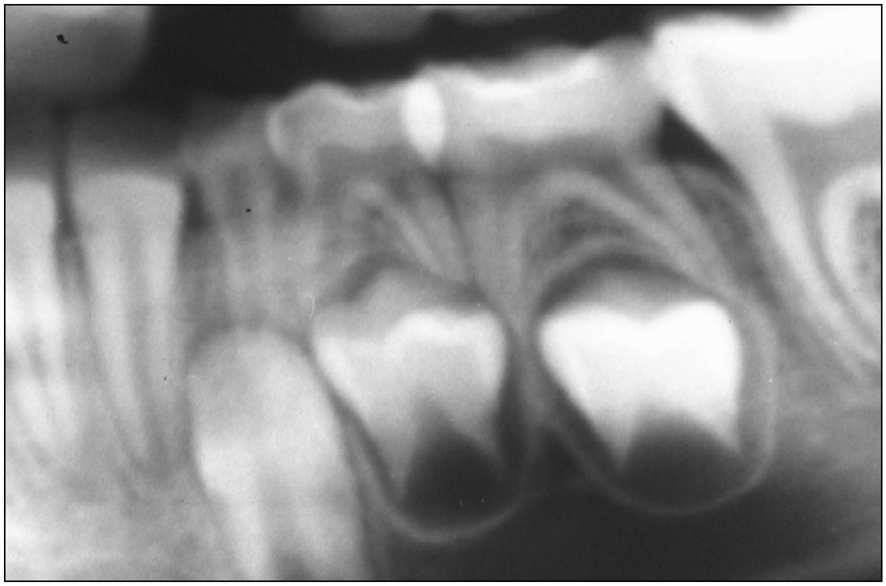


Figure 13: The Pm1 is at the late 'root initiation' stage (Ri) almost 'root ¼' stage (R¼), the Pm2 is at the 'root initiation' stage (Ri)

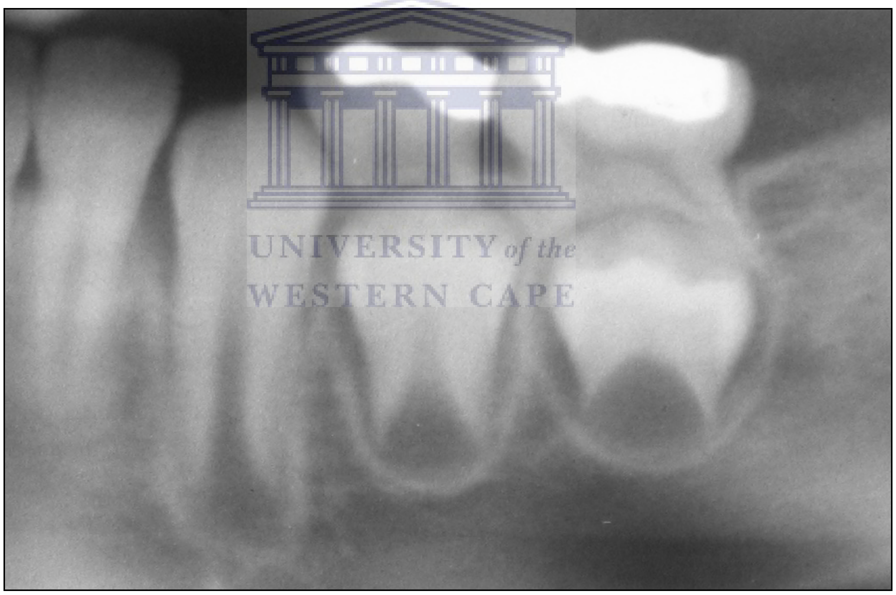


Figure 14: The canine is at the 'root ¾' stage (R¾), the Pm1 is at the 'root ¼' stage (R¼), the Pm2 is at the 'root initiation' stage (Ri)

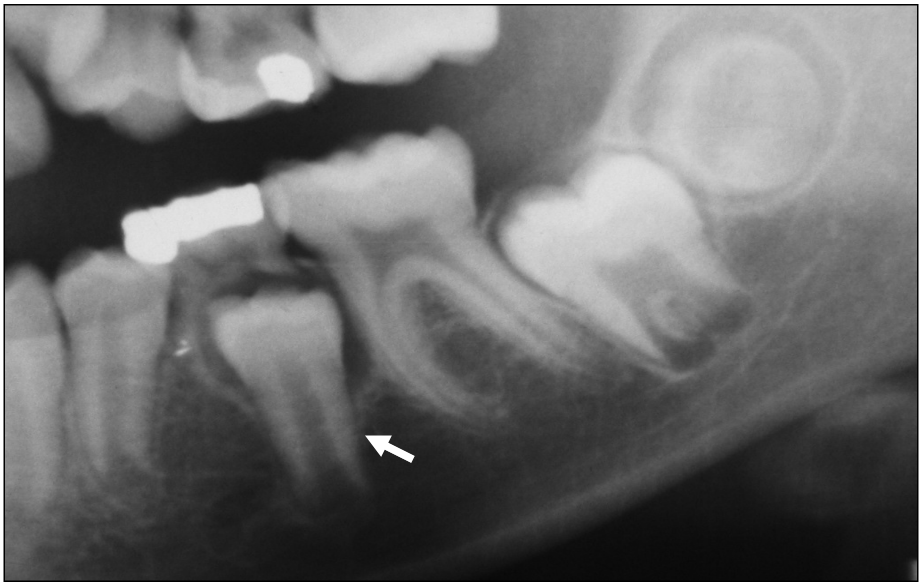


Figure 15: The Pm1 is at the ‘root ¾’ stage (R¾) almost ‘root complete’ stage (Rc), the Pm2 (arrow) is at the ‘root ½’ stage (R½) almost ‘root ¾’ stage (R¾). The apices of the M1 are at the ‘apex ½’ calcified stage (A½), the M2 is at the ‘root ¼’ stage (R¼). The M3 is at the ‘cusp coalescent’ stage (Cco)

1.4.3 Development of the molars

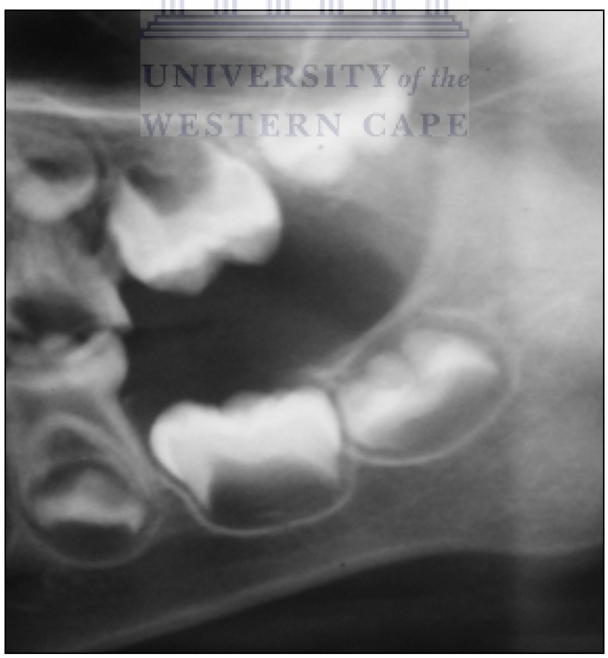


Figure 16: The M1 is at the ‘crown complete’ Stage (Crc), this is the stage just before ‘root initiation’ (Ri), followed by the root cleft formation; the M2 is at the ‘cusp outline complete’ stage (Coc)

The 1st molar starts to form intra-utero and the tips of the cusps begin calcification at birth. Figure 16 shows the 1st molar at the crown complete stage (Crc) (approximate age 4 years); the image shows the enamel cap and the underlying dentine covering the mesial and distal pulp horns and ending in a sharp point. As the dentine of the root starts to develop there is increased development of the dentine which has a beveled edge (Fig 17); this is the root initiation (Ri) stage that is followed by calcification of the cleft between the roots (Cli). Initially the cleft calcification is a point of calcified tissue but soon develops an inverted curve (Fig 18); as this curve elongates downwards the roots start to form and calcify leading to the 'root ¼' stage of development (R¼). The root length at stage 'root ¼' is less than the crown height. When the root length is equal to the crown height, the stage of 'root ½' (R½) is reached. 'Root ¾' stage (R¾) is reached when the root is longer than the crown height, the root canals are parallel and the root tip is conical shaped. The 'root complete' (Rc) stage is attained when the root shape has narrowed and the root canal has started to narrow slightly compared to the canal above. The root apex is still wide open and the radiolucent area in the adjacent bone is prominent.

The closure of the apex begins with narrowing of the root canal and the adjacent radiolucency reducing in size (A½) (See Fig.19 – distal root of M1). When the apex is closed (Ac) the periodontal ligament space is a uniform width around the root tip.

Figure 17: The 1st molar (M1) at the 'root initiation' stage (Ri). The cusps of the 2nd molar have fused and the stage of 'cusp outline complete' (Coc) has been attained. [Note: There is initial calcification of the crown of the Pm2 within the follicle]

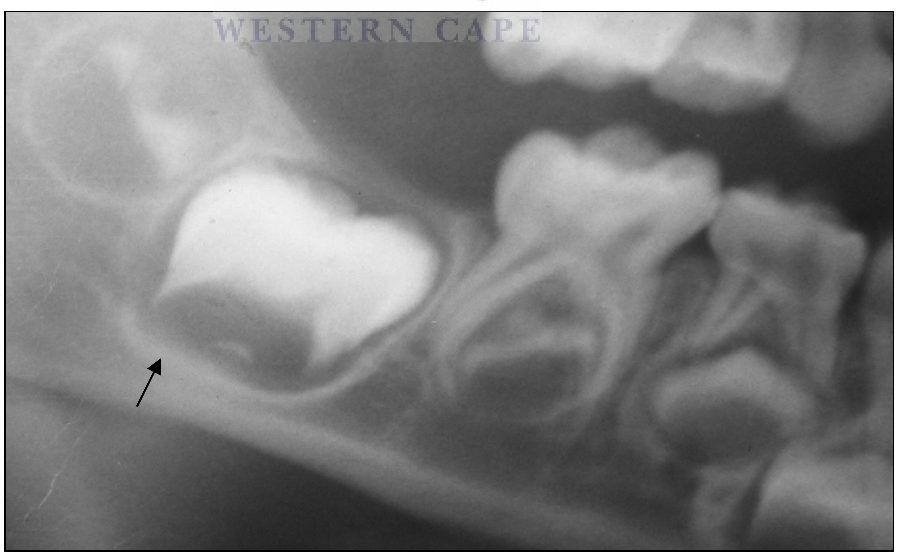


Figure 18: The first molar (M1) showing the 'root initiation' and early root cleft (arrow) calcification with an inverted 'U'

Figure 19: The 2nd molar shows that as the cleft of the root formation continues to calcify the stage of 'root ¼' (R¼) is reached

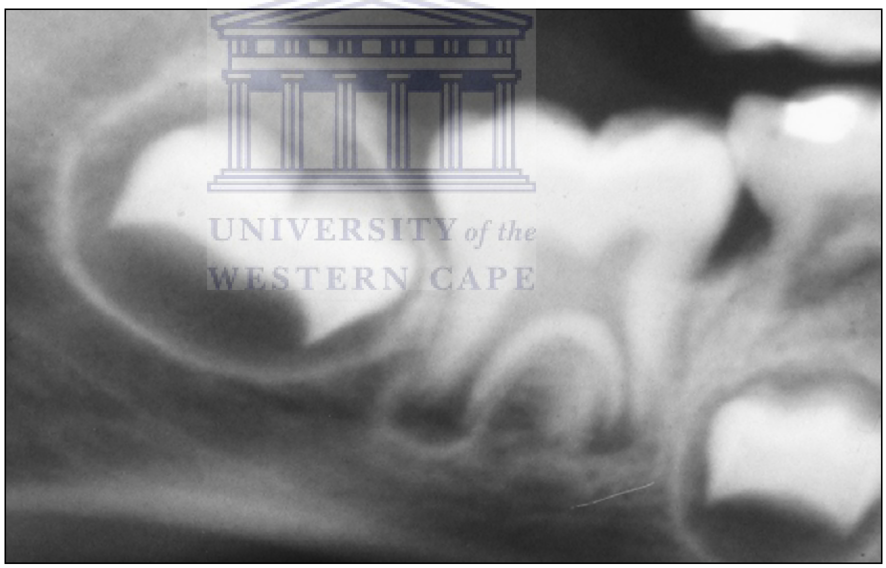


Figure 20: The roots of the 1st molar show 'root ¼' stage (R¼) of development. The 2nd molar is at the 'crown ¾' (Cr ¾) stage.

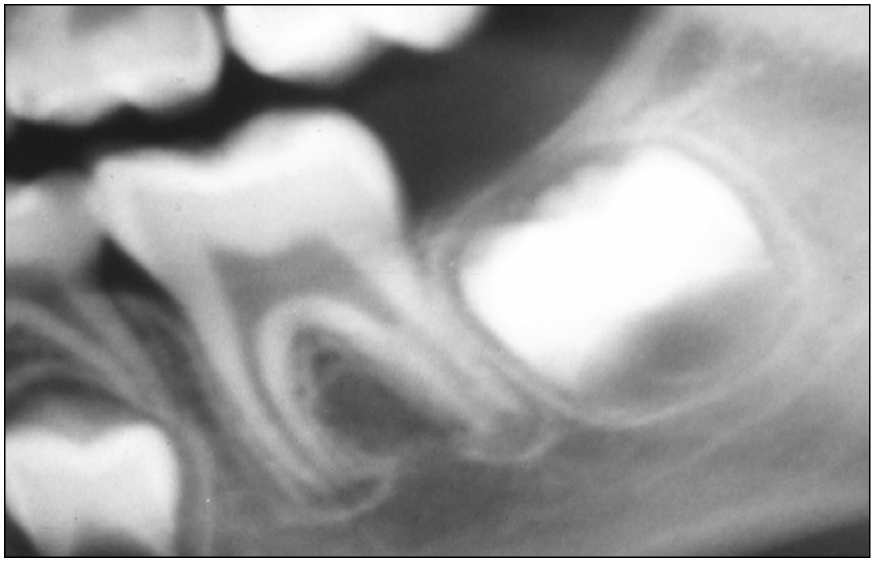


Figure 21: The roots of the 1st molar have elongated; the mesial root is at the 'apex ½' stage (A½) showing the narrowing of the root canal; the distal root is at the 'root complete' stage (Rc), showing parallel root walls and the apex having the same width as the root canal

The roots of the molars develop at different rates; the mesial root often develops faster than the distal root. Figure 21 shows that the mesial root apex is starting to close whereas the distal root is at the 'root complete' stage (Rc) and the apex has not narrowed at all. Figure 22, however, shows both roots at the same stage of development. The distal root of the 1st molar often appears longer than the mesial root (Fig 22).

The development of the crown of the 2nd molar progresses through the various stages from cusp initiation, cusp coalescence, cusp outline complete and then crown formation and eventually root formation. The mesial and distal roots also develop at different rates but not as markedly as those of the 1st molar.

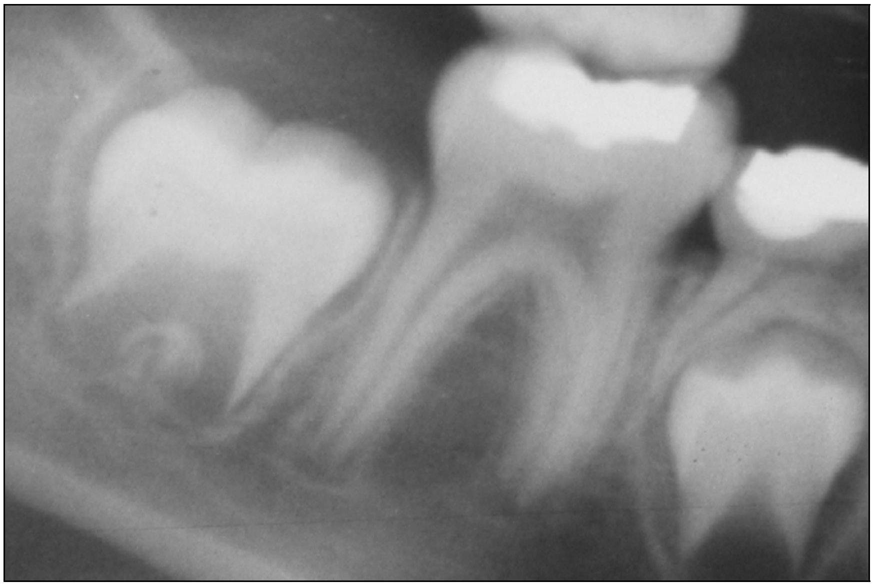


Figure 22: The 1st molar shows the mesial and distal roots at the same stage of development 'root complete' (Rc). The 2nd molar is at 'root ¼' stage (R¼)

1.4.4 Variations during development

1.4.4.1 Canine & Premolars

The canine and premolars develop at similar rates and stages. The root development has been divided into Ri, R¼, R½, R¾ and Rc; these stages are often difficult to establish as there are intermediary stages where the length of the root is between two stages.

Figure 23 shows the PM1 and Pm2 at the R¼ stage of root development; the root of PM1 is distinctly longer than Pm2, but is not yet twice the length of the crown and must therefore be designated as at the 'root ¼' stage (R¼).

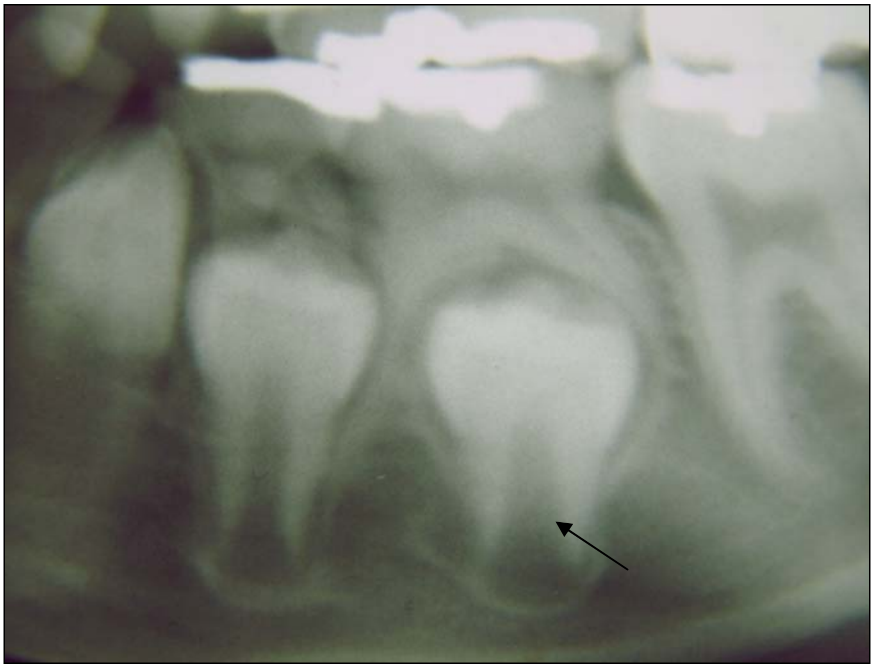


Figure 23: The Pm1 and the Pm2 are both at the 'root ¼' stage (R¼). The root of Pm1 is slightly longer than Pm2.

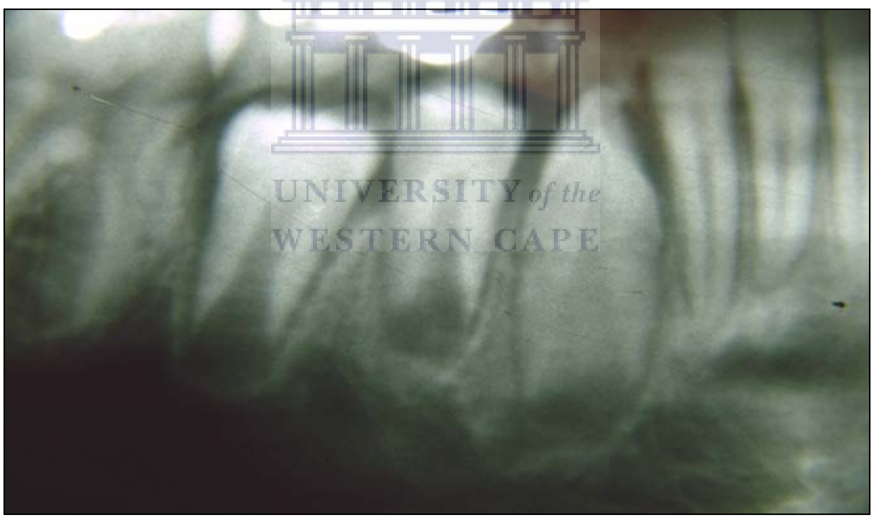


Figure 24: Both Pm1 & Pm2 and the canine are at 'root ½' stage (R ½). [Note the conical shape of the root canals.]

The stage of 'root half' (R½) shows the root canal to be an elongated cone with a wide open apex and the root walls pointed (Fig 24). As the root elongates to the 'root complete' stage (Rc) (Fig 25), the root walls become parallel, the root canal is of even width and the apex is slightly flared. The uncalcified root apical area is visible as a small radiolucency.

Figure 25: The apex of the Pm1 is at 'apex ½' stage (A ½); the Pm2 is at the 'root complete' stage (Rc). Both the mesial and distal root apices of the M1 have calcified (Ac)

The calcification of the root apex from half complete to the complete stage shows initial narrowing of the apical walls of the root (A½) and subsequent closure of the apex (Ac).

1.5 AIMS AND OBJECTIVES

1.5.1 Aim

The aim of this study was to establish the accuracy of the standard dental age estimation methods of Moorrees, Fanning and Hunt (1963) [MFH] and Demirjian, Goldstein and Tanner (1973) [DGT] on samples of the South African child population. If these existing tables were found to be inaccurate to then construct applicable dental age related tables for South African children.

1.5.2 Objectives

(a) Compare age estimation of tooth eruption with crown and root calcification

(b) To develop dental age related tables for South African male and female children of different population groups.

(c) Estimation of the ages of South African children using the methods of Moorrees *et al* [MFH] and Demirjian *et al* [DGT] and gauge the accuracy of these methods

(d) The development of correction tables for the MFH and DGT methods of age estimation applicable to South African children

(e) Testing of the correction tables for MFH and DGT on the original samples of South African children

(f) Testing of the correction tables for MFH and DGT on new samples of South African children

(g) The development of new dental age related tables for South African children from the data of the study

(h) Testing the new dental age estimation tables on different samples of South African children and statistically analyzing the results compared to the MFH and DGT methods.

1.6 STYLE OF THE THESIS

The style of this thesis is in a format in which each chapter from 3 to 8 is a self-standing analysis.

CHAPTER 2

COMPARISON OF AGE ESTIMATION BY TOOTH ERUPTION WITH CALCIFICATION STAGES OF CROWNS AND ROOTS; A REVIEW

This chapter compares the age estimation of children by means of the eruption times of their teeth with age estimation by radiographic imaging of the developing teeth.

Eruption is the process by which teeth, in their bony crypts, migrate through the jaws and emerge into the mouth. It continues as each tooth moves into occlusion and beyond, to compensate for the effects of wear, so that eruption is a continuous process that never completely ceases. Clear-cut stages are therefore difficult to define (Hillson, 1996).

2.1 ALVEOLAR EMERGENCE OF THE TEETH.

The emergence of the tooth through the crest of the alveolar process is not a sudden event. In dry bone specimens it is first seen as a small aperture which gradually widens as the tooth crown rises higher until it has opened out to the full crown diameter. In radiography the same process is seen as a gradual decreasing rim of lamina dura overlying the tooth. Anthropologists studying dry specimens define alveolar emergence as the first appearance of the tooth cusps above the alveolar crest; in radiographs it is the stage at which the alveolar bone has been completely resorbed over the occlusal surface of the tooth (Hillson, 1996).

2.2 GINGIVAL EMERGENCE (CLINICAL ERUPTION)

The appearance of the teeth through the gingiva is also a gradual process. Cusp tips appear as small pinpoint nodules before the bulk of the occlusal surface follows.

Haavikko (1970) defined tooth eruption as clinically erupted when the crown of the tooth or part of it has roentgenologically been observed to have penetrated the mucous membrane. Saleemi *et al* (1994) recorded teeth as emerged if any part of the crown was visible in the mouth seen with the naked eye.

2.3 ENTRY OF THE CROWN INTO OCCLUSION

With the dentition in situ each crown may be judged with reference to its neighbours, or by first signs of wear. This is a definition that is difficult to use clinically but may be useful for anthropological purposes (Hillson, 1996).

2.4 EXFOLIATION OF DECIDUOUS TEETH

The process of deciduous tooth resorption can be observed in dry specimens and radiographically. The timing of deciduous teeth resorption is known from several radiographic studies (Fanning, 1961; Moorrees, Fanning and Hunt, 1963; Haavikko, 1973). Depending on the definitions used, alveolar emergence may be in advance of gingival emergence by a few months to a year or more (Haavikko, 1973). In addition, the sequence with which teeth emerge at the alveolar crest may be different from the gingival emergence sequence as stated by Garn and Lewis in 1963, (Hillson, 1996). Eruption has been considered the traditional method for dental age estimation (Clements *et al*, 1957) and the emergence of teeth as an indicator of age has been used by physical anthropologists, dentists and forensic pathologists for many years. It has therefore been accepted as a rough guide of the stage of development compared to chronological age of a child.

Studies on the emergence of the teeth through the gingiva show that eruption takes place during three periods of childhood and early adulthood (Hillson, 1996).

1. Period of deciduous dentition
2. Period of mixed dentition, when the permanent first molars emerge distal to the deciduous tooth row; the deciduous incisors are replaced by the permanent incisors
3. Period of permanent dentition, when all the deciduous teeth are replaced by permanent teeth.

The deciduous teeth start to emerge through the gums during the first few months of life (5 to 7 months), and the first 4 teeth are usually apparent by 14 months. The eruption pattern is constant; central incisors appear first then the lateral incisors. The 1^{st} molars emerge at about 15 to 18 months, the canines between 16 and 19 months and the 2^{nd} molars at 23 to 30 months. Most children have a normal complement of 20 deciduous teeth at the age of 3 years.

2.5 ERUPTION OF PERMANENT TEETH

In 1837 Saunders established gingival emergence of molars as an indicator of children's ages (Hillson, 1996). Exploitation of young children in factories during the industrial revolution in Britain became widespread, and led to a series of legislative measures to apply limits to the age at which a child could be employed. Modern forensic odontology rarely relies on gingival or alveolar emergence for age estimates. The eruption of the permanent dentition begins at about 6 years. There are four distinct phases in human tooth emergence into the mouth (Hillson, 1996);

Stage1: deciduous teeth most of which emerge during the 2^{nd} year of life

Stage 2: the emergence of the permanent 1^{st} molar (M1), the central incisor (I1) and then the lateral incisor (I2) at 6-8 years

Stage 3: the eruption of the canine (C), followed by the 1^{st} premolar (Pm1), the 2^{nd} premolar (Pm2) and the 2^{nd} molar (M2) at 10-12 years

Stage 4: is the eruption of the 3^{rd} molar (M3) at 18+ years.

This is theoretically interesting, but is subject to several factors that could either accelerate or retard the eruption of the teeth, i.e. early loss of teeth due to caries, trauma, or early extractions would accelerate the eruption pattern. Early loss of deciduous molars causes tooth drifting which closes the gap for the erupting permanent premolars and results in impaction and subsequent delayed eruption of these teeth.

There are important differences between maxillary and mandibular growth patterns and the emergence of teeth in these jaws, but there is no significant difference between left and right sides of either jaw (Bambach, Saracci and Young, 1973; Billewitcz, et. al, 1973; Demirjian, Goldstein and Tanner, 1973). Individual variation will produce uncertainty in age estimation due to variable rates of development. Prematurity and infant mortality do not introduce bias in the rate of dental development, but they do contribute to variance (Khan, Chakraborty and Paul, 1981). Nutritional status plays a major role in eruption times and was shown to retard deciduous tooth eruption in rural Guatemalan children by 2 months (Delgardo et. al, 1975).

Radiographic studies are far more accurate in correlating age with the development of the teeth. Gingival emergence has, however, been used in growth studies in which the children cannot be routinely radiographed (Filipsson, 1975; Moorrees and Kent, 1978).

The eruption data for permanent teeth of 2847 African and Asian children age 4-14 years in Nairobi was analysed by Hassanali and Odhiambo (1982). They found the range of error varies from 18-30% of the median age for African males, 21-29% for African females, 15-33% for Asian males and 18-33% for Asian females.

A longitudinal study of Swedish urban children from birth to 18 years was undertaken by Hagg and Taranger (1986). All deciduous teeth in this study, except the mandibular 2nd molars, emerged earlier in boys than in girls. All permanent teeth emerged earlier in girls, the sex differences being 2.5 to 14 months. The comparison between dental eruption age and chronological age for deciduous teeth varied by ± 4 months, but for permanent teeth it varied by ± 3 years Hagg and Taranger (1985).

The eruption of permanent teeth has been studied in far greater detail in several studies (Hurme, 1949, 1951; Dahlberg and Menegaz-Bock, 1958; Jaswal, 1983; Smith and Garn, 1987). There is considerable variation in both sequence and timing of tooth eruption; however, it is possible to state a normal sequence that applies to many populations around the world (Hillson, 1996).

The order of emergence for the upper permanent dentition: M1, I1, I2, Pm1, C, Pm2, M2, M3.

The order of emergence for the lower permanent dentition: M1, I1, I2, C, Pm1, Pm2, M2, M3.

Gingival emergence (Table 1) has a strong correlation between the left and right sides (antimeres) and equivalent teeth in the upper and lower jaws (isomeres). Lower teeth emerge earlier than their equivalents in the upper jaw, especially the anterior teeth. The permanent dentition (especially canines) in girls usually emerges before that of boys in the same population, but there are differences in other population groups (Garn *et al*, 1973a). The permanent teeth of Europeans (particularly molars) erupt later than in other populations, whereas children from poorer families show slightly later tooth emergence than the children from a higher socio-economic level (Garn *et al*, 1973b).

Table 1: Summary of gingival emergence of deciduous and permanent teeth (Hillson, 1996)

Deciduous dentition
First incisors (lower then upper)
Second incisors (upper then lower)
First molars
Canines
Second molars (lower then upper)
Permanent dentition
First molars
First incisors
Second incisors
Upper first premolars, or lower canines
Upper canines, or lower first premolars
Second premolars
Second molars
Third molars

Some pairs of teeth are particularly close in eruption timing and the eruption order is frequently reversed (Smith and Garn, 1987). The most common variation (especially in the lower jaw) is a reversal of the eruption sequence of the first incisors and first molars (I1, M1 instead of M1, I1). Later there is considerably more variation; the most stable sequences are Pm2, Pm1 in the lower jaw and Pm2, M2 in the upper jaw. Common deviations are Pm2, C; C, Pm1; Pm1, C; and M2, Pm2.

The following sequences therefore encompass the most likely pattern of variation (the brackets indicate that the order is commonly reversed) (Hillson, 1996):

Upper jaw   M1, I1, I2, (Pm1, C, Pm2) M2, M3

Lower jaw   (M1, I1), I2, (C, Pm1), (Pm2, M2), M3

The stages of development of the teeth were thought to be affected by environmental factors as well as genetic inheritance until Lavelle (1976) showed that the development of the teeth is primarily under genetic control. The enamel formation of deciduous teeth is almost completed before the child is born and there has been no evidence that climate or disease have any major effect on the development of deciduous teeth in contrast to musculo-skeletal development (Neill *et al.* 1973; Trustwell and Hanson, 1973; Friedlander and Bailit, 1969; Khan, Chakraborty and Paul, 1981). There has however been evidence that the socio-economic factors of a family play an important role in the time of emergence of teeth (Enwanwu, 1973). The use of emergence of teeth as a marker of age introduces an important variance and thereby limits its applicability at certain ages. The number of teeth that have emerged in a mouth is a discontinuous variable that represents a continuous process; the eruptions are sufficiently close to one another in time to provide estimates of age only during particular periods of growth.

Aging by tooth emergence is limited to children under the age of 3 and from 6 to 12 years of age. Only approximate categorization can be achieved between the ages of 3 and 6 years (Townsend and Hammel, 1990).

Schour and Massler (1941) published the well known diagram of both tooth formation and eruption dividing the sequence into 22 stages (Fig. 1). This study was based on the work of Logan and Kronfeld (1933). Although this study was carried out on a small number of terminally ill children most of whom were under 2 years of age when they died, it performs well in comparison with the studies of Moorrees, Fanning and Hunt (1963) and Gustafson and Koch (1974). A revision of this work was undertaken by Ubelaker (1978), who removed one prenatal stage and added a new stage at 18 months and applied data drawn from numerous studies. The Ubelaker chart (Table 3) was developed for studies on Native Americans, but is recognised as a standard reference throughout the world (Buikstra and Ubelaker, 1994).

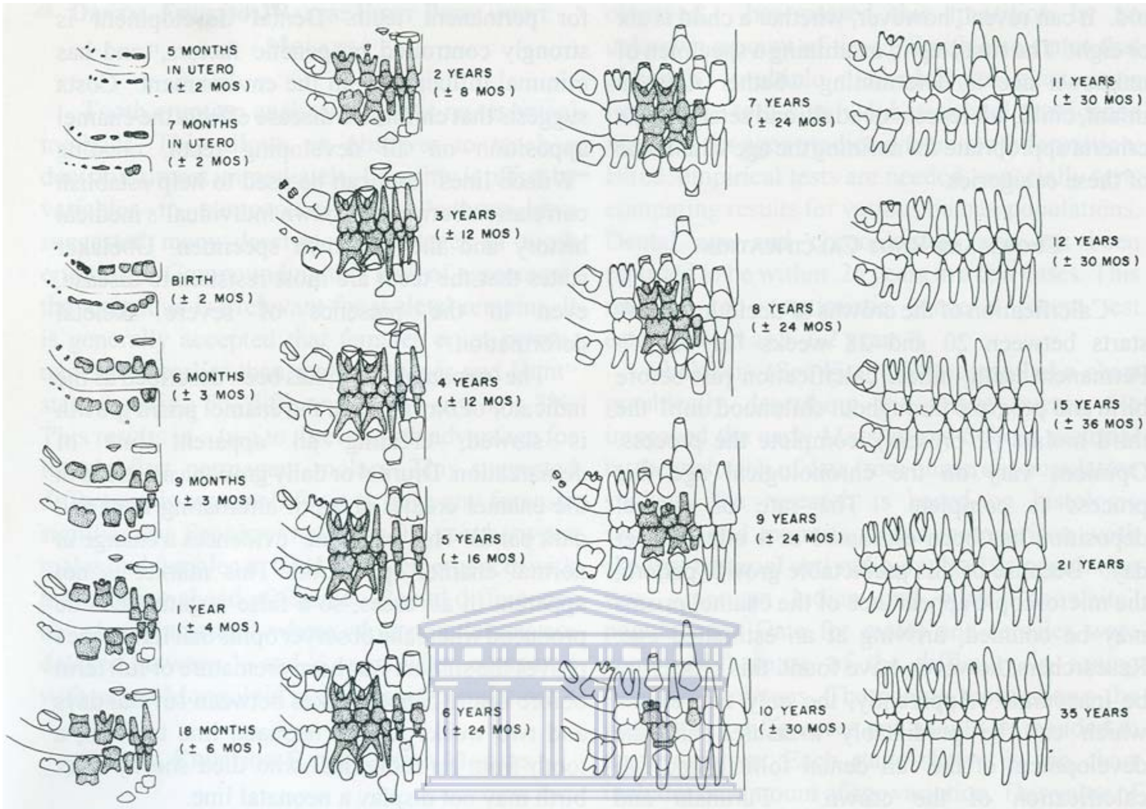
Conclusion

Estimation of age is a task of the physical anthropologist and the eruption and development of the dentition have been used extensively to estimate the ages of children at death. The most widely used are the charts of Schour and Massler (1941) and that of Buikstra and Ubelaker (1994) as these are pictorial and easy to use. The clinical emergence of the primary and secondary dentition in the mouth is at best a rough guide as to the chronological age of children, but this method is not as accurate as the developmental stages of crown and root formation as seen on radiographic images.

Figure 1: Schour and Massler Chart

Figure 5.8 Schour and Massler's original dental development diagram. Reproduced from Schour, I. & Massler, M. (1941) The development of the human dentition, *Journal of the American Dental Association,* **28,** 1153–1160, with the kind permission of the American Dental Association, 211E Chicago Avenue, Chicago 60611.

Figure 2: Ubelaker Dental Age Development Chart



Ubelaker DH. Human skeletal remains: excavation, analysis, interpretation, Chicago: Aldine, 1978.

CHAPTER 3

THE PUBLISHED STUDIES OF DENTAL AGE ESTIMATION BY CALCIFICATION OF PERMANENT MANDIBULAR TEETH

A period of investigation took place during 1950's and 1960's when a large number of radiographs of children were examined as part of an ongoing study of growth amongst American children (Gleiser and Hunt, 1955; Demisch and Wartmann, 1956; Nolla, 1960; Fanning, 1961). Thereafter, Canadian growth studies on French-Canadian children in Montreal were carried out utilizing radiographic data (Demirjian, Goldstein and Tanner, 1973; Haavikko, 1974; Demirjian and Goldstein, 1976; Demirjian and Levesque, 1980). Similar studies have been carried out on European children in the Netherlands and Finland (Nylström *et al*, 1986) as well as a cross-sectional study on Finnish children (Haavikko, 1970). Subjects in all these studies were of European derivation. Gustafson and Koch (1974) published a chart (Table 1) covering the development of the dentition from 8 months before birth to 16 years of age. The chart was based on pooled data collected from 19 sources published between 1909 and 1964. Four landmarks in the process of development of each tooth were recorded, the commencement of mineralization, the completion of crown formation, the completion of tooth eruption and the termination of root formation. Each landmark is represented graphically on the chart by a small triangle.

Trodden (1982) studied the eruption and calcification times of a small group of Inuit and Amerindians from Canada and derived dental age estimation tables for this population group. All the radiographic studies included at least three stages of tooth formation beginning with crown calcification following with crown completion and root formation and completion. Originally Nolla (1960) started with 11 stages of tooth formation

(Table 2) that was subsequently modified (Moorrees, Fanning and Hunt, 1963; Andersen, Thompson and Popovich, 1976; Nyström *et al*, 1986). The stages are based on simple fractions of crown and root formation and are simple to use and are easily modified. Demirjian *et al*. (1973) proposed an 8 stage system of crown and root calcification labeled from A to H (Table 3). The developmental stage of each tooth is gauged by comparison with Table 3 then given a 'self-weighted' score from Table 6 (male or female). The sum of the 'self-weighted' scores is converted to an age from Table 4 and 5. This method of Demirjian has subsequently been tested on several population groups with varying success.

Table 1: Tooth development tables of Gustafson and Koch (1974)

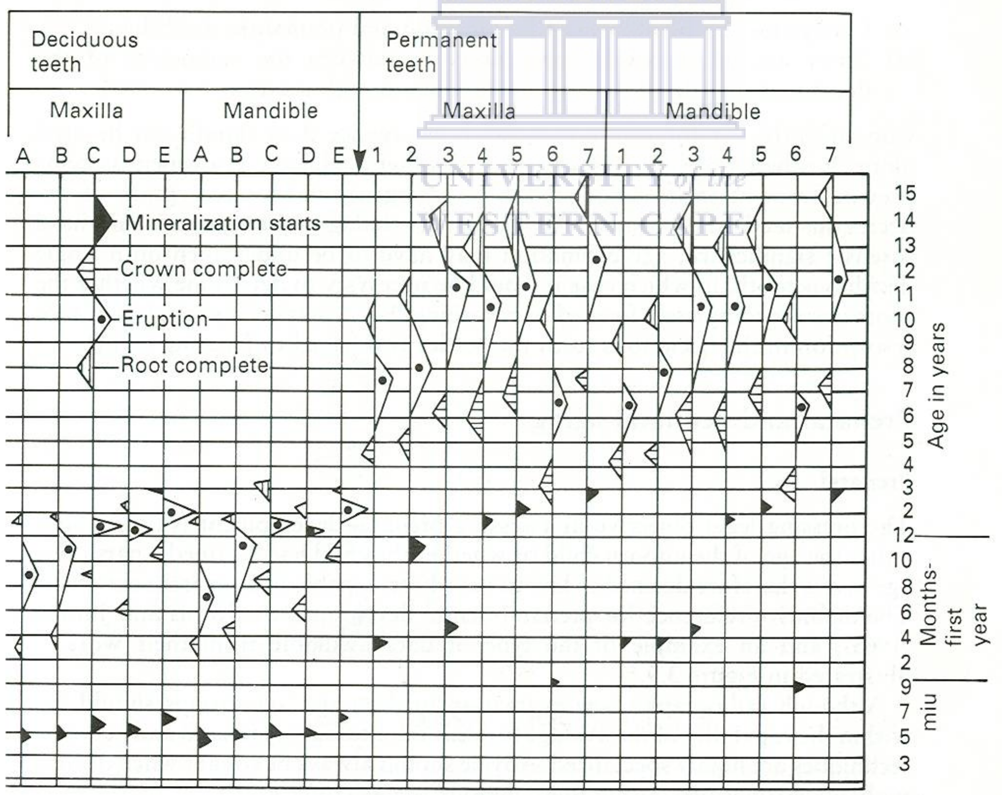


Table 2: The developmental stages of adult teeth by Nolla (1960)

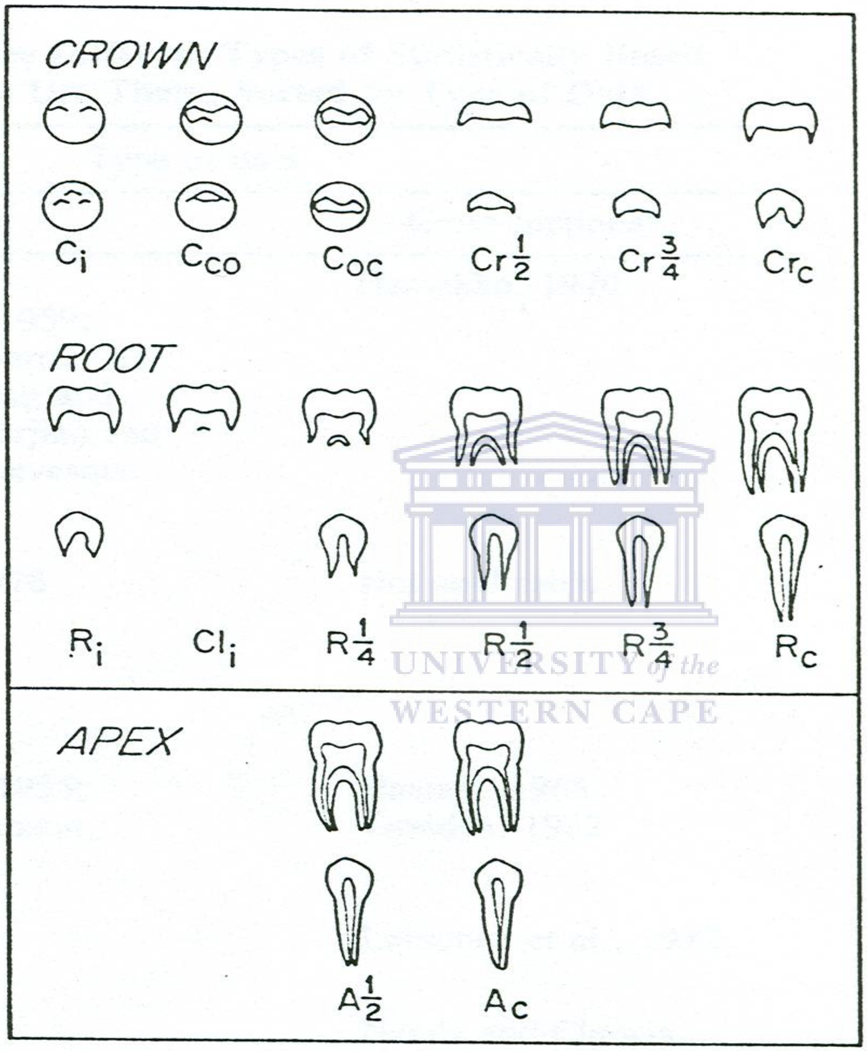
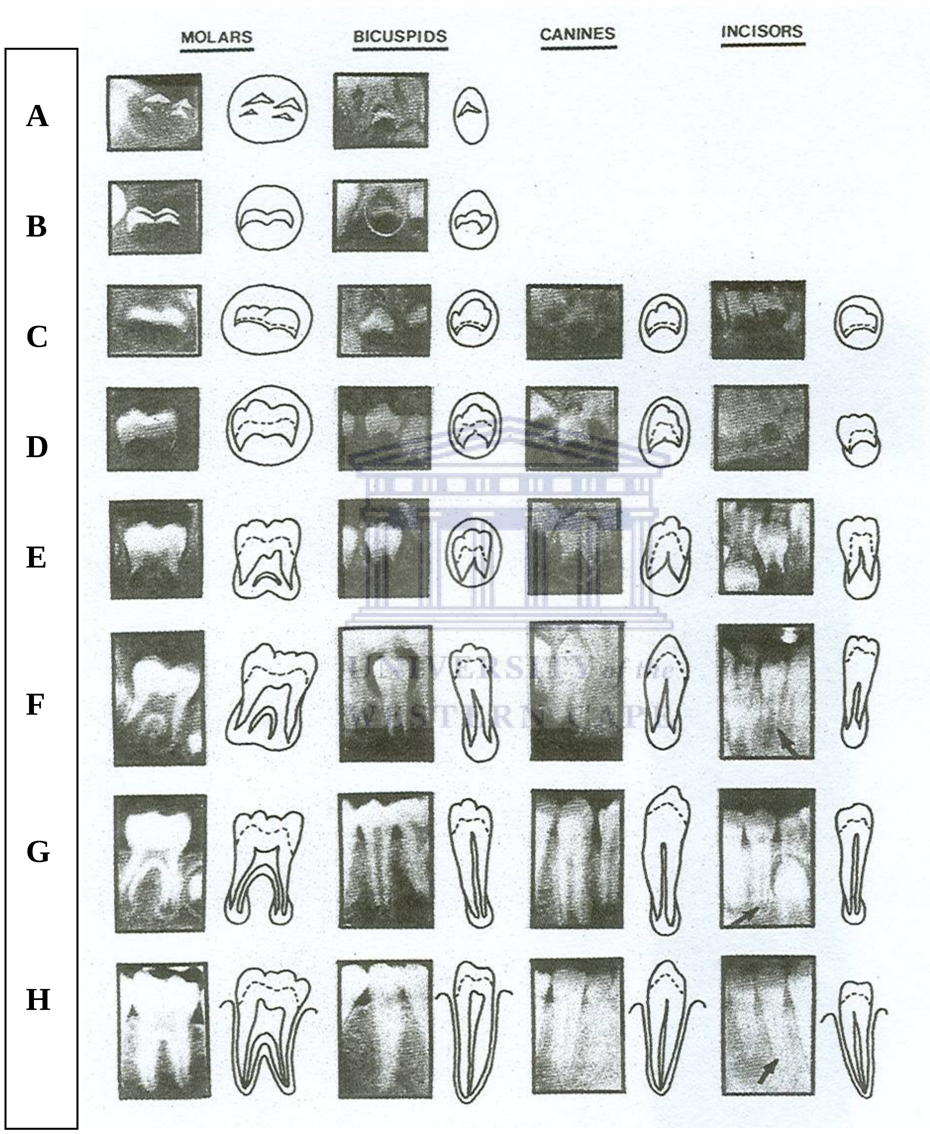


Fig. 3. Stages of permanent tooth formation redrawn from Moorrees et al. (1963a). This scale represents a detailed division of stages and the system has been widely used. The 14 stages are shown here with their standard abbreviations. Capitals: C = cusps; Cr = crown; R = root; Cl = cleft; A = apex; subscripts: i = initiated; co = coalescence; oc = outline complete; c = complete. It is best to designate these stages by abbreviation rather than number because the system is often modified by interpolating in additional stages, or omitting others (e.g., Anderson et al., 1976; Haavikko, 1970; and even Moorrees et al, 1963a).

Table 3: Developmental stages of teeth of Demirjian



Demirjian A, Goldstein H, Tanner JM. (1973).

Table 4: Demirjian *et al* (1973) conversion table for boys

Conversion of Maturity Score to Dental Age (7 Teeth)

Age	Score	Age	Score	Age	Score	Age	Score
				Boys			
3.0	12.4	7.0	46.7	11.0	92.0	15.0	97.6
.1	12.9	.1	48.3	.1	92.2	.1	97.7
.2	13.5	.2	50.0	.2	92.5	.2	97.8
.3	14.0	.3	52.0	.3	92.7	.3	97.8
.4	14.5	.4	54.3	.4	92.9	.4	97.9
.5	15.0	.5	56.8	.5	93.1	.5	98.0
.6	15.6	.6	59.6	.6	93.3	.6	98.1
.7	16.2	.7	62.5	.7	93.5	.7	98.2
.8	17.0	.8	66.0	.8	93.7	.8	98.2
.9	17.6	.9	69.0	.9	93.9	.9	98.3
4.0	18.2	8.0	71.6	12.0	94.0	16.0	98.4
.1	18.9	.1	73.5	.1	94.2		
.2	19.7	.2	75.1	.2	94.4		
.3	20.4	.3	76.4	.3	94.5		
.4	21.0	.4	77.7	.4	94.6		
.5	21.7	.5	79.0	.5	94.8		
.6	22.4	.6	80.2	.6	95.0		
.7	23.1	.7	81.2	.7	95.1		
.8	23.8	.8	82.0	.8	95.2		
.9	24.6	.9	82.8	.9	95.4		
5.0	25.4	9.0	83.6	13.0	95.6		
.1	26.2	.1	84.3	.1	95.7		
.2	27.0	.2	85.0	.2	95.8		
.3	27.8	.3	85.6	.3	95.9		
.4	28.6	.4	86.2	.4	96.0		
.5	29.5	.5	86.7	.5	96.1		
.6	30.3	.6	87.2	.6	96.2		
.7	31.1	.7	87.7	.7	96.3		
.8	31.8	.8	88.2	.8	96.4		
.9	32.6	.9	88.6	.9	96.5		
6.0	33.6	10.0	89.0	14.0	96.6		
.1	34.7	.1	89.3	.1	96.7		
.2	35.8	.2	89.7	.2	96.8		
.3	36.9	.3	90.0	.3	96.9		
.4	38.0	.4	90.3	.4	97.0		
.5	39.2	.5	90.6	.5	97.1		
.6	40.6	.6	91.0	.6	97.2		
.7	42.0	.7	91.3	.7	97.3		
.8	43.6	.8	91.6	.8	97.4		
.9	45.1	.9	91.8	.9	97.5		

Table 5: Demirjian *et al* (1973) conversion table for girls

Conversion of Maturity Score to Dental Age 7 Teeth (Mandibular Left Side)

Age	Score	Age	Score	Age	Score	Age	Score
				Girls			
3.0	13.7	7.0	51.0	11.0	94.5	15.0	99.2
.1	14.4	.1	52.9	.1	94.7	.1	99.3
.2	15.1	.2	55.5	.2	94.9	.2	99.4
.3	15.8	.3	57.8	.3	95.1	.3	99.4
.4	16.6	.4	61.0	.4	95.3	.4	99.5
.5	17.3	.5	65.0	.5	95.4	.5	99.6
.6	18.0	.6	68.0	.6	95.6	.6	99.6
.7	18.8	.7	71.8	.7	95.8	.7	99.7
.8	19.5	.8	75.0	.8	96.0	.8	99.8
.9	20.3	.9	77.0	.9	96.2	.9	99.9
4.0	21.0	8.0	78.8	12.0	96.3	16.0	100.0
.1	21.8	.1	80.2	.1	96.4		
.2	22.5	.2	81.2	.2	96.5		
.3	23.2	.3	82.2	.3	96.6		
.4	24.0	.4	83.1	.4	96.7		
.5	24.8	.5	84.0	.5	96.8		
.6	25.6	.6	84.8	.6	96.9		
.7	26.4	.7	85.3	.7	97.0		
.8	27.2	.8	86.1	.8	97.1		
.9	28.0	.9	86.7	.9	97.2		
5.0	28.9	9.0	87.2	13.0	97.3		
.1	29.7	.1	87.8	.1	97.4		
.2	30.5	.2	88.3	.2	97.5		
.3	31.3	.3	88.8	.3	97.6		
.4	32.1	.4	89.3	.4	97.7		
.5	33.0	.5	89.8	.5	97.8		
.6	34.0	.6	90.2	.6	98.0		
.7	35.0	.7	90.7	.7	98.1		
.8	36.0	.8	91.1	.8	98.2		
.9	37.0	.9	91.4	.9	98.3		
6.0	38.0	10.0	91.8	14.0	98.3		
.1	39.1	.1	92.1	.1	98.4		
.2	40.2	.2	92.3	.2	98.5		
.3	41.3	.3	92.6	.3	98.6		
.4	42.5	.4	92.9	.4	98.7		
.5	43.9	.5	93.2	.5	98.8		
.6	45.2	.6	93.5	.6	98.9		
.7	46.7	.7	93.7	.7	99.0		
.8	48.0	.8	94.0	.8	99.1		
.9	49.5	.9	94.2	.9	99.1		

Table 6: Self weighted scores for dental stages for 7 teeth (Mandibular left side) Demirjian *et al* (1973)

Boys

Tooth	Stage 0	A	B	C	D	E	F	G	H
M_2	0.0	2.1	3.5	5.9	10.1	12.5	13.2	13.6	15.4
M_1				0.0	8.0	9.6	12.3	17.0	19.3
PM_2	0.0	1.7	3.1	5.4	9.7	12.0	12.8	13.2	14.4
PM_1			0.0	3.4	7.0	11.0	12.3	12.7	13.5
C				0.0	3.5	7.9	10.0	11.0	11.9
I_2				0.0	3.2	5.2	7.8	11.7	13.7
I_1					0.0	1.9	4.1	8.2	11.8

Girls

Tooth	Stage 0	A	B	C	D	E	F	G	H
M_2	0.0	2.7	3.9	6.9	11.1	13.5	14.2	14.5	15.6
M_1				0.0	4.5	6.2	9.0	14.0	16.2
PM_2	0.0	1.8	3.4	6.5	10.6	12.7	13.5	13.8	14.6
PM_1			0.0	3.7	7.5	11.8	13.1	13.4	14.1
C				0.0	3.8	7.3	10.3	11.6	12.4
I_2				0.0	3.2	5.6	8.0	12.2	14.2
I_1					0.0	2.4	5.1	9.3	12.9

NB: Stage 0 is no calcification

Table 7: Comparison Table of Tooth Developmental Stages to Demirjian's A to H Stages

Molar		Premolar		Canine		Incisor	
	Demirjian		Demirjian		Demirjian		Demirjian
Ci	**A**	Ci	**A**				
Coc	**B**	Coc	**B**				
Cr1/2	**C**	Cr1/2	**C**	Cr1/2	**C**	Cr1/2	**C**
Crc	**D**	Crc	**D**	Crc	**D**	Crc	**D**
Ri	**D**	Ri	**D**	Ri	**D**	Ri	**D**
Cli	**D**						
R1/4	**E**	R1/4	**E**	R1/4	**E**	R1/4	**E**
R1/2	**F**	R1/2	**F**	R1/2	**F**	R1/2	**F**
R3/4	**G**	R3/4	**G**	R3/4	**G**	R3/4	**G**
Rc	**G**	Rc	**G**	Rc	**G**	Rc	**G**
A1/2	**H**	A1/2	**H**	A1/2	**H**	A1/2	**H**
Ac	**H**	Ac	**H**	Ac	**H**	Ac	**H**

Table 7 shows the equivalent Demirjian, Goldstein and Tanner (1973) stages (A to H) compared to the stages of Moorrees, Fanning and Hunt (1963). The Cli (Cleft initiation) stage pertains only to molars.

Table 8: Age related tables for males indicating the mean and two standard deviations for each stage of tooth development by Moorrees *et al* (1963)

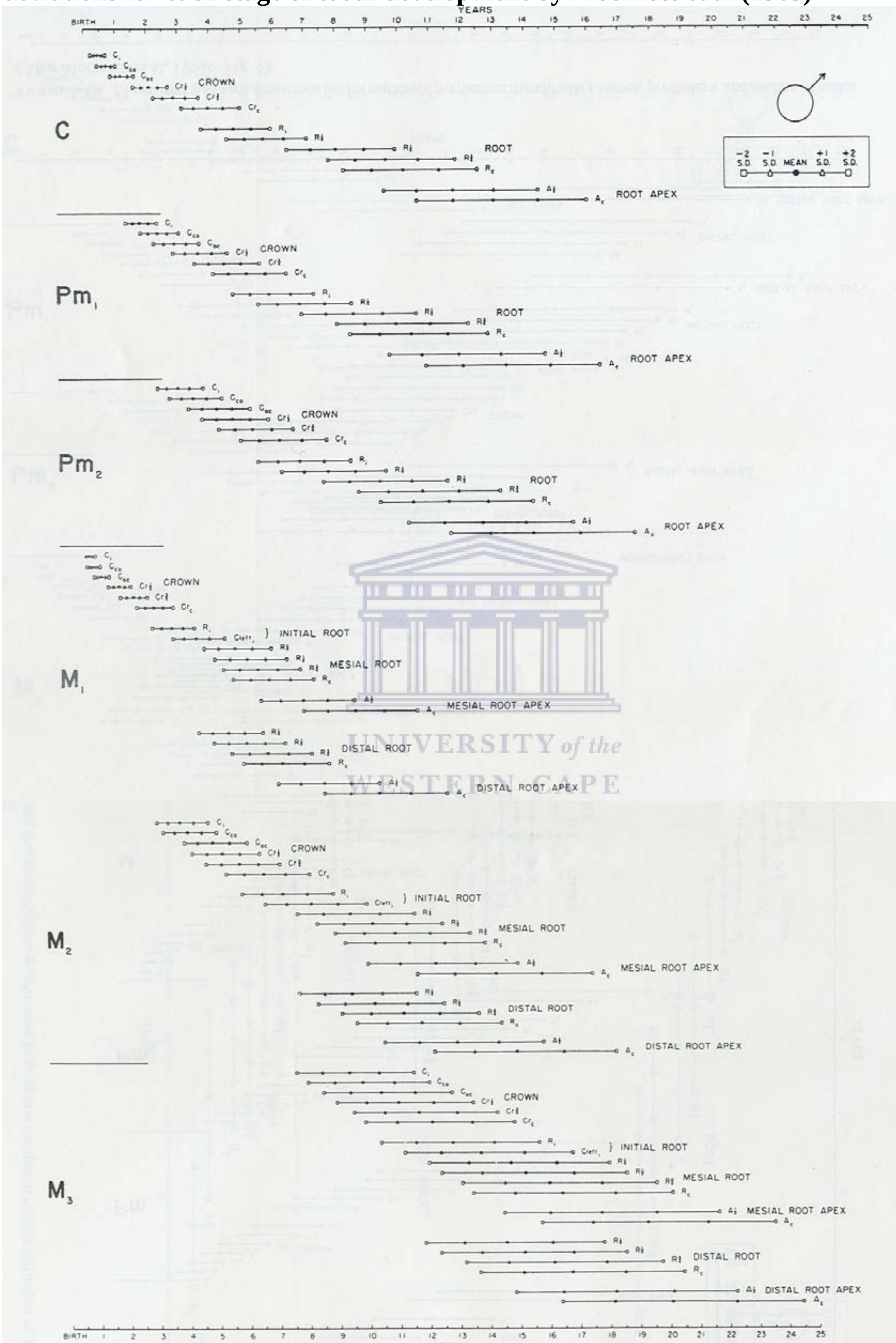
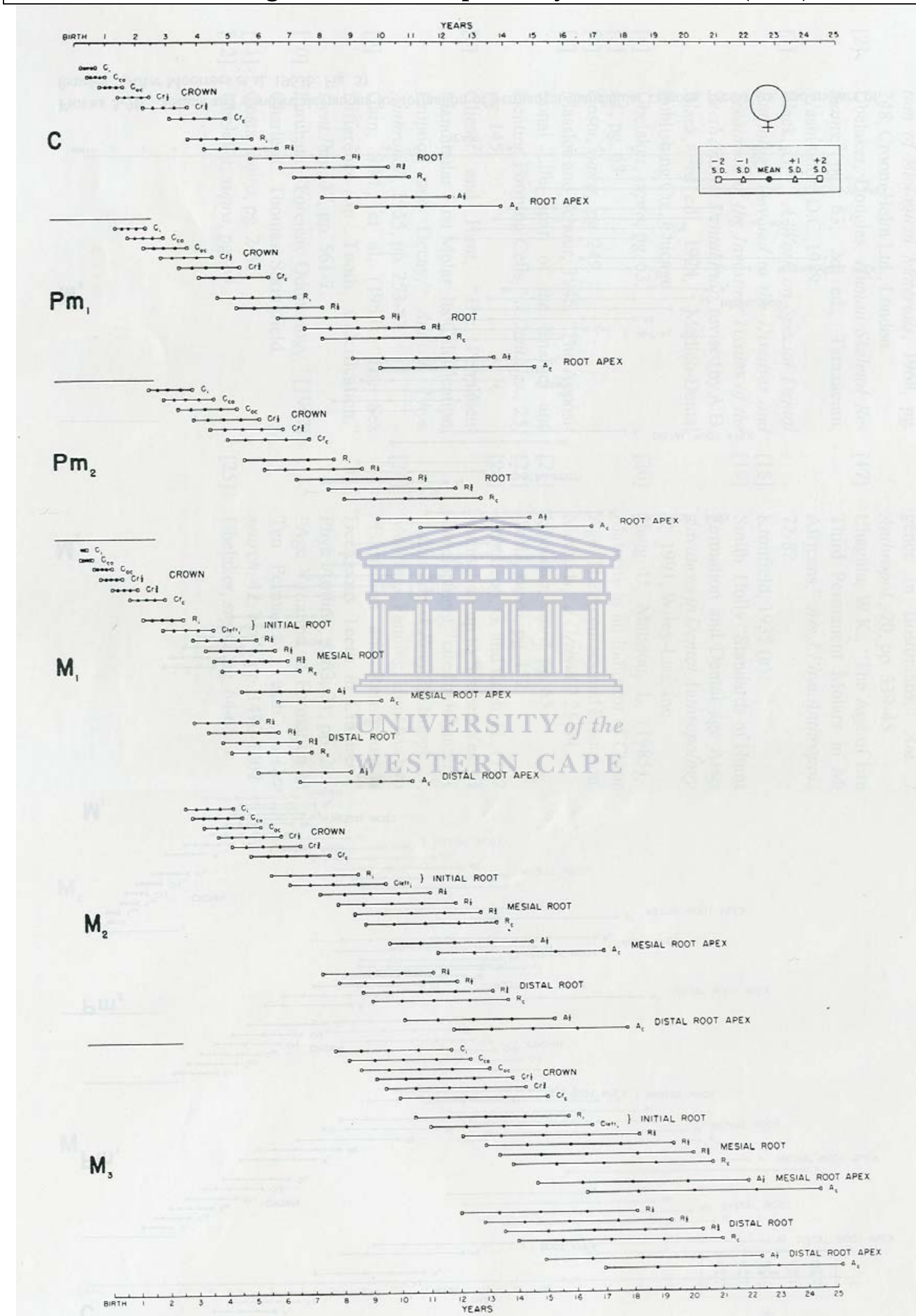


Table 9: Age related tables for females indicating the mean and two standard deviations for each stage of tooth development by Moorrees *et al* (1963)



3.1 AGE OF ATTAINMENT OF DEVELOPMENTAL STAGES

Tables 12 and 13 present the age of attainment chronologies for stages of tooth development for males and females as published by Smith (1991). In each case the mean age of attainment has been derived from the graphic charts of Moorrees, Fanning and Hunt (1963) (Tables 8 & 9). This work indicates the variances for each stage of tooth development of all the teeth of one jaw quadrant. These tables show the age at which the transition from one stage into the next developmental stage occurs. The standard abbreviation of developmental stages of teeth is shown in Table 10 and the tooth notations for each quadrant in Table 11.

3.2 AGE PREDICTION

In contrast, Tables 14 and 15 were designed by Smith (1991) for age prediction based on the stage of tooth development using the work of Moorrees, Fanning and Hunt (1963). These tables are appropriate at predicting the age of the individual by the developmental stages of the teeth. These tables contain the same data as Tables 12 and 13 above, but the data have been reworked to show the following; the age opposite a stage represents the midpoint between age of appearance of that stage and the next stage. To assign a dental age, each tooth is assessed independently, and the mean of all available ages is assigned as the dental age. One key difference between the two types of tables can be noted in the last lines, i.e. the 'apex completed' (Ac) stage. An age can be shown for this terminal stage in Tables 12 and 13, however the (Ac) stage in Tables 14 and 15 reflects that the subject has passed this maturity stage by an unknown amount of time. The system has some limitations as it lacks data for early stages of incisor development and is limited to mandibular teeth. Moorrees, Fanning and Hunt (1963) give some data for maxillary incisors, but data for maxillary teeth are rare in all studies.

Table 10: The standard abbreviation of developmental stages of teeth

Ci	Cusp initiation
Cco	Cusp coalescence
Coc	Cusp outline complete
Cr½	Crown half formed
Cr¾	Crown three quarters formed
Crc	Crown completely formed
Ri	Root initiation
Cli(Rcl)	Cleft initiation (molars only)
R¼	Root one quarter formed
R½	Root half formed
R¾	Root three quarters formed
Rc	Root complete
A½	Apex one half complete
Ac	Apex complete

Table 11 Tooth notation for each quadrant

I1	Central incisor
I2	Lateral incisor
C	Canine
Pm1	1st Premolar
Pm2	2nd Premolar
M1	1st Molar
M2	2nd Molar
M3	3rd Molar

Table 12: Mean age of Development Stages for Males (Smith, 1991) (Permanent Mandibular Teeth)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.5	1.8	3	0	3.7	9.3
Cco			0.7	2.4	3.5	0.2	3.9	9.7
Coc			1.4	2.9	4.2	0.5	4.7	10.4
Cr½			2.1	3.7	4.7	1.1	5.1	10.9
Cr¾			2.9	4.5	5.4	1.6	5.6	11.6
Crc			4	5.2	6.3	2.2	6.5	12
Ri			4.8	5.9	6.9	2.8	7.1	12.8
Rcl						3.6	8	13.7
R¼		5.4	5.7	6.9	7.7	4.6	9.4	14.5
R½	5.3	6.3	8	8.6	9.5	5.2	10.1	15.1
R⅔	5.9	6.9						
R¾	6.5	7.4	9.6	9.9	10.8	5.9	11.1	16.3
Rc	7	8	10.2	10.5	11.6	6.3	11.7	16.7
A½	7.7	8.6	11.8	11.9	12.7	7.6	12.9	18.2
Ac	8.1	9.3	13	13.4	14.3	9.4	14.9	20

Values from Moorrees *et al*. (1963); all stages in years

Table 13: Mean age of Development Stages for Females (Smith, 1991) (Permanent Mandibular Teeth)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.5	1.8	3	0	3.5	9.6
Cco			0.8	2.2	3.6	0.3	3.7	10.1
Coc			1.2	2.9	4.2	0.8	4.2	10.7
Cr½			2	3.6	4.8	1	4.8	11.3
Cr¾			3	4.3	5.4	1.5	5.4	11.7
Crc			4	5.1	6.2	2.2	6.2	12.3
Ri			4.7	5.8	6.8	2.7	7	12.9
Rcl						3.5	7.7	13.5
R¼	4.5	4.7	5.3	6.5	7.5	4.5	9.2	14.8
R½	5.1	5.2	7.1	8.2	8.8	5.1	9.8	15.7
R⅔	5.6	5.9						
R¾	6.1	6.4	8.3	9.2	10	5.7	10.7	16.6
Rc	6.6	7.6	8.9	9.9	10.6	6	11.2	17.2
A½	7.4	8.1	9.9	11.1	12	7	12.5	18.3
Ac	7.7	8.5	11.3	12.2	13.7	8.7	14.6	20.7

Table 14: Values for Predicting Age from Stages of Permanent Mandibular Tooth Formation (Males) (Smith, 1991)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.6	2.1	3.2	0.1	3.8	9.5
Cco			1	2.6	3.9	0.4	4.3	10
Coc			1.7	3.3	4.5	0.8	4.9	10.6
Cr½			2.5	4.1	5	1.3	5.4	11.3
Cr¾			3.4	4.9	5.8	1.9	6.1	11.8
Crc			4.4	5.6	6.6	2.5	6.8	12.4
Ri			5.2	6.4	7.3	3.2	7.6	13.2
Rcl						4.1	8.7	14.1
R¼		5.8	6.9	7.8	8.6	4.9	9.8	14.8
R½	5.6	6.6	8.8	9.3	10.1	5.5	10.6	15.6
R⅔	6.2	7.2						
R¾	6.7	7.7	9.9	10.2	11.2	6.1	11.4	16.4
Rc	7.3	8.3	11	11.2	12.2	7	12.3	17.5
A½	7.9	8.9	12.4	12.7	13.5	8.5	13.9	19.1
Ac								

Values from Moorrees *et al*. (1963); all stages in years

Table 15: Values for Predicting Age from Stages of Permanent Mandibular Tooth Formation for (Females) (Smith, 1991)

Development Stage	I1	I2	C	Pm1	Pm2	M1	M2	M3
Ci			0.6	2	3.3	0.2	3.6	9.9
Cco			1	2.5	3.9	0.5	4	10.4
Coc			1.6	3.2	4.5	0.9	4.5	11
Cr½			2.5	4	5.1	1.3	5.1	11.5
Cr¾			3.5	4.7	5.8	1.8	5.8	12
Crc			4.3	5.4	6.5	2.4	6.6	12.6
Ri			5	6.1	7.2	3.1	7.3	13.2
Rcl						4	8.4	14.1
R¼	4.8	5	6.2	7.4	8.2	4.8	9.5	15.2
R½	5.4	5.6	7.7	8.7	9.4	5.4	10.3	16.2
R⅔	5.9	6.2						
R¾	6.4	7	8.6	9.6	10.3	5.8	11	16.9
Rc	7	7.9	9.4	10.5	11.3	6.5	11.8	17.7
A½	7.5	8.3	10.6	11.6	12.8	7.9	13.5	19.5
Ac								

Values from Moorrees *et al*. (1963); all stages in years

3.3 DENTAL AGE

Dental age conveys the age best associated with a developmental stage in a normal reference population. This can be either an age prediction or a maturity assessment (Gustafson and Koch, 1974). Several studies have investigated the dental age using children of known age and have provided information on some test subjects aged by their systems; these studies claim estimated dental ages to within a few months of the actual ages (Gustafson and Koch, 1974; Crossner and Mansfeld, 1983; Liliequist and Lundberg, 1971).

Crossner and Mansfeld (1983) compared age predictions using the system of Liliequist and Lundberg (1971) with that of Gustafson and Koch (1974) for 44 children adopted into Sweden from countries in Asia and South America. They found that ages from the two systems agreed within two months in 40% of cases and disagreed by 3 – 6 months in 60% of cases. They reported that 70% of the estimates of dental age fell within ± 3 months of the true age, and discrepancies are no more than 6 months in a subset of 23 children with known age (age ranged from 2.5 to 11 years). Smith (1991), however, commented that the degree of accuracy was remarkable considering the extreme heterogeneity of the sample. She also remarked that this study, in which they stated that the system based on Swedish children when used on children from Asia and South America worked just as well, was doubtful and that the system was lacking precision.

A more rigorous test was applied by Hagg and Matsson (1985) in which they compared the methods of Liliequist and Lundberg (1971), Gustafson and Koch (1974) and Demirjian, Goldstein and Tanner (1973) for accuracy in the prediction of age in 150 Swedish children aged 3.5 – 12.5 years. Their results showed that the method of Liliequist and Lundberg (1971) systematically under estimated age and had the lowest overall accuracy. That of Gustafson and Koch (1974) was the most difficult to replicate between examiners and its age estimates were poor for females, but acceptable for males. The maturity scales of Demirjian, Goldstein and Tanner (1973) based on French Canadian children gave the most accurate age predictions. The subject age could be estimated to within 15 to 25 months with 95% confidence.

In juvenile skeletal material, age prediction is often complicated by unknown sex of the individual (Smith, 1991). In these cases it would be appropriate to average the dental age estimates for males and females (Tables 14 & 15). The dental ages in the worst case were found to be inaccurate by 0.1 to 0.5 years. The overall success of age prediction is partly due to the advantage gained by averaging the age estimation using several teeth and not a single tooth.

Davis and Hagg (1994) tested the Demirjian method on Chinese children between the ages of 5 to 7 years and found that there was an error between the estimated age and the chronological age of 11months in boys and 7 months in girls. The 95% confidence level interval was approximately ± 15 months for both sexes.

In a study by Farah, Booth and Knott (1999) of Australian children they found the Demirjian method to be accurate, but suggested however that the accuracy could vary in different population groups. A study by Willems *et al* (2001) found that the method of Demirjian over-estimated the chronological age of Belgian children by 0.5 years for boys and 0.6 years for girls. By performing a weighted ANOVA they adapted their scoring system for this population group. This resulted in age scores expressed in years that were more accurate for these children (Tables 17 & 18).

In a modified Demirjian method where a cubic regression model was derived and used to compare the dental maturity rate of Swedish and Korean children, Tievens and Mornstad

(2001) found that the tooth development in Swedish boys was 2 months ahead and the girls 6 months ahead of their Korean counterparts.

Chaillet, Nylstrom and Demirjian (2005) tested the Demirjian method on several ethnic groups and found the method to be efficient with a standard deviation of 2.15 years. They also found that Australian children have the fastest dental maturation rate and the Koreans the slowest.

A subsequent study by Maber, Liversidge and Hector (2006) of the ages of a sample of Bangladeshi and British White children was recently undertaken in which the pantomographic radiographs of each child were used to estimate the age using the individual methods of Demirjian, Nolla, Haavikko and Willems with varying success (Table 16). They found that the Willems adjusted data of the Demirjian's method was the most accurate method of age estimation for this group of children (Table 16). The Willems *et al* method calculates the age of the individual by the sum of the scores for each tooth in the left mandible excluding the 3rd molar.

Recently Rózylo-Kalinowska, Kiworkowa-Raczkowska and Kalinowski (2007) tested the Demirjian method on a Polish group of 994 children between the ages of 6 and 16 and found that the developmental standards set by Demirjian, Goldstein and Tanner (1973) were not suitable for the Polish children.

Table 16: Mean accuracy (in years) for each method for children aged 3.00-16.99 years by Maber, Liversidge and Hector (2006)

	Sex	N	Mean	S.E.	S.D.
D	Boys	491	0.25	0.04	0.84
	Girls	455	0.23	0.04	0.84
	Both	946	0.24	0.03	0.86
W	Boys	491	-0.05	0.04	0.81
	Girls	455	-0.20	0.04	0.89
	Both	945	-0.12	0.04	0.85
N	Boys	491	-0.87	0.04	0.87
	Girls	455	-1.18	0.05	0.96
	Both	946	-1.02	0.03	0.93
H	Boys	437	-0.56	0.04	0.91
	Girls	395	-0.79	0.06	1.11
	Both	832	-0.67	0.04	1.01
H < 14	Boys	392	-0.39	0.04	0.77
	Girls	357	-0.57	0.05	0.87
	Both	749	-0.47	0.03	0.82

D: Demirjian, **W**: Willems, **N**: Nolla, **H**: Haavikko; **H** <**14**: Haavikko age less than 14 years; SE: standard error, SD: standard deviation. (Maber *et al*. 2006)

TABLE 17:
Developmental tooth stages according to Demirjian's technique with corresponding age scores expressed directly in years for 7 left mandibular teeth; Boys (Willems *et al*, 2001)

Stage **Tooth**	A	B	C	D	E	F	G	H
Central Incisor			1.68	1.49	1.5	1.86	2.07	2.19
Lateral Incisor			0.55	0.63	0.74	1.08	1.32	1.64
Canine				0.04	0.31	0.47	1.09	1.9
First bicuspid	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
Second Bicuspid	0.08	0.05	0.12	0.27	0.33	0.45	0.4	1.15
First Molar				0.69	1.14	1.6	1.95	2.15
Second Molar	0.18	0.48	0.71	0.8	1.31	2	2.48	4.17

TABLE 18:
Developmental tooth stages according to Demirjian's technique with corresponding age scores expressed directly in years for 7 left mandibular teeth; Girls (Willems *et al*, 2001)

Stage **Tooth**	A	B	C	D	E	F	G	H
Central Incisor			1.83	2.19	2.34	2.82	3.19	3.14
Lateral Incisor				0.29	0.32	0.49	0.79	0.7
Canine			0.6	0.54	0.62	1.08	1.72	2
First bicuspid	-0.95	-0.15	0.16	0.41	0.6	1.27	1.58	2.19
Second Bicuspid	-0.19	0.01	0.27	0.17	0.35	0.35	0.55	1.51
First Molar				0.62	0.9	1.56	1.82	2.21
Second Molar	0.14	0.21	0.21	0.32	0.66	1.28	2.09	4.04

CONCLUSION

The tables of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) are useful when comparing dental maturation with skeletal development in White children, but it has been shown that these methods vary in accuracy when used on different population or ethnic groups when trying to estimate the chronological age of a child. The method derived by Demirjian, Goldstein and Tanner (1973) has been used extensively, but was found only to be relatively accurate in European child populations.

Willems *et al* (2001) tested the Demirjian method on Belgian children and found that it over estimated the ages of their child sample. Similarly Davis and Hagg (1994) were unsuccessful with this method in Chinese children.

The process of identification of skeletal remains is complicated by the fact that it is not easy to establish whether a skeleton of a juvenile is either male or female and often it is impossible to accord racial traits. It therefore follows that the age estimation charts of Moorrees *et al* and Demirjian *et al* are questionable if used on South African children.

This has thus led to the conclusion that these tables that were derived from American (Moorrees, Fanning and Hunt, 1963) and French-Canadian children (Demirjian, Goldstein and Tanner, 1973) may not be applicable for other population groups and need to be tested on samples of South African children.

CHAPTER 4

THE DEVELOPMENT OF DENTAL AGE RELATED TABLES FOR SOUTH AFRICAN CHILDREN

Dental age related tables for permanent teeth by Schour & Massler (1941), Moorrees, Fanning and Hunt [MFH] (1963), Gustafson & Koch (1971) and Demirjian, Goldstein & Tanner [DGT] (1973) have been used by forensic scientists for estimating the chronological ages of juvenile skeletal remains with varying success. The tables of Moorrees, Fanning and Hunt (1963), that utilized developmental stages for the adult canine to the 3rd molar, were routinely used for comparing juvenile dental development with skeletal maturity. The accuracy of the MFH tables was questioned by Smith (1991) who reworked the data and thereby produced tables that predicted the average dental age of juvenile males and females. It became evident that the accuracy of the MFH tables was not always applicable to other population groups and the standard deviations of each stage were too vague to be of use for age estimation. Demirjian, Goldstein and Tanner (1973) devised a method of dental age estimation by weighting the tooth developmental stages of 7 of the mandibular teeth and deriving a conversion table that related the combined weighting to the chronological age for males and females. In the research of MFH (1963) they studied the development of the permanent canine, premolars and the 3 molars; that of DGT (1973) included the incisors, but excluded the 3rd molar. The DGT (1973) method has been used by several authors with varying success and has resulted in publications debating its accuracy on different population groups in Europe, Asia and Australia (Davis and Hagg, 1994; Tievens and Mornstad, 2001; Willems *et al* 2001; Maber, Liversidge and Hector; 2006). A study undertaken on Indian children in south India by Koshy and Tandon (1998) utilized the DGT method to estimate the chronological age. They found that this method was not applicable and gave an overestimation of the age by 3.04 and 2.82 years in males and females respectively.

In a study of White and Black children by Chertkow (1980) using the ossification of the hand and wrist bones compared to the calcification of the teeth, he found that the stage of calcification of the mandibular canine was a possible indicator of the growth spurt in white children during puberty. Black children in comparison to White were found to be slightly ahead in their calcification of the canines.

The use of both of the MFH (1963) and DGT (1973) tables by the author (VMP) to estimate ages of skeletal remains of children and juveniles in South Africa was disappointingly inaccurate. It was therefore deemed necessary to derive dental age related tables for South African children. This investigation of South African children included the stages of development of all 8 teeth of the left mandible. Both the studies of MFH (1963) and DGT (1973) were of White children; this study, however, took cognisance of the different population origins in our samples of South African children.

The Black and Indian children who attend orthodontic dental practices in Kwa-Zulu Natal are from a similar socio-economic background and are exposed to similar environmental conditions that may have an effect on their skeletal maturation rate. These samples were chosen in conjunction with the Tygerberg sample to have children from different population origins to develop dental age related tables.

There has been no comprehensive published data with regard to age related stages of dental development of South African children and the aim of this study was to develop dental age related tables for South African children of differing population origins.

Materials and methods

The first sample consisted of children treated at the Tygerberg Dental Faculty. These Tygerberg children were of mixed ancestry. Some of the children had both parents of

European origin; the Coloured[1] children had either one European parent or both parents of mixed ethnic origin. This group was designated the Tygerberg sample. Data were obtained from the archival records of 916 children treated at the Tygerberg Dental Hospital from 1975 to 2000 and contained their Pantomographic radiographs. Of this sample 835 Pantomographs were chosen which showed all the teeth and no pathological lesions. The age range was from 3 to 16 years and consisted of 455 females and 380 males.

Pantomographic radiographs of 91 Black (Zulu) children were obtained from a private Orthodontic dental practice in Durban, Kwa-Zulu Natal. This sample contained 47 males and 44 females with an age range of 7 to 16 years. A third sample of 157 Indian children was obtained from 2 Orthodontic dental practices in Durban. The age range was from 6-16 years and there were 82 females and 75 males.

The Pantomographic images were used to visualize the stages of development of the teeth in the left mandible. Each individual developmental stage for the incisors, canines, premolars and molars was recorded for each child and correlated to their chronological age. The chronological age was obtained by subtracting the date of birth from the date on which the radiograph was taken.

Pivot tables were constructed to correlate the chronological age with the mean age at which the various development stages of the crown and root of each tooth took place for both males and females. Graphic representation of the developmental stages of each tooth was derived for both sexes.

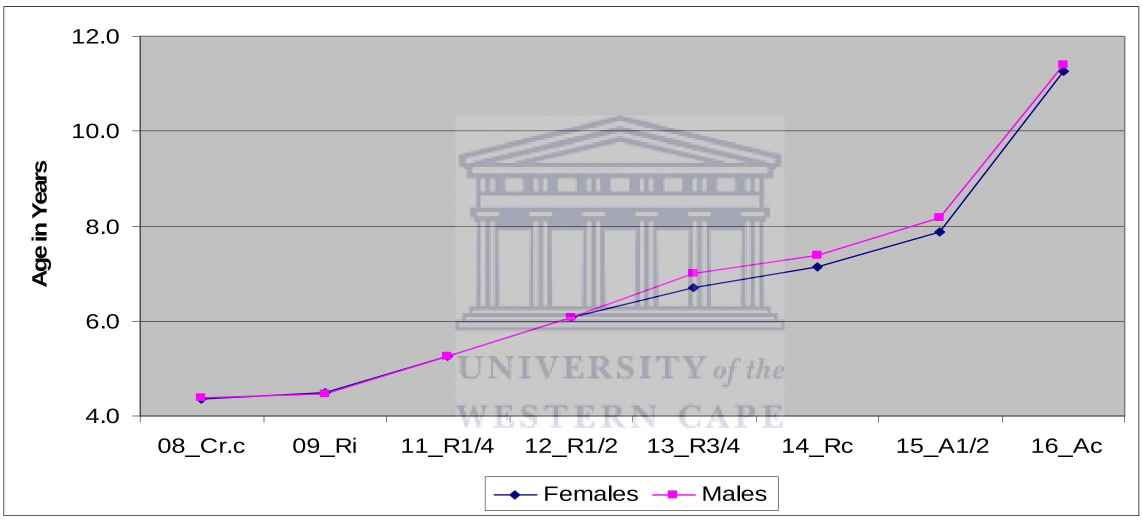
[1] **Coloured people of South Africa.** The Coloured people were descended largely from Cape slaves, the indigenous Khoisan population, and other black people who had been assimilated to Cape colonial society by the late nineteenth century. Since they are also partly descended from European settlers, Coloureds are popularly regarded as being of “mixed race” although the amount of admixture from the parental populations is highly variable (Adhikari, 2006).

Dental age related tables for each of the samples (Tygerberg, Black and Indian) were constructed including the standard deviation for each developmental stage.

Results

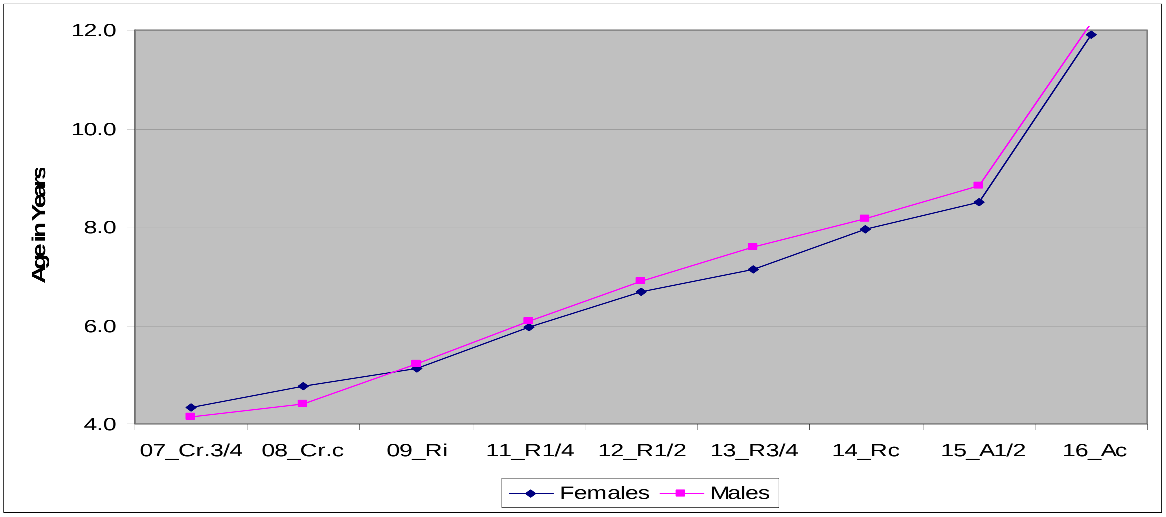
1. **The Tygerberg Sample:** The dental age estimation graphs of the Tygerberg sample of males and females are depicted below and show the mean age at which calcification occurs for each developmental stage of the individual left eight permanent mandibular teeth for males and females.

Graph 1: Tygerberg sample. The age related stages of the Central Incisor (I1) for males and females



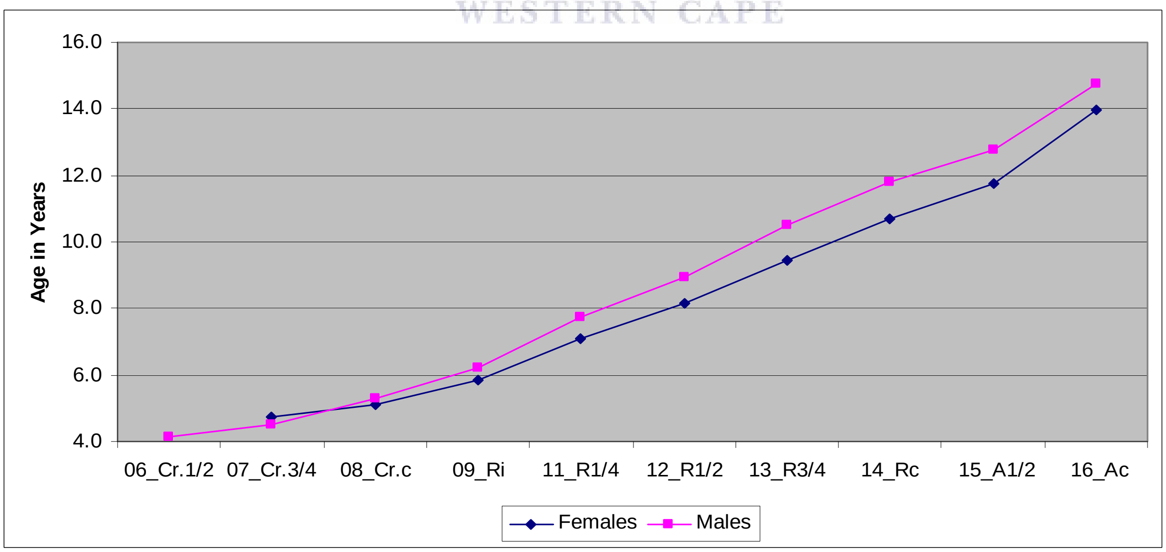
Central mandibular incisor (I1) There is no difference in the development of the I1 between boys and girls until the age of 6 years; then the root formation (R¾ to A½) in girls calcifies 3 months earlier than the boys. The apex closes at the age of 11.3 years in girls and 11.4 years in boys.

Graph 2: Tygerberg sample. The age related stages of the Lateral Incisor (I2) for males and females



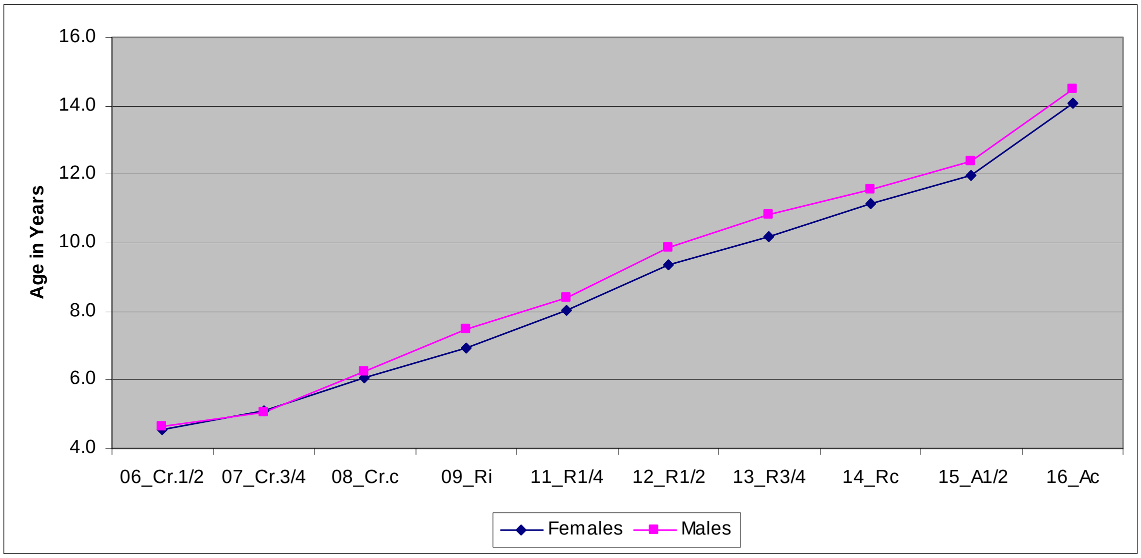
Lateral mandibular incisor (I2). The crown calcification of the I2 occurs slightly earlier in boys initially, but at age 5 years the root formation in girls is approximately 2 months ahead of the boys. The root calcification is ahead by 5 months at the R¾ stage in females. The apices close at 11.9 years in girls and 12.1 years in boys.

Graph 3: Tygerberg sample. The age related stages of the Canine (C) for males and females



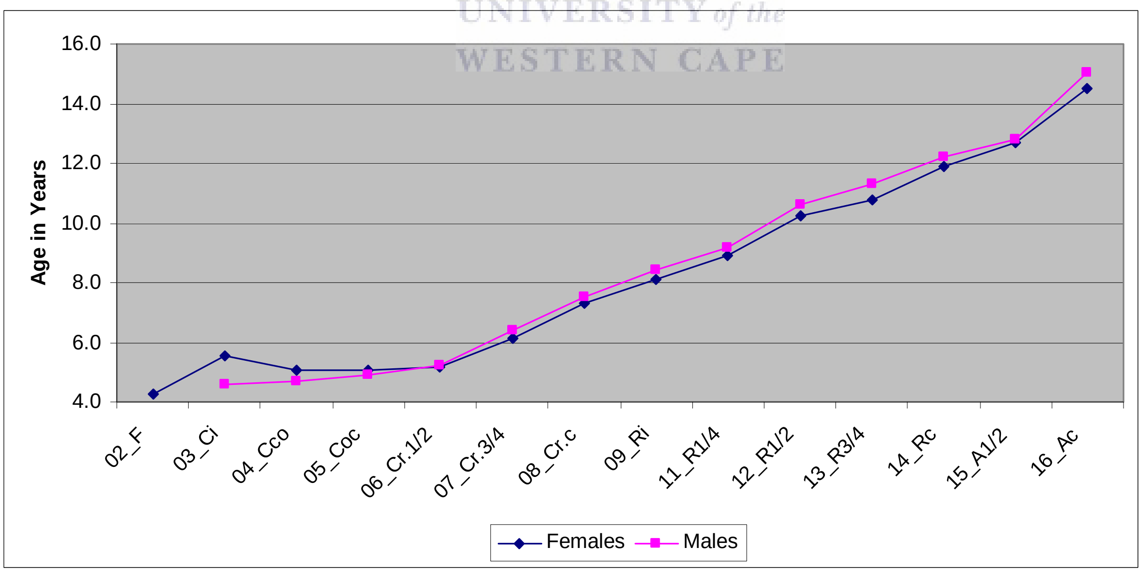
Canine (C): The crown formation in both sexes is even in the early stages up to age 6 years, then the calcification of the roots is earlier in girls from 3 months in the Ri stage to 12 months at the Rc stage (10.7 females:11.8 males). The apex closes at 14 years in girls and 14.7 years in boys.

Graph 4: Tygerberg sample. The age related stages of the 1st Premolar (Pm1) for males and females



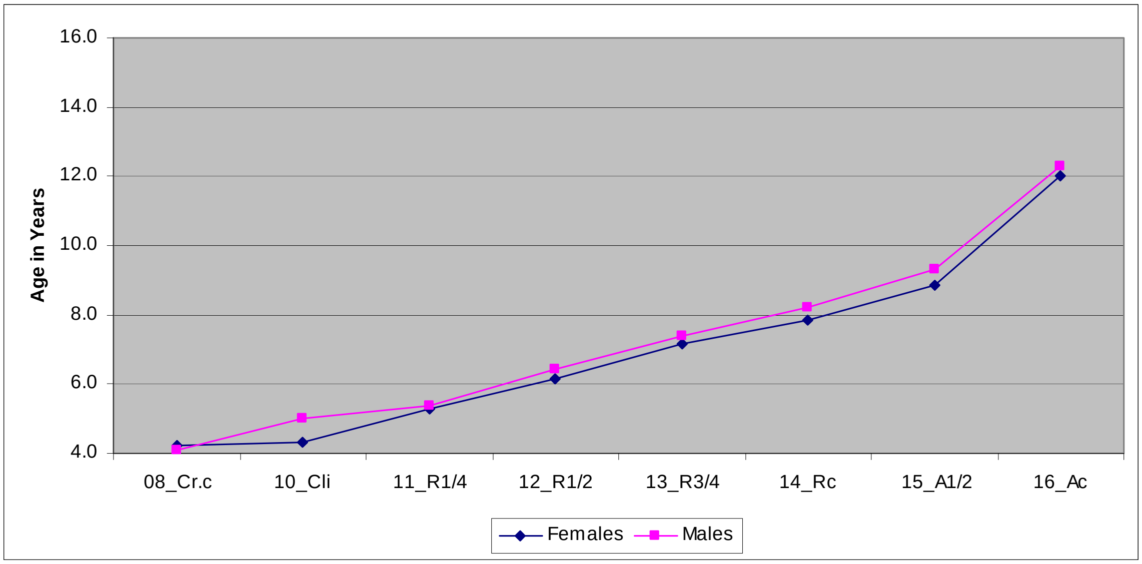
Premolar (Pm1): Initially the crown development is similar until the crown is complete (Crc), then the girls develop faster from 2 months at the (Ri) stage to 6 months at (Rc) stage. The apex closes at 14.1 years in girls and 14.5 years in boys.

Graph 5: Tygerberg sample. The age related stages of the 2nd Premolar (Pm2) for males and females



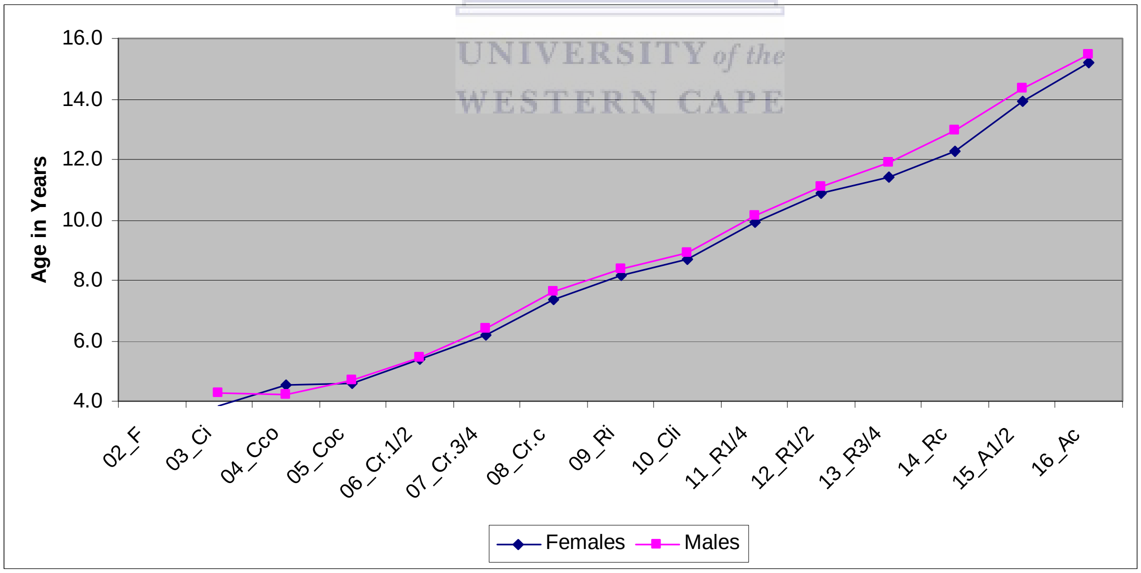
Premolar (Pm2): Initially crown formation (Ci) and calcification is ahead in boys, but the girls start developing more rapidly at the age of 5 years. The root calcification in girls is ahead of the boys by 2 to 3 months until root complete (Rc) stage. The apex closes at 14.5 years in females and 15 years in males.

Graph 6: Tygerberg sample. The age related stages of the 1st Molar (M1) for males and females



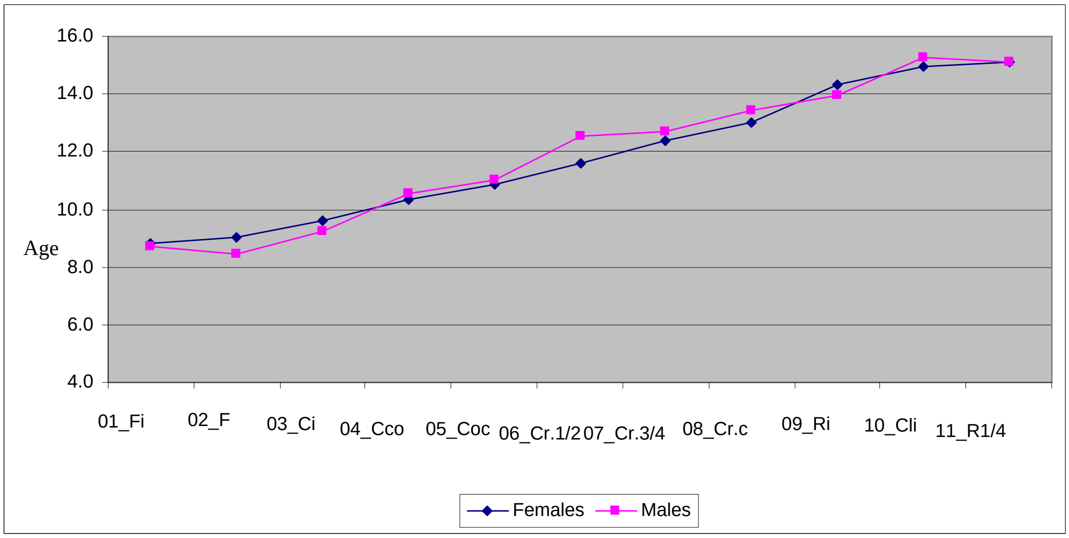
Molar (M1): There is only a 2 to 3 month difference in the development of this tooth between boys and girls; the girls being slightly earlier. The apex closes at 12 years in girls and 12.3 years in boys.

Graph 7: Tygerberg sample. The age related stages of the 2nd Molar (M2) for males and females



Molar (M2): The development of this tooth was monitored from the follicle (F) stage to the closure of the apex (Ac). There is very little difference between the boys and the girls; approximately 2 to 3 months throughout the calcification of both the crown and the root. The girls are marginally ahead in development. The apex closes at 15.2 years in girls and 15.5 years in boys.

Graph 8: Tygerberg sample. The age related stages of the 3rd Molar (M3) for males and females



Molar (M3): Initial follicle development occurs at age 8.8 years. Up to the age of 10 years the calcification of the crown is earlier in boys; then the girls develop more rapidly until the age of 15 years; the difference being no more than 4 months during root formation.

Table 1 The dental age related table for Males from the Tygerberg sample in years (SD)

	I 1	I 2	C	Pm 1	Pm 2	M 1	M 2	M 3
Fi								8.7 (1.30)
F								8.4 (1.52)
Ci					4.6 (0.40)		4.3 (0.12)	9.2 (1.33)
Cco					4.7 (0.67)		4.2 (0.54)	10.6 (1.14)
Coc					4.9 (1.16)		4.7 (0.57)	11 (0.95)
Cr.1/2			4.1 (0.5)	4.6 (0.63)	5.2 (0.71)		5.4 (0.73)	12.5 (1.21)
Cr.3/4		4.1 (0.5)	4.5 (0.60)	5.1 (0.66)	6.4 (0.54)		6.4 (0.78)	12.7 (1.40)
Cr.c	4.4 (0.35)	4.4 (0.52)	5.3 (0.75)	6.3 (0.69)	7.5 (0.84)	4.1 (0.21)	7.6 (1.03)	13.4 (1.55)
Ri	4.5 (0.57)	5.2 (0.58)	6.2 (0.63)	7.5 (1.00)	8.4 (0.95)		8.4 (0.69)	14 (1.63)
Cli						5 (1.17)	8.9 (0.92)	15.2 (0.84)
R1/4	5.3 (0.56)	6.1 (0.64)	7.7 (0.73)	8.4 (0.89)	9.2 (1.13)	5.4 (0.76)	10.1 (0.98)	15.1 (0.83)
R1/2	6.1 (0.57)	6.9 (0.67)	9 (0.98)	9.8 (1.00)	10.6 (0.97)	6.4 (0.45)	11.1 (0.98)	
R3/4	7 (0.57)	7.6 (0.74)	10.5 (1.09)	10.8 (0.81)	11.3 (0.97)	7.4 (0.63)	11.9 (0.77)	
Rc	7.4 (0.58)	8.2 (0.69)	11.8 (0.85)	11.6 (0.74)	12.2 (1.23)	8.2 (0.71)	12.9 (0.96)	
A1/2	8.2 (0.70)	8.8 (0.72)	12.8 (1.00)	12.4 (0.81)	12.8 (1.27)	9.3 (0.85)	14.4 (1.08)	
Ac	11.4 (2.19)	12.1 (1.88)	14.7 (1.25)	14.5 (1.22)	15 (0.99)	12.3 (1.88)	15.5 (0.58)	

I 1 = Central incisor; I 2 = Lateral incisor; C = Canine; Pm 1 = 1st Premolar; Pm 2 = 2nd Premolar; M 1 = 1st Molar; M 2 = 2nd Molar; M 3 = 3rd Molar.

Table 2 The dental age related table for females from the Tygerberg sample in years (SD)

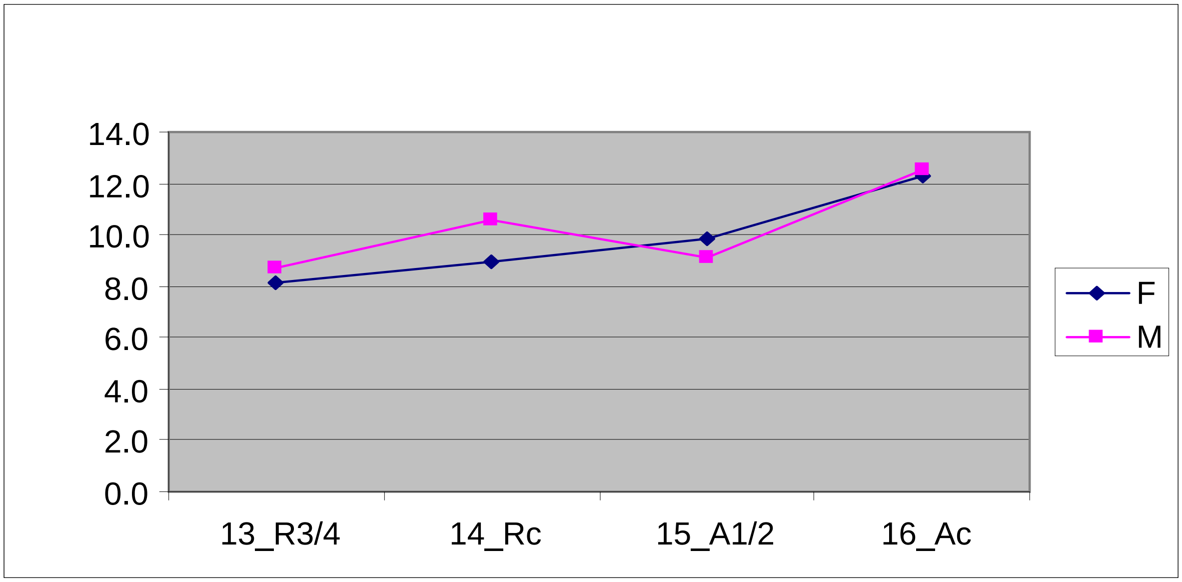
	I 1	I 2	C	Pm 1	Pm 2	M 1	M 2	M 3
Fi								8.8 (1.19)
F					4.3			9 (1.40)
Ci					5.5 (1.69)		3.9 (0.68)	9.6 (1.10)
Cco					5.1 (0.89)		4.6 (0.46)	10.3 (1.44)
Coc					5.1 (0.97)		4.6 (0.27)	10.8 (1.02)
Cr.1/2				4.5 (0.26)	5.2 (0.74)		5.4 (0.84)	11.6 (0.98)
Cr.3/4		4.3 (0.5)	4.7 (0.69)	5.1 (0.72)	6.1 (0.68)		6.2 (0.74)	12.4 (1.40)
Cr.c	4.3 (0.5)	4.8 (0.66)	5.1 (0.88)	6.1 (0.83)	7.3 (0.80)	4.2 (0.08)	7.4 (0.90)	13 (1.09)
Ri	4.5 (0.58)	5.1 (0.75)	5.9 (0.61)	6.9 (0.52)	8.1 (0.83)		8.2 (0.74)	14.3 (1.37)
Cli						4.3 (0.55)	8.7 (0.91)	15 (1.33)
R1/4	5.3 (0.63)	6 (0.56)	7.1 (0.66)	8 (0.82)	8.9 (1.13)	5.3 (0.46)	9.9 (0.90)	15.1 (1.09)
R1/2	6.1 (0.47)	6.7 (0.58)	8.2 (0.97)	9.4 (0.84)	10.2 (1.02)	6.1 (0.51)	10.9 (1.02)	
R3/4	6.7 (0.63)	7.1 (0.53)	9.5 (0.98)	10.2 (1.05)	10.8 (1.18)	7.1 (0.63)	11.4 (0.62)	
Rc	7.1 (0.48)	8 (0.70)	10.7 (1.02)	11.1 (0.85)	11.9).84)	7.9 (0.76)	12.3 (0.87)	
A1/2	7.9 (0.65)	8.5 (0.56)	11.7 (0.74)	11.9 (0.70)	12.7 (1.16)	8.8 (0.69)	13.9 (1.07)	
Ac	11.3 (2.23)	11.9 (1.97)	14 (1.65)	14.1 (1.55)	14.5 (1.35)	12 (1.97)	15.2 (1.22)	

I 1 = Central incisor; I 2 = Lateral incisor; C = Canine; Pm 1 = 1st Premolar; Pm 2 = 2nd Premolar;
M 1 = 1st Molar; M 2 = 2nd Molar; M 3 = 3rd Molar.

From the pivot tables dental age related tables were constructed for males and females (Tables 1 & 2) for the Tygerberg sample. These tables show the mean age at which the stages of crown and root calcification occur. The standard deviations for each age are indicated in parentheses.

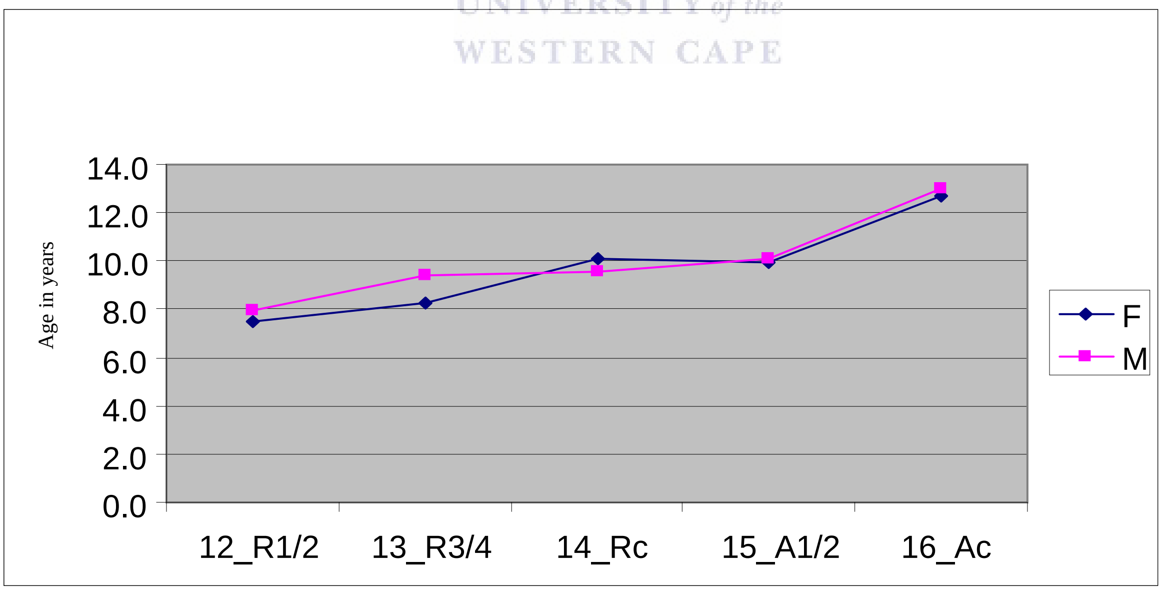
2. The Indian Sample: The dental age estimation graphs of the Indian sample of males and females are depicted below and show the mean age at which calcification occurs for each developmental stage of the eight permanent mandibular teeth.

Graph 9: Indian sample. The age related stages of the Central Incisor (I1) for males and females



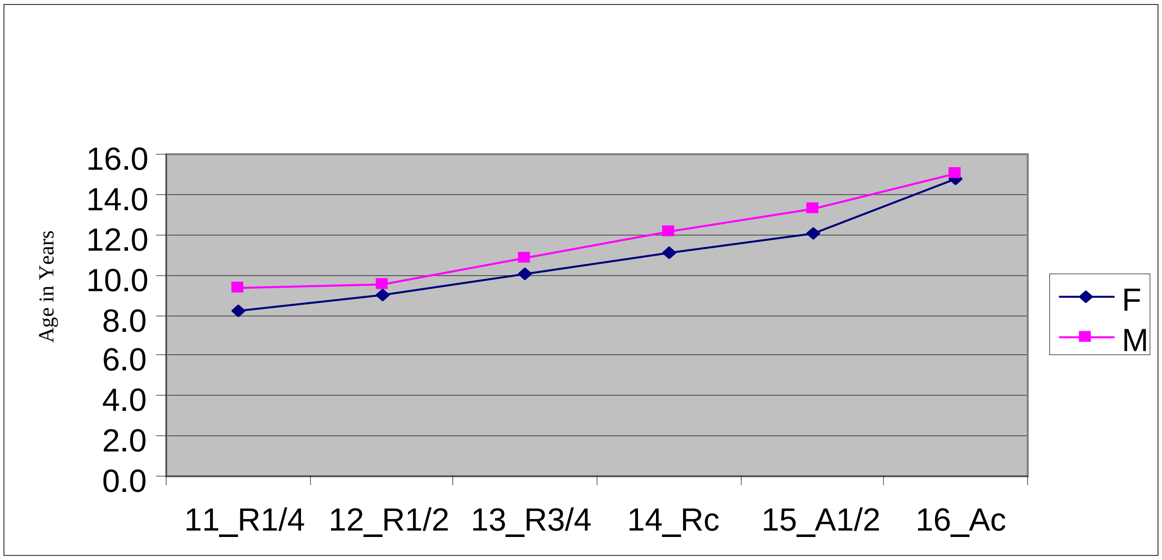
Central mandibular incisor (I1) shows a slightly earlier calcification of the root at R¾ stage in girls, but the completion stage (Rc) is 1.7 years ahead of the boys. The apices close at 12.3 and 12.5 years (F:M).

Graph 10: Indian sample. The age related stages of the Lateral Incisor (I2) for males and females



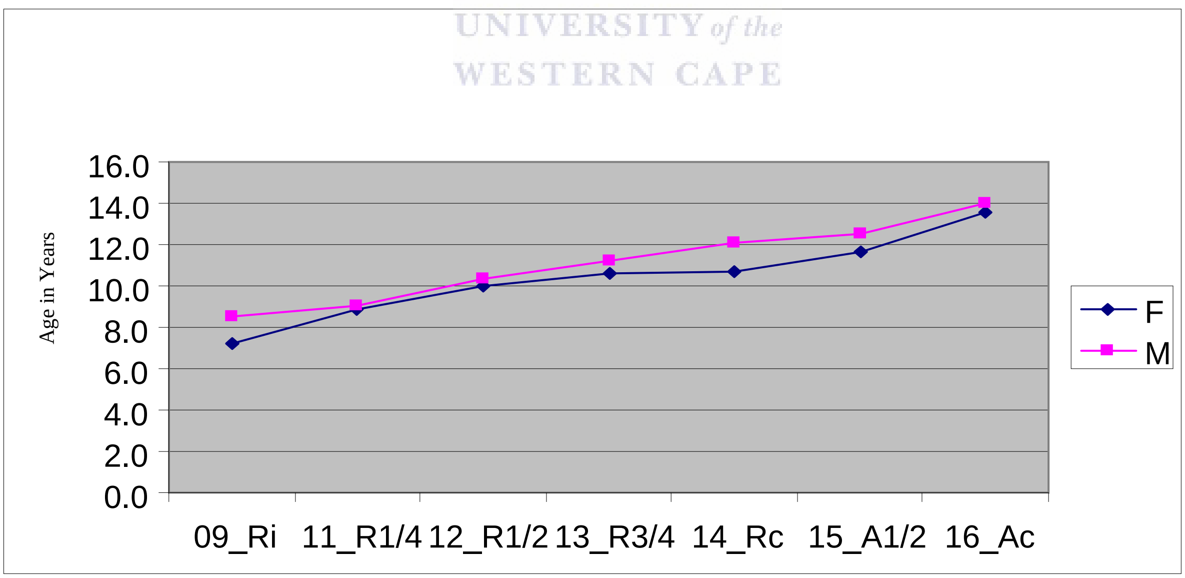
Lateral mandibular incisor (I2) shows the calcification stage R¾ of girls to be 1.1 years ahead of the boys, thereafter there is insignificant difference in the calcification times.

Graph 11: Indian sample. The age related stages of the Canine (C) for males and females



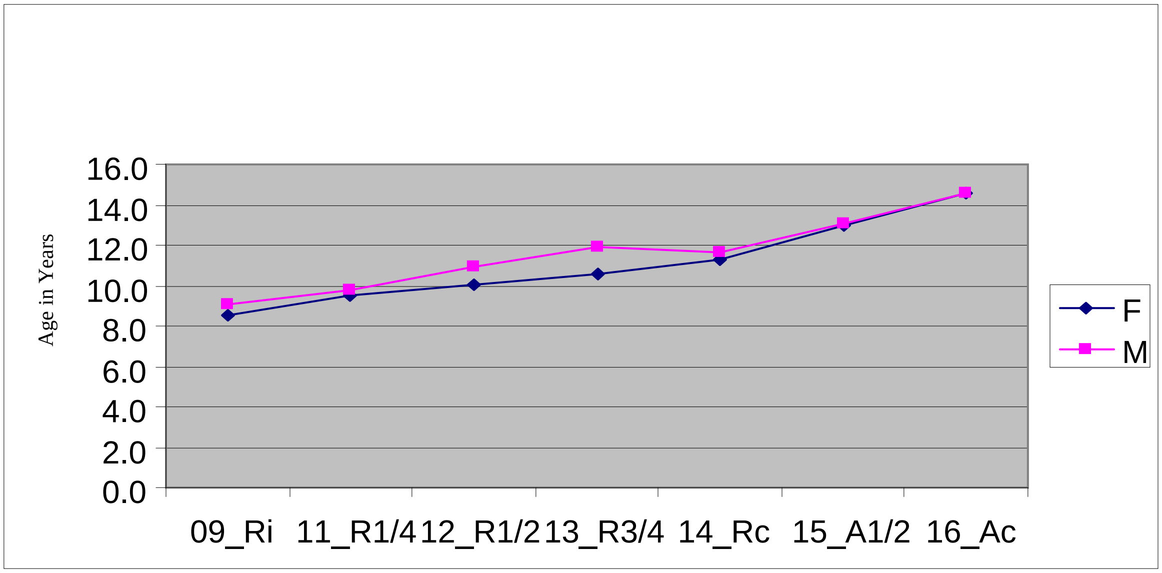
Canine (C): The calcification times for the canines is slower in the boys by approximately 1 year compared to the girls. The apices close at 14.8 and 15 years (F:M).

Graph 12: Indian sample. The age related stages of the 1st Premolar (Pm1) for males and females



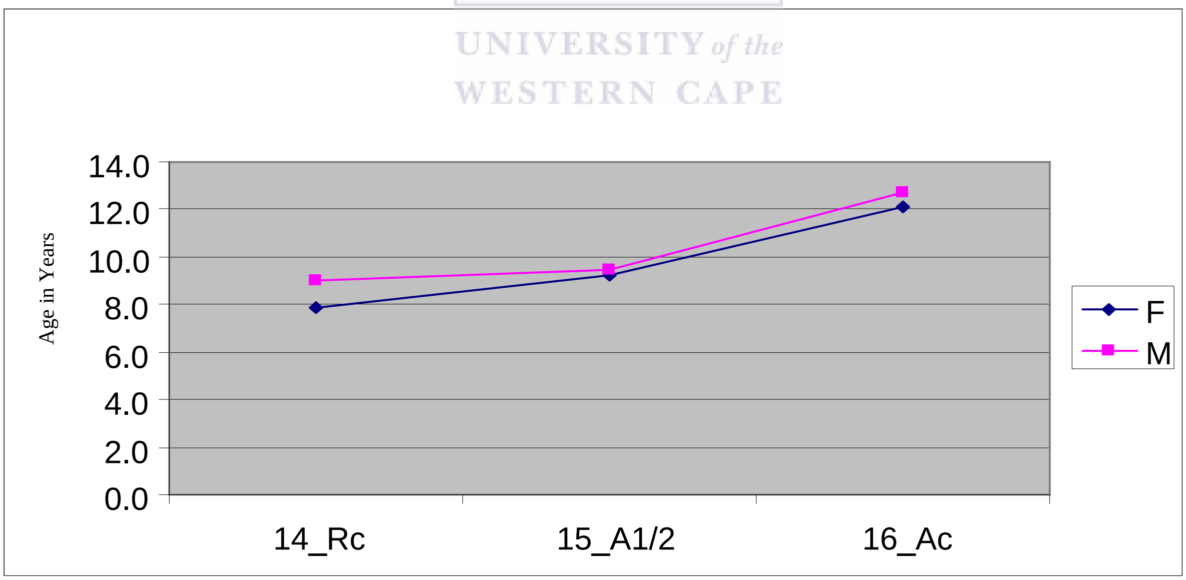
Premolar (Pm1): Initially there is a 6 months difference in the calcification times (R¼ to R¾), but at Rc stage the boys are slower by 1.4 years. The apices close 6 months earlier in girls.

Graph 13: Indian sample. The age related stages of the 2nd Premolar (Pm2) for males and females



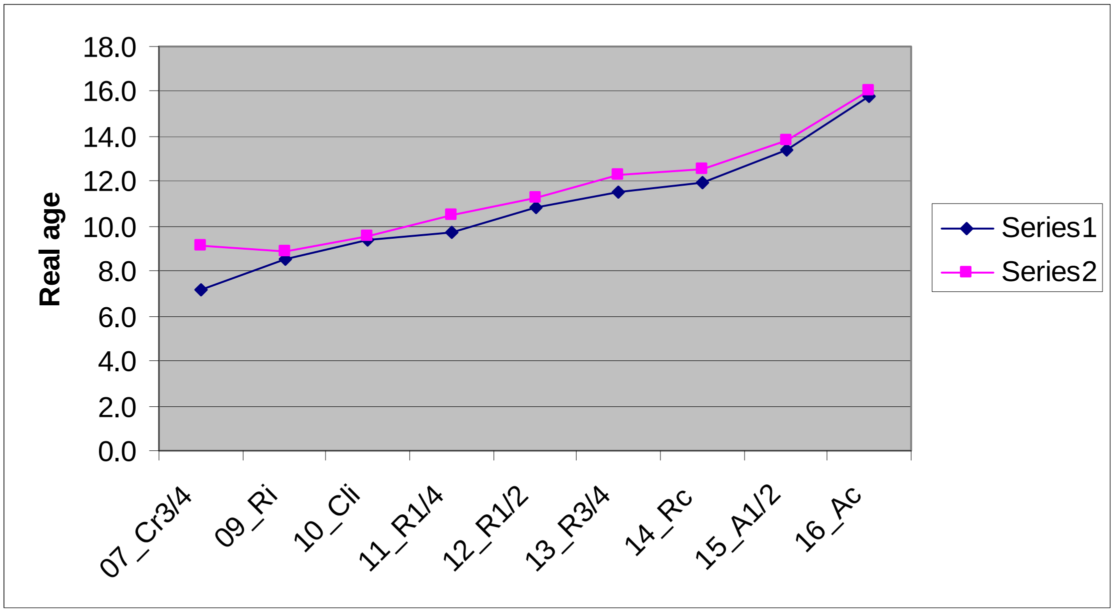
Premolar (Pm2): Initially calcification is 6 months earlier in girls, but at R¾ the girls are 1.4 years earlier. The apices close at 14.5 years.

Graph 14: Indian sample. The age related stages of the 1st Molar (M1) for males and females



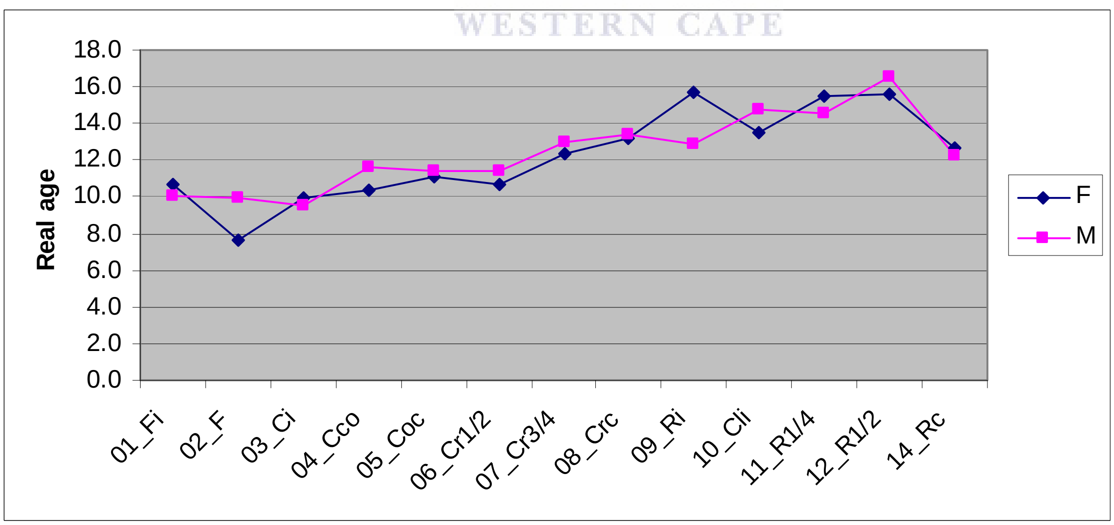
1st Molar (M1): At the Rc stage the girls are 1.1 year ahead of the boys. The apices close at 12.1 and 12.7 years (F:M).

Graph 15: Indian sample. The age related stages of the 2nd Molar (M2) for males and females



2nd Molar (M2): The differences in the calcification times for this tooth was approximately 3 months slower in boys up to the apex closure stage.

Graph 16: Indian sample. The age related stages of the 3rd Molar (M3) for males and females



3rd Molar (M3): At the crown initiation stage calcification is 10 years for both males and females. Thereafter the females are slightly ahead of the males until root initiation / cleft initiation stage where the males are earlier than the females by 2 years (between the ages of 14 and 16 years). By R¼ calcification the females are slightly ahead by 9 months.

Table 3: The dental age related table for the sample of Indian females in years (SD)

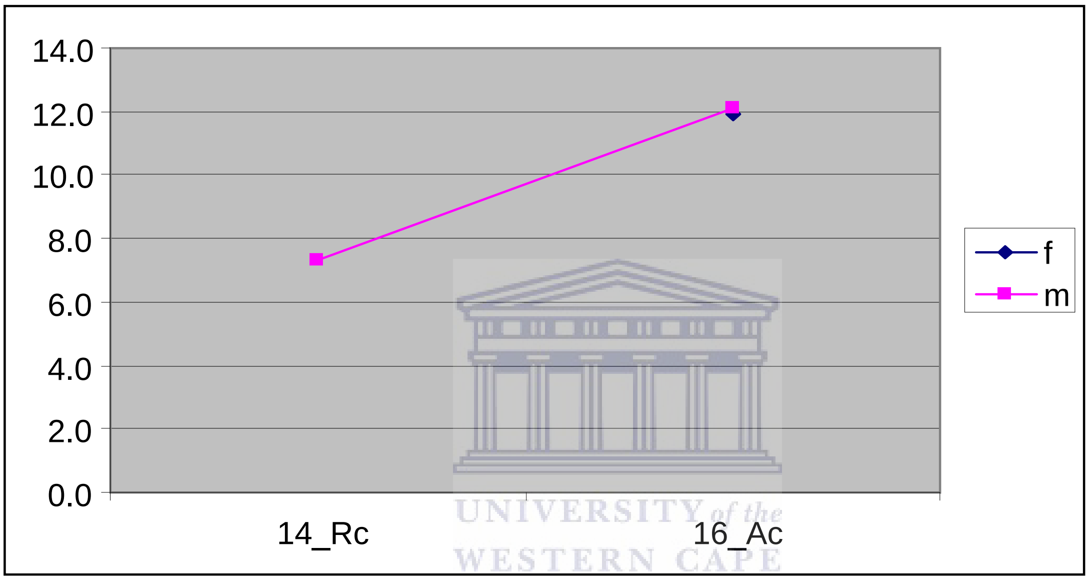
	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								7.60
Ci								9.9(0.91)
Cco								10.3(1.02)
Coc								11(1.45)
Cr1/2								10.7(0.83)
Cr3/4							7.10	12.3(1.12)
Crc								13.1(1.12)
Ri			6.90	7.2(0.36)	8.5(0.77)		8.50	
Cli							9.4(0.91)	13.5(0.33)
R1/4			8.2(0.42)	8.9(0.83)	9.5(0.73)		9.7(1.12)	15.5(0.89)
R1/2	6.90	7.5(0.88)	9(1.07)	10(0.94)	10(0.87)		10.8(0.72)	15.6(1.42)
R3/4	8.2(0.74)	8.3(0.59)	10(0.96)	10.6(1.56)	10.6(0.87)		11.5(1.18)	
Rc	8.9(0.97)	10.1(0.72)	11.1(1.34)	10.7(0.63)	11.3(2.06)	7.9(0.57)	12(2.16)	
A1/2	9.9(0.68)	10(0.77)	12(1.25)	11.7(1.52)	13(0.92)	9.3(0.95)	13.4(0.85)	
Ac	12.3(1.18)	12.7(1.69)	14.8(1.08)	13.5(1.43)	14.5(1.41)	12.1(1.87)	15.8(0.77)	

Table 4: The dental age related table for the sample of Indian males in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								10.00
Ci								9.6(1.39)
Cco								11.6(1.54)
Coc								11.4(1.30)
Cr1/2								11.4(0.61)
Cr3/4							9.2(1.08)	12.9(0.83)
Crc								13.4(0.66)
Ri			6.70	8.5(2.09)	9(0.60)		8.90	
Cli							9.5(0.64)	14.7(1.30)
R1/4			9.4(0.99)	9(0.72)	9.7(1.01)		10.5(1.22)	14.6(0.40)
R1/2	6.70	7.9(1.10)	9.5(1.05)	10.3(0.76)	10.9(1.00)		11.2(1.03)	
R3/4	8.7(0.39)	9.4(0.92)	10.9(0.96)	11.2(1.50)	11.9(0.63)		12.3(0.71)	
Rc	10.6(0.56)	9.6(1.09)	12.1(0.80)	12.1(0.73)	11.6(1.94)	9(1.06)	12.6(1.80)	
A1/2	9.1(0.84)	10.1(0.97)	13.3(0.69)	12.5(1.07)	13.1(0.70)	9.4(0.80)	13.8(0.74)	
Ac	12.5(1.6)	13(1.28)	15(1.14)	14(1.28)	14.6(1.38)	12.7(1.46)	16.1(0.90)	

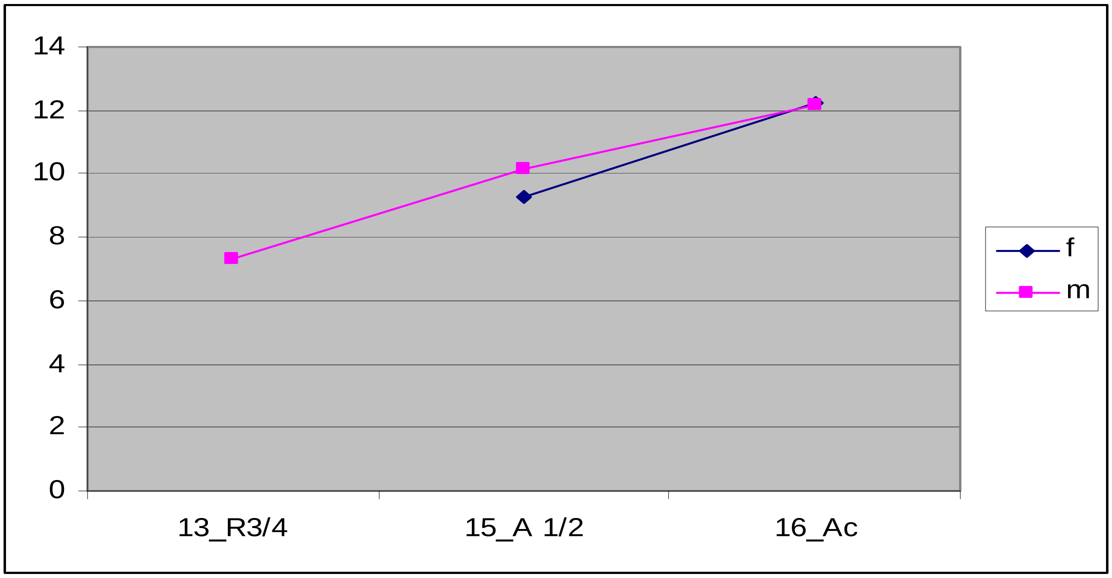
3. **The Zulu Sample:** The dental age estimation graphs of the sample of Black male and female children from Kwa-Zulu Natal are depicted below and show the mean age at which calcification occurs for each developmental stage of the eight permanent mandibular teeth. The age range was from 7 to 15 years.

Graph 17: Zulu sample. The age related stages of the central incisor (I1) for males and females



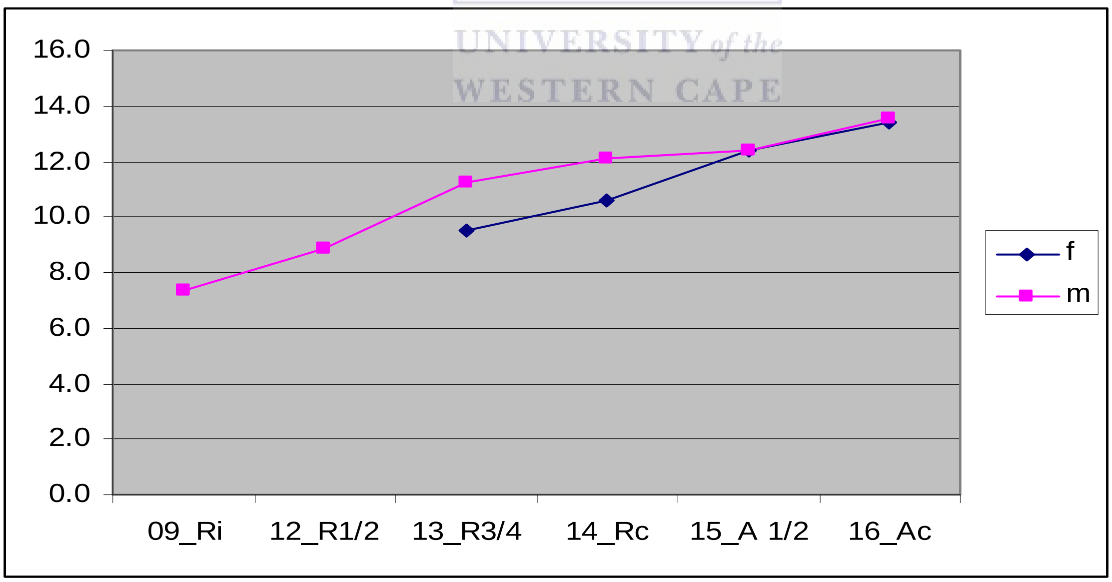
Central incisor (I1): There was only one individual at Rc stage; the apex closes at 11.9 years in females and 12.1 years in males.

Graph 18: Zulu sample. The age related stages of the lateral incisor (I2) for males and Females



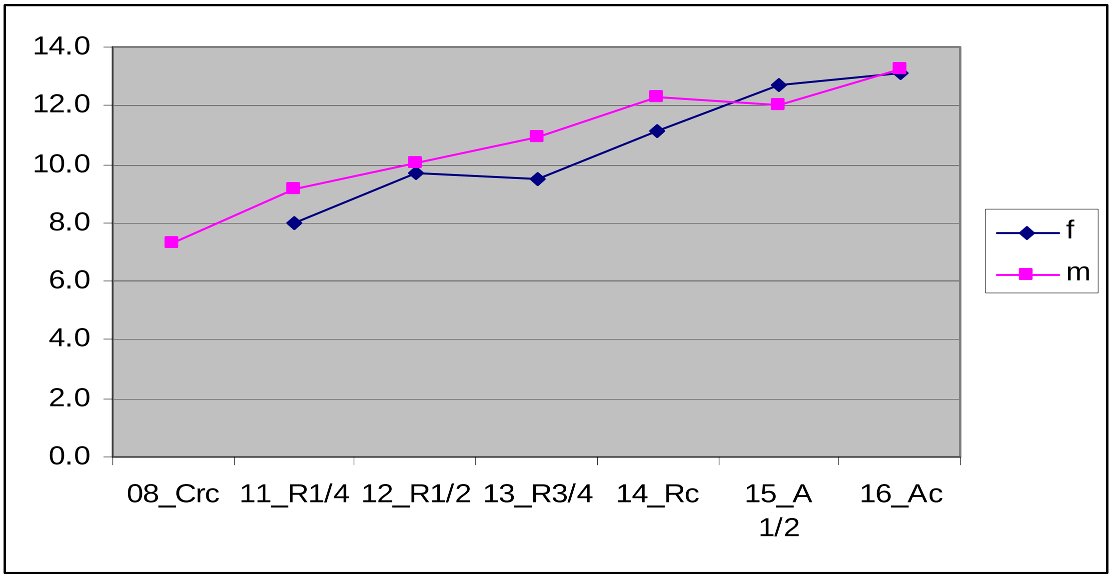
Lateral incisor (I2): There is a difference of time of the apex being half-calcified (A½), 10.2 years in males and 9.3 years in females. The apices are calcified in both sexes at 12.2 years.

Graph 19: Zulu sample. The age related stages of the canine (C) for males and females



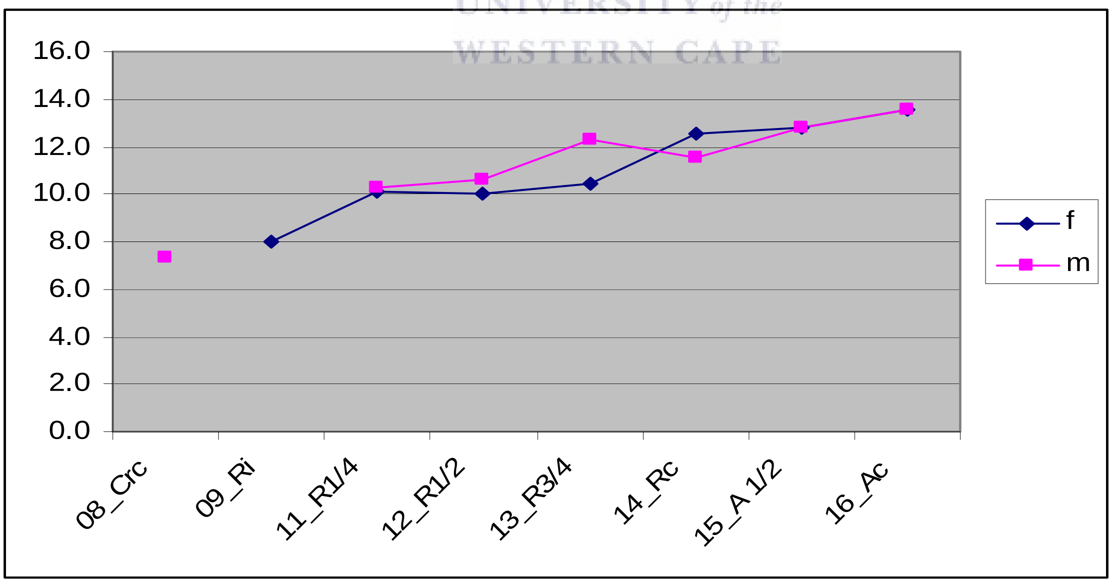
Canine (C): The root calcification in females is at the R¾ stage at 9.5 years, the males are 11.3 years old at this stage. At root complete stage the females are 10.6 years and the males are12.1 years old. The root apices are calcified (Ac) at 13.5 years in both sexes.

Graph 20: Zulu sample. The age related stages of the 1st premolar (Pm1) for males and females



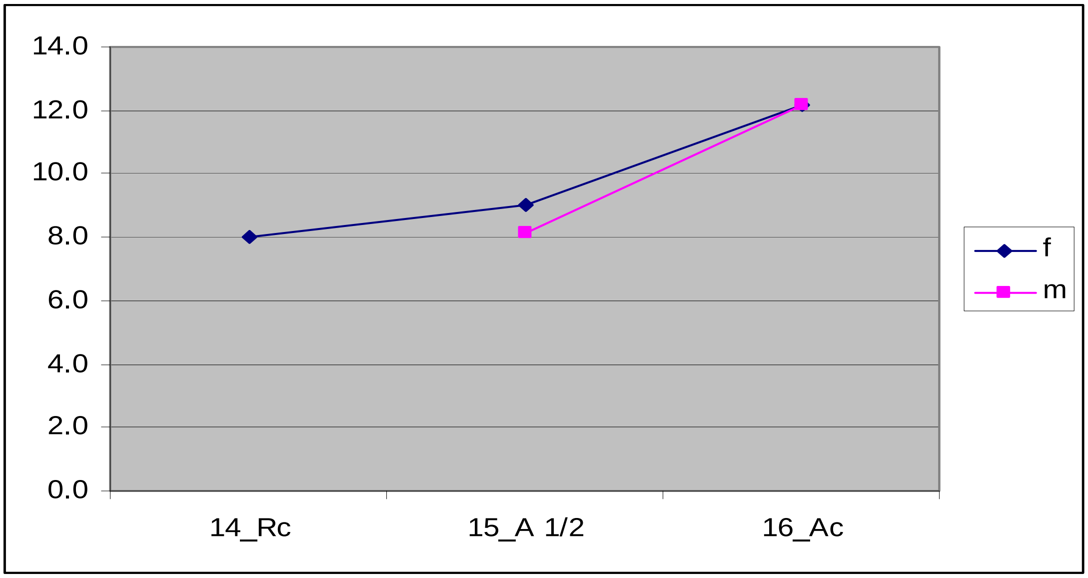
1st premolar (Pm1): The root calcification stages in males are slower than the females by approximately a year. The apex is calcified in males at 13.3 years and in females at 13.1 years.

Graph 21: Zulu sample. The age related stages of the 2nd premolar (Pm2) for males and females



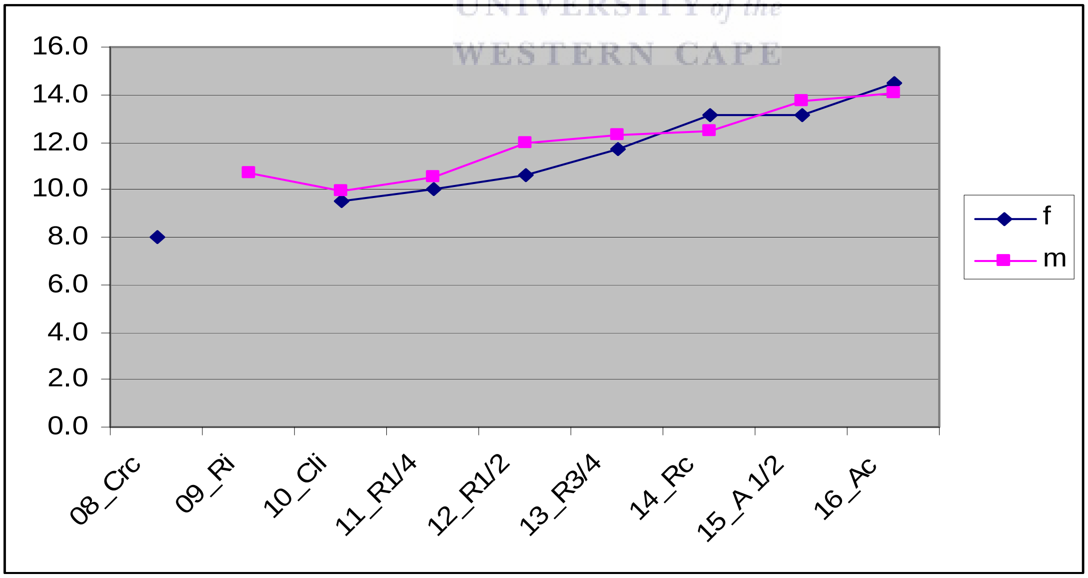
2nd premolar (Pm2): The root calcification is at the R¼ stage at 10.3 years in both sexes. At R¾ stage the girls are 1.8 years ahead of the boys. The root complete stage is reversed in males and females, the males being 1 year ahead of the females. The apices are calcified at 13.5 years in both sexes.

Graph 22: Zulu sample. The age related stages of the 1st molar (M1) for males and Females



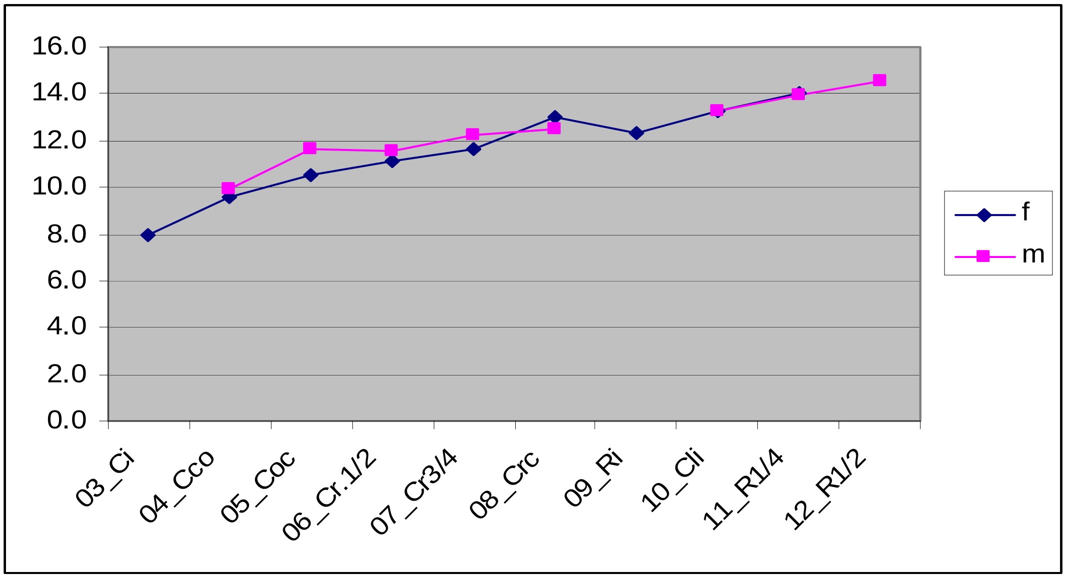
1st molar (M1): There is a difference in the A½ stage with the males being 0.9 years ahead of the females. The apex of this tooth is calcified at 12.2 years in both sexes. Most of the sample of Zulu children was above 10 years of age.

Graph 23: Zulu sample. The age related stages of the 2nd molar (M2) for males and Females



2nd molar (M2): The root calcification in males is slower than females by 0.5 years at Cli stage, at R½ stage the difference is 1.3 years, at R ¾ stage the difference is 0.6 years. The root complete (Rc) stage is reversed with the males being earlier than females by 0.7 years. The apices are calcified (Ac) at 14 years in males and 14.5 years in females.

Graph 24: Zulu sample. The age related stages of the 3rd molar (M3) for males and females



3rd molar (M3): The crowns calcify earlier in females by 6 months; the roots calcify in the same time frame in both sexes, R¼ is at 13.9 years.

Table 5: Age Related Tables for Zulu male children - Ages in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								
Cco								9.9(1.69)
Coc								11.7(0.97)
Cr.1/2								11.6(3.39)
Cr.3/4								12.3(1.23)
Cr.c				7.30	7.30			12.5(1.25)
Ri			7.30				10.7(2.49)	
Cli							10(2.07)	13.2(0.99)
R1/4				9.20	10.3(1.06)		10.6(1.04)	13.9(0.66)
R1/2			8.90	10.1(1.26)	10.6(1.39)		11.9(1.47)	14.60
R3/4			11.3(1.35)	10.9(1.11)	12.3(0.95)		12.3(0.57)	
Rc			12.1(1.64)	12.3(1.19)	11.6(1.23)		12.4(1.12)	
A1/2		10.20	12.4(1.09)	12(1.18)	12.8(1.04)	8.1(1.10)	13.7(0.63)	
Ac	12.1(1.52)	12.2(1.51)	13.5(0.92)	13.3(0.96)	13.5(1.05)	12.2(1.46)	14(0.90)	

Table 6 Age Related Tables for Zulu female children - Ages in years (SD)

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								8.00
Cco								9.6(1.24)
Coc								10.5(1.19)
Cr.1/2								11.10
Cr.3/4								11.6(1.39)
Cr.c							8.00	13(1.09)
Ri					8.00			
Cli							9.5(1.11)	13.2(1.17)
R1/4				8.00	10.1(1.11)		10.1(1.28)	14(0.54)
R1/2				9.7(0.75)	10.6(1.97)		10.6(1.52)	
R3/4			9.5(1.18)	9.5(1.21)	10.5(1.30)		11.7(0.89)	
Rc			10.6(0.54)	11.1(1.03)	12.6(1.53)		13.1(1.26)	
A1/2		9.3(1.80)	12.4(1.26)	12.7(1.17)	12.8(1.12)	9.0(1.80)	13.1(0.80)	
Ac	11.9(1.84)	12.2(1.51)	13.4(1.04)	13.1(1.10)	13.6(0.82)	12.2(1.65)	14.5(0.11)	

Discussion

The Tygerberg sample of children was mainly of White and Coloured origin. The age related tables for this group showed there was a slight difference in the ages at which crown and root calcification took place for males and females. The population origin of each child was not available in numerous cases, therefore the Tygerberg children were regarded a heterogeneous sample group. The sample of Zulu children ranged from 7 to 15 years, but had few young children; this limited the data on crown and root formation of the incisors and 1st molar. The development of the canine to the 3rd molar was, however, comparable to the Tygerberg and Indian samples.

Most of the data of calcification stages of the teeth within the left mandible were limited by the sizes of the samples except for the 2nd molar. The comparable data for this tooth in all three sample groups is from the crown complete (Crc) to the root apex closure (Ac) stages. This tooth appears to show greater stability in its development in both females and male in its relation to the chronological age.

Conclusion

The dental age related tables of the 3 sample groups show that there is relatively little difference in the ages at which the various teeth calcify between the males and females in each sample group. This suggests that when estimating of the age of skeletal remains of a juvenile the sex of the individual may influence the result by 2 to 8 months. Knowing the population origin of the individual will improve the age estimation.

CHAPTER 5

DENTAL AGE ESTIMATION: TESTING STANDARD METHODS OF DENTAL AGE ESTIMATION BY MOORREES, FANNING AND HUNT AND DEMIRJIAN, GOLDSTEIN AND TANNER ON THREE SOUTH AFRICAN CHILDREN SAMPLES.

Charts prepared from population surveys have been used to determine the age of individuals for orthodontic and forensic purposes for many years and have been regarded as sufficiently accurate to estimate chronological age of a juvenile. Standard charts show the bone age, dental age, height and weight, sexual development and secondary growth patterns of children and juveniles. These charts have become the standard references for age assessment used throughout the world (Tanner, 1962). Subsequent studies have used radiographs of the jaws to determine the state of development of the entire mandibular dentition; the maxillary teeth are not easily seen on Pantomographic radiographs and little data is available for these teeth. These charts are based on dental surveys of cross sections of various populations and show the progressive states of dental development for each year of age (Cameron & Sims, 1974). Tanner (1962) suggested that the rate of skeletal growth had increased over the first half of the 20th century therefore creating the difference between the earlier age estimation charts and the recent ones.

Moorrees, Fanning and Hunt (1963) published charts based on a radiographic survey of the development of both the deciduous and permanent dentition. These charts indicate the average age and two standard deviations for the various developmental stages of the teeth. The range between ± two standard deviations represents an age range in which 95% of the population would be expected to reach the appropriate developmental landmark. These charts have proved useful for the assessment of a child’s dental development with regard to the skeletal developmental stage and for planning orthodontic treatment. They have also been used for age estimation of skeletal remains.

A study of dental maturity by Demirjian, Goldstein and Tanner (1973) using the Pantomographic radiographs of 2928 boys and girls of French-Canadian ancestry between the ages of 2 and 20 was undertaken. The progressive developmental stages of the 7 left mandibular teeth were allocated labels A to H. The various stages of dental development were recorded for each of the age groups. Maturity scores, based on the work of Tanner, Whitehouse and Healy (1962) were developed and allotted to each tooth during its developmental stages. The total of the maturity scores of the 7 teeth was then converted to tables for both boys and girls to obtain an estimated chronological age.

Several authors have tested the Demirjian *et al* method against their child population groups with varying success.(Hägg & Matson (1985); Davis PJ & Hägg U (1994); Farah CS, Booth DR, Knott SC(1999); Willems G, Van Olman A, Spiessens B Carels C (2001); Maber M, Liversidge HM, Hector MP (2006); Rózylo-Kalinowska, Kiworkowa-Raczkowska and Kalinowski (2007).

The aim of this study was to test the accuracy of the dental age estimation methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) against population samples of children of known chronological age from the Western Cape (Tygerberg sample), Black (Zulu) and Indian from Kwa-Zulu Natal.

Materials and methods

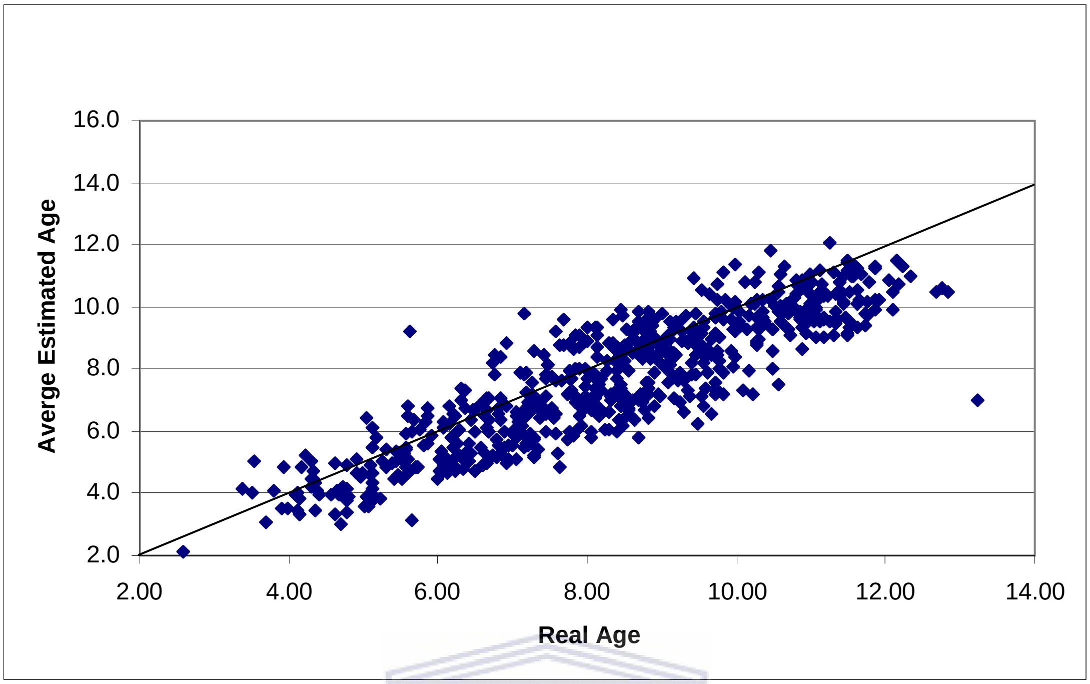
The data used for this study consisted of 916 Pantomographic radiographs of children between the ages of 3 years to 16 years that had routine dental treatment at the Dental

Faculty at Tygerberg. These were recorded as the Tygerberg sample. The Pantomographic radiographs of 90 Black (Zulu) children (43 females and 47 males) with an age range of between 7 and 15 years were obtained from an orthodontic practice in Durban. A sample of 157 Indian children (82 females and 75 males) with an age range of 6 to 16 years was obtained from 2 orthodontic practices in Durban. Only radiographs showing normal development and no pathological lesions were used. Each radiograph was numbered for further reference together with the name, sex, date of birth and the date on which the radiograph was taken. The chronological age of each individual was calculated by subtracting the date of birth from the date when the radiograph was taken. Each radiograph was then examined and the stages of development of each of the permanent mandibular teeth in the left mandibular quadrant were recorded. The age of each child was estimated firstly using the method of MFH (1963) and then that of DGT (1973). The estimated ages of the Tygerberg sample were then compared to their chronological ages. The data from the Indian and Zulu samples were analyzed in a similar manner. The data from each of the sample groups was used to analyze the error between the chronological age (real age) of each child with the age estimations of MFH and DGT methods respectively.

Results

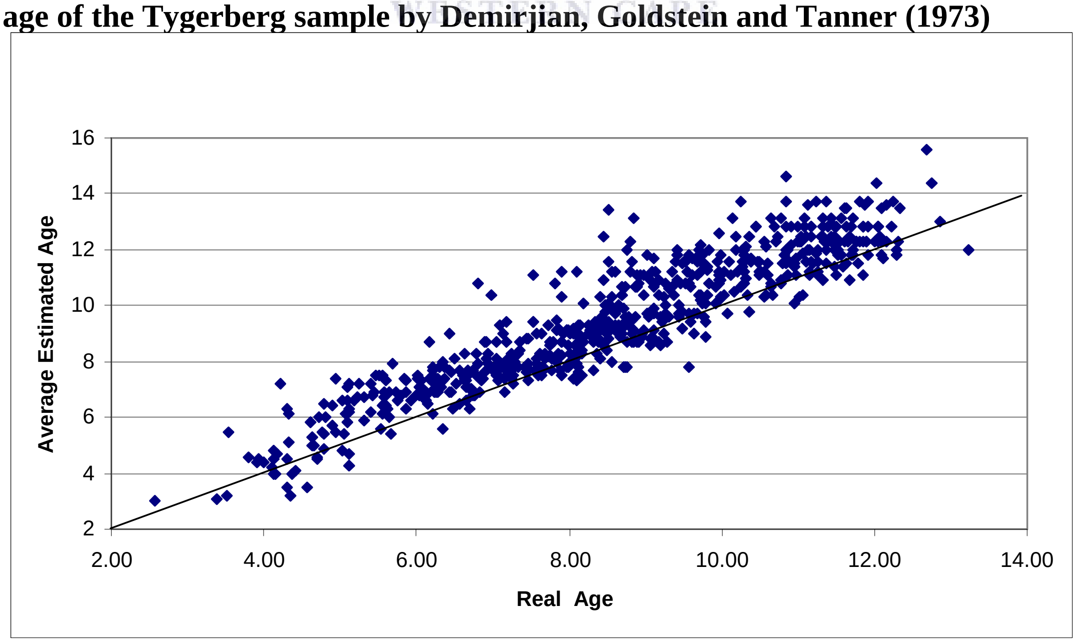
The data from the Tygerberg sample was used to compare the real age (chronological age) to the estimated age by both MFH (1963) and DGT (1973) methods. Graph 1 shows a scatter diagram of the estimated ages using MFH method and compared to the real age; it was found that in the Tygerberg sample, this method under-estimated the ages in 89.2% of the sample on average by 0.91 years; the DGT method over-estimated the ages of these children on average by 0.89 years in 85.7% of the sample (Graph 2).

Graph 1: Comparison between chronological age and the average estimated age of the Tygerberg sample by Moorrees, Fanning and Hunt (1963)



Graph 1 shows the comparison between the real age and the average estimated age by Moorrees *et al* of the Tygerberg sample. There is under-estimation of the chronological ages in 89.2% of the sample

Graph 2: Comparison between the chronological age and the average estimated age of the Tygerberg sample by Demirjian, Goldstein and Tanner (1973)



Graph 2 shows the comparison between the real age and the average estimated age of the Tygerberg sample by Demirjian *et al*. There is over-estimation of the chronological ages in 85.7% of the sample.

The data for each of the 3 sample groups i.e. Tygerberg, Indian and Zulu, were used to test the degree of error between the estimated age and the chronological age. The estimation error was calculated in the following manner; the real age was compared to the difference between the estimated age minus the real age for both MFH and DGT methods (Graphs 3, 4, 6, 7, 8 & 9).

Table 1 shows that the average age under-estimation of the Tygerberg sample by the MFH method was 0.91 years in 89.2% of the sample; the average age over-estimation by the DGT method of this sample was 0.89 years in 85.7% of the sample.

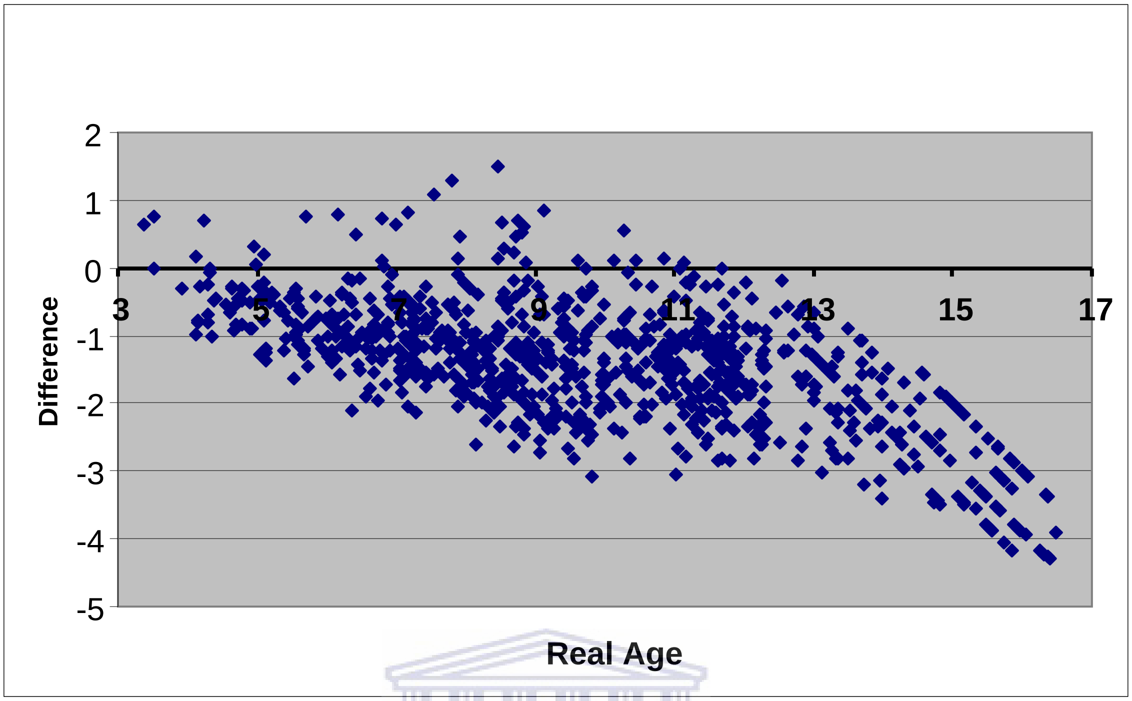
Table 1: Average age estimation of the Tygerberg sample in years

Moorrees *et al*	**Demirjian *et al***
-0.91 (in 89.2%)	**0.89 (in 85.7%)**

In the Tygerberg sample the Moorrees *et al* method under-estimated the chronological age of 89.2% of the sample by 0.91 years. The Demirjian *et al* method over-estimated the chronological age of 85.7% of the sample by 0.89 years.

Graph 3 shows the estimation error compared to the chronological age of the Tygerberg sample of children by the MFH method. This graph shows that 96% of the sample lies below the chronological age. The error increases with age from 13 to 16 years.

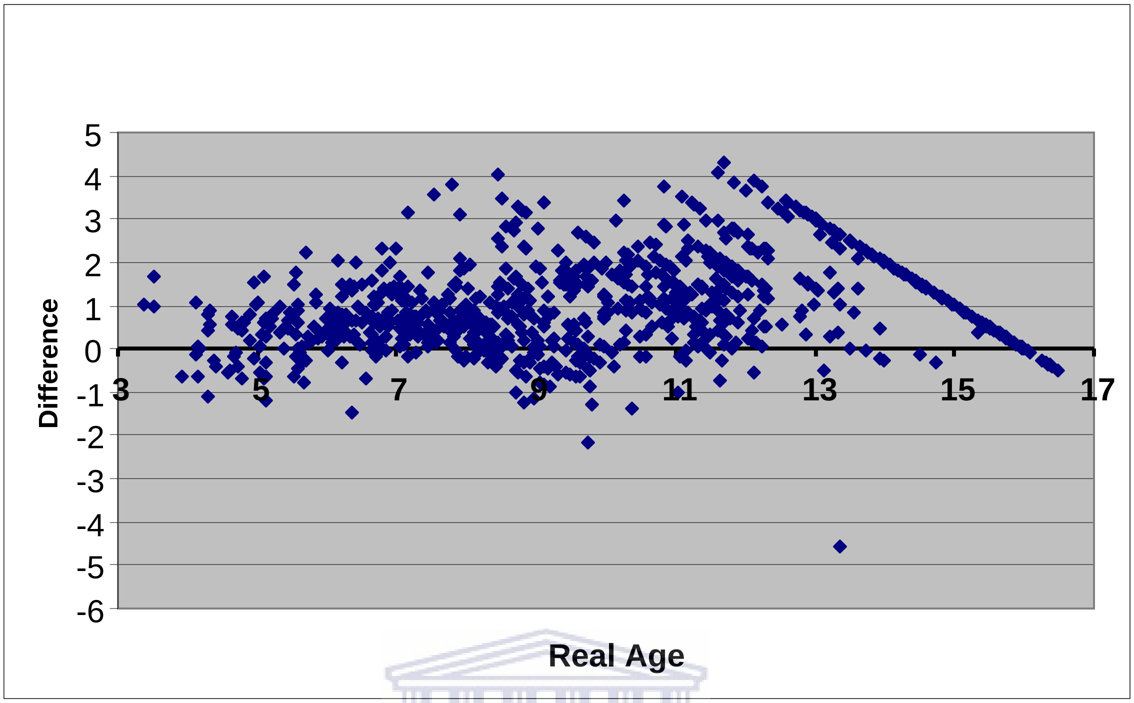
Graph 3: Tygerberg children. Age estimation error using the MFH method



Graph 3 shows the *estimation error* by the Moorrees *et al* method of the chronological ages of the Tygerberg children; 96% of the sample lies below the chronological age.

Graph 4 shows the estimation error compared to the chronological age of the Tygerberg sample by the DGT method. This graph shows that 86.3% of the sample lies above the chronological age.

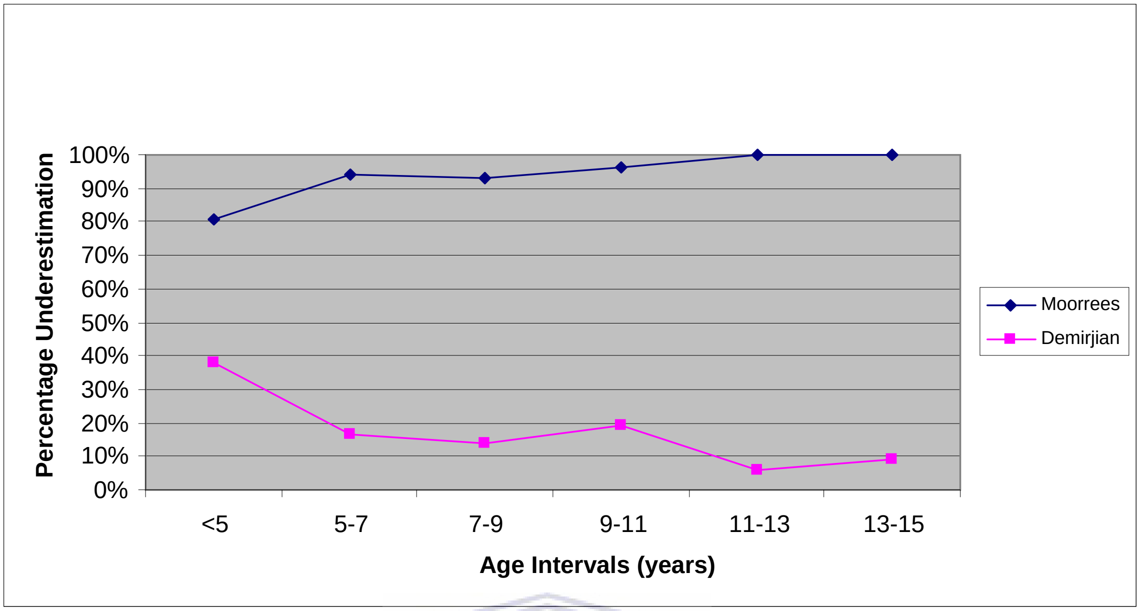
Graph 4: Tygerberg children. Age estimation error using the DGT method



Graph 4 shows the *estimation error* by the Demirjian *et al* method of the chronological ages of the Tygerberg sample. 86.3% of the sample lies above the chronological age.

Graph 5 shows the degree of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals. This graph indicates that the MFH method under-estimates 81% of individuals who are under 5 years of age; 94% between 5 and 7 years; 93% between 7 and 9 years; 97% between 9 and 11 years and 100% between 11 and 15 years. The DGT method therefore over-estimates 62% of individuals under the age of 5 years; 83% between 5 and 7 years; 86% between 7 and 9 years; 81% between 9 and 11 years; 94% between 11 and 13 years and 91% between 13 and 15 years (Table 2).

Graph 5: The percentage of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals



Graph 5 shows the percentage of under-estimation of the ages of the Tygerberg sample in age intervals using the Moorrees *et al* method; the over-estimation of the ages by Demirjian *et al* is the complement to the figures. [See Table 2.]

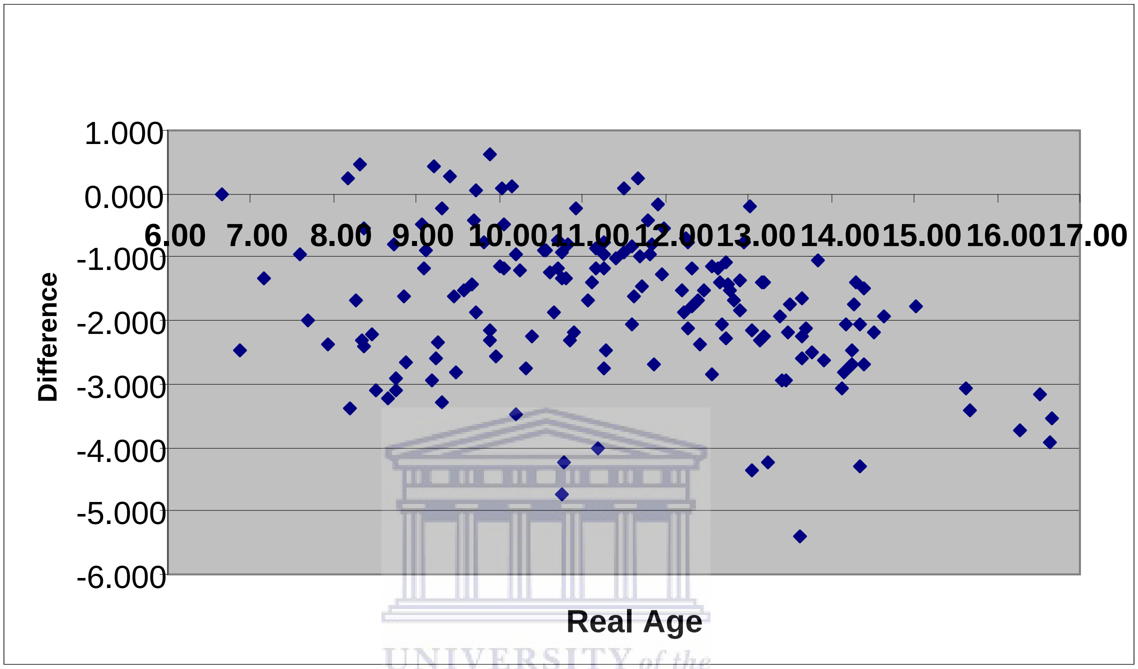
Table 2: The percentage under-estimation of the ages of the Tygerberg sample in age intervals by Moorrees *et al* and over-estimation by Demirjian *et al*

Demirjian						
Age Interval	**<5**	**5-7**	**7-9**	**9-11**	**11-13**	**13-15**
% Over Est.	62%	83%	86%	81%	94%	91%
Moorrees						
Age Interval	**<5**	**5-7**	**7-9**	**9-11**	**11-13**	**13-15**
% Under Est.	81%	94%	93%	97%	100%	100%

Table 2 shows the percentage of the Tygerberg sample in which the ages have been under-estimated by the Moorrees *et al* method and the percentage that have been over-estimated by the Demirjian *et al* method in age intervals.

Graph 6 shows the under-estimation of the ages of the Indian children by the MFH method; 93.7% of the sample lies below the chronological age.

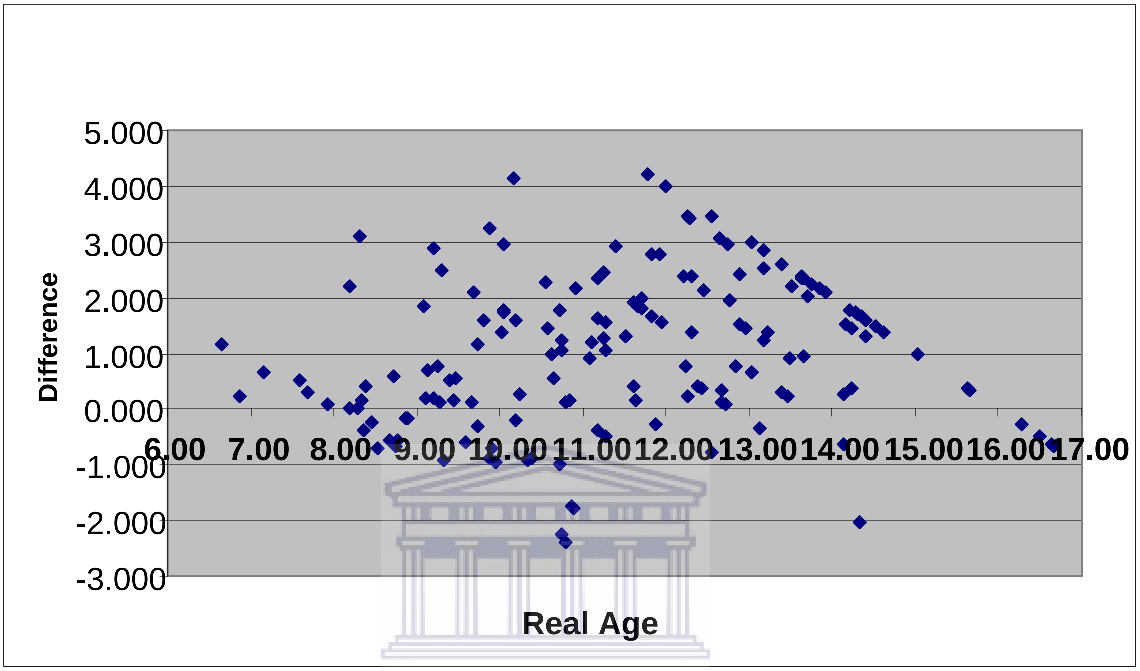
Graph 6: Indian children. Age estimation error using the MFH method



Graph 6 shows the *estimation error* by the Moorrees *et al* method of the chronological age of the Indian sample. 93.7% of the sample lies below the chronological age.

Graph 7 shows the over-estimation of the ages of 79.2% of the Indian children by the DGT method.

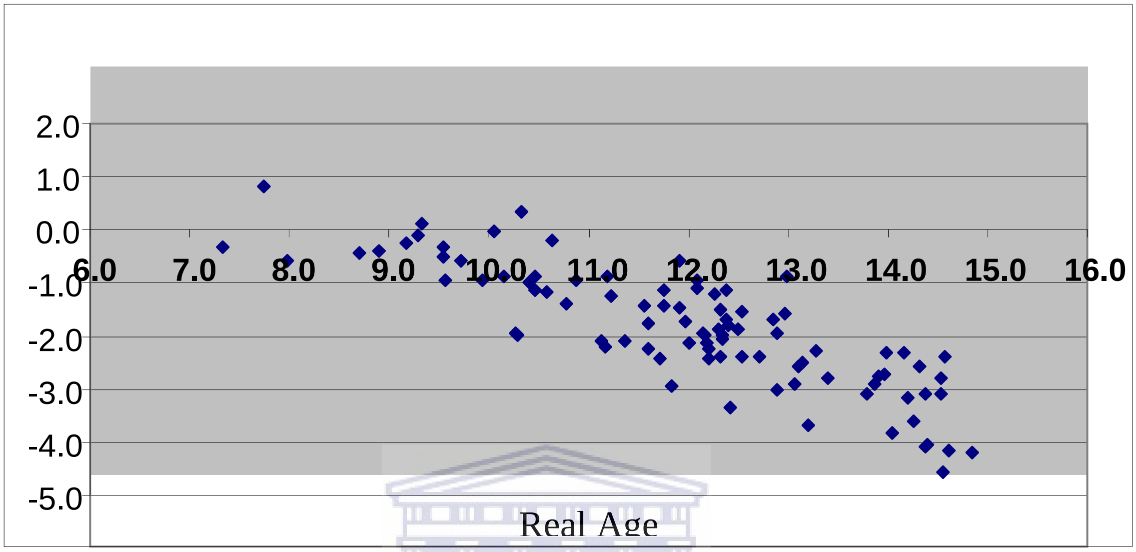
Graph 7: Indian children. Age estimation error using the DGT method



Graph 7 shows the *estimation error* by Demirjian *et al* of the chronological age of the Indian sample. 79.2% of the sample lies above the chronological age.

Graph 8 shows the under-estimation of the ages of 96.7% of the Zulu children by the MFH method.

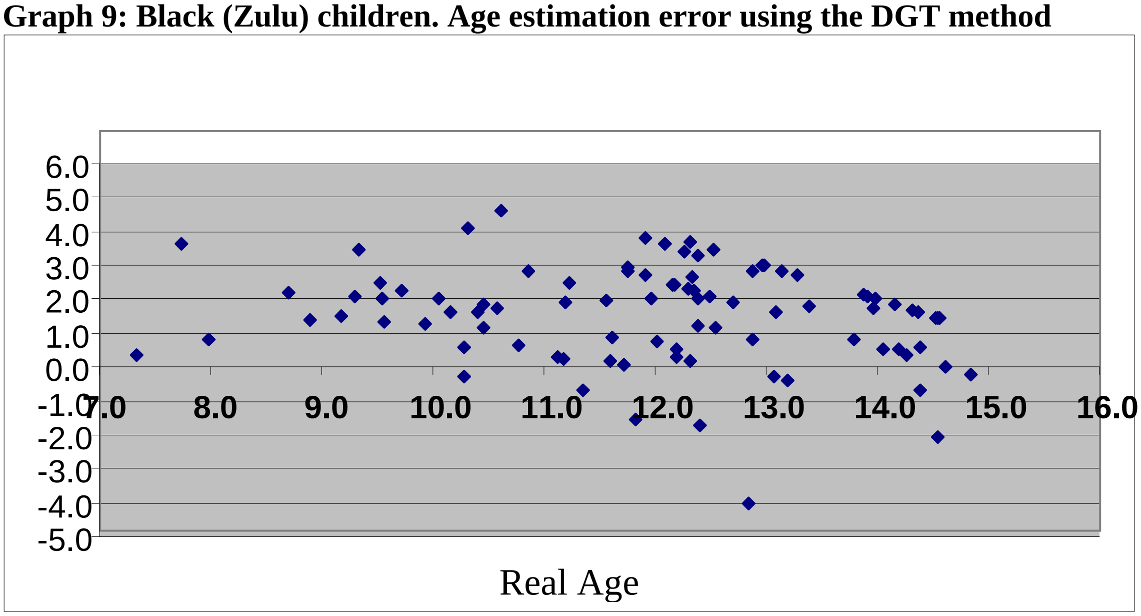
Graph 8: Black (Zulu) children. Age estimation error using the MFH method



Graph 8 shows the *estimation error* by Moorrees *et al* of the chronological age of the Zulu sample. 96.7% of the sample lies below the chronological age.

Graph 9 shows the over-estimation of the ages of 90% of the Zulu children by the DGT method.

Graph 9: Black (Zulu) children. Age estimation error using the DGT method



Graph 9 shows the *estimation error* by Demirjian *et al* of the chronological age of the Zulu sample. 90% of the sample lies above the chronological age.

Table 3 shows the percentage of the 3 samples in which there was under-estimation and over-estimation of the chronological ages by the methods of MFH and DGT respectively. The method of MFH under-estimated the ages of 96% of the Tygerberg sample, 93.7% of the Indian sample and 96.7% of the Zulu sample. The DGT method over-estimated the ages of 86.3% of the Tygerberg sample, 79.2% of the Indian sample and 90% of the Zulu sample.

Table 3: The percentage of samples where age is over-estimated and under-estimated

	Under-estimation by Moorrees *et al*	Over-estimation by Demirjian *et al*
Tygerberg (n = 814)	96%	86.3%
Indian (n = 153)	93.7%	79.2%
Zulu (n = 91)	96.7%	90.0%

This table shows the percentage under-estimation of the chronological ages of all 3 sample groups by Moorrees *et al* and the percentage over-estimation by Demirjian *et al* for the Tygerberg, Indian and Zulu children.

Discussion

The method of Moorrees, Fanning and Hunt (1963) was used extensively for dental age estimation until Demirjian, Goldstein and Tanner (1973) published their new dental age estimation method. The MFH method was used to predict the stage of development of the teeth at a certain age whereas the DGT method was originally regarded as a better method of dental age estimation. Several authors have however shown that the use of DGT method was not accurate when applied to their population sample. (Hägg and Matsson, 1985; Davis and Hägg, 1994; Farah, Booth and Knott, 1999; Willems *et al* 2001).

This study limited the age range of the samples to individuals between the ages of 6 and 16 years. The study showed that the method of MFH under-estimated the ages of the three South African sample groups and the method of DGT over-estimated the ages of these groups. The under-estimation of the ages of all 3 samples by MFH was over 90% in each sample group. The over-estimation of the ages of the samples varied from 79.2% for Indians, 86.3% for the Tygerberg children and 90% for the Black children. The isolated individuals in the graphs where the age estimation by MFH (Graph 3) and that of DGT (Graph 4) are severely under-estimated or over-estimated respectively are either due to incorrect documentation of the date of birth on the radiograph or individuals that are genetically very advanced or retarded in their growth patterns. An increase in error with age is also noted especially with the DGT method. This could be due to the construction of the weighted tables in which a small change in weighted value is applied to the ages between 13 and 16 years.

Conclusion

The Moorrees, Fanning and Hunt method consistently under-estimates the ages of the three samples of South African children. The Demirjian *et al* method over-estimates the ages of these samples. These methods are not applicable to accurately estimate the ages of South African juveniles. It therefore follows that dental age related tables for the different ethnic groups in South Africa are necessary for age estimation of these children.

CHAPTER 6

DEVELOPMENT OF CORRECTION TABLES FOR THE MOORREES AND DEMIRJIAN METHODS WHEN USED TO ESTIMATE THE AGES OF SOUTH AFRICAN CHILDREN

In Chapter 5 the age estimation of the three samples of South African children using the Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) methods was described. These methods were inaccurate in estimating the chronological ages of the Tygerberg, Indian and Zulu children by either under-estimating the age in the case of MFH method or over-estimating the age using the DGT method. The average margin of error was approximately 1 year in each case. This indicated that these methods were not suitable for accurately estimating the ages of the South African sample groups of this study.

The aim was therefore to derive correction tables for the MFH and the DGT methods to compensate for the margin of error of each method when applied to South African children.

Materials and methods

The raw data of the Tygerberg, Indian and Zulu sample groups were used (Chapter 5). The interquartile ranges of the errors of each of the age estimation methods of MFH and DGT were calculated for each age midpoint in the Tygerberg, Indian and Zulu samples. The age range was between 7 and 16 years for all three sample groups. The interquartile ranges were used to calculate the median error of the age estimation for each age midpoint between 7 and 16 years for each sample group. Graphs and tables were developed using this data. The median age estimation error was used to develop a table of correction factors from 7 to 16 years for the age estimation methods of MFH and DGT respectively for the 3 sample groups i.e. Tygerberg, Indian and Zulu children.

Results

The age estimation data of the Tygerberg sample utilizing the MFH and the DGT methods were used to calculate the interquartile ranges of the respective age estimation errors. The 1st to 3rd quartiles of the age estimation errors of the MFH method on the Tygerberg sample showed that the median error increases as the age increases from 7 to 16 years (Graph 1, Table 1). At the age of 7 years the median under-estimation of the age is 1 year; this median increases to 3.4 years at the age of 16 years.

Graph 1: The quartiles for the MFH method compared to the age mid-points (Tygerberg)

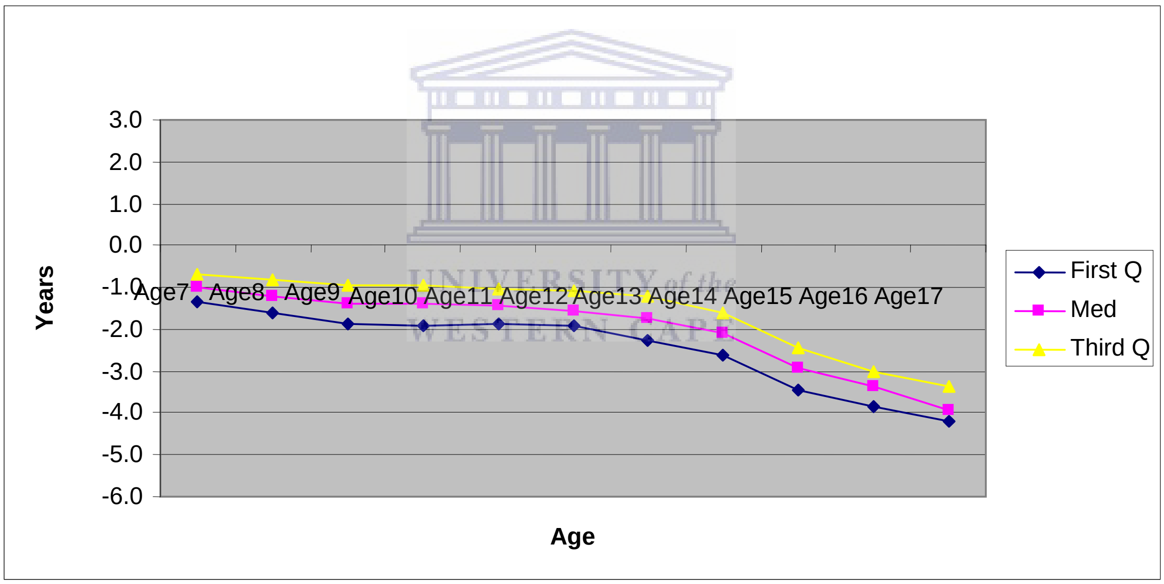


Table 1: Interquartile ranges of age estimation errors using the MFH method (Tygerberg)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-2.1	-2.6	-3.1	-3.1	-3.0	-3.0	-3.4	-3.5	-4.2	-4.3
First Q	-1.3	-1.6	-1.9	-1.9	-1.9	-1.9	-2.3	-2.6	-3.5	-3.8
Med	-1.0	-1.2	-1.4	-1.4	-1.5	-1.6	-1.7	-2.1	-2.9	-3.4
Third Q	-0.7	-0.8	-0.9	-1.0	-1.0	-1.1	-1.2	-1.6	-2.4	-3.0
Max	1.3	1.5	1.5	0.8	0.5	0.1	-0.2	-0.7	-1.5	-2.1

Table 1 and Graph 1 show the interquartile ranges of the age estimation errors on the Tygerberg sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

The DGT method of age estimation on the Tygerberg sample resulted in median quartiles that varied as the age increased to the age of 14 years, the error decreased to the age of 16 years. The errors were large between the ages of 10 and 15 years (Graph 2, Table 2).

Graph 2: The quartiles for the DGT method compared to the age mid-points (Tygerberg)

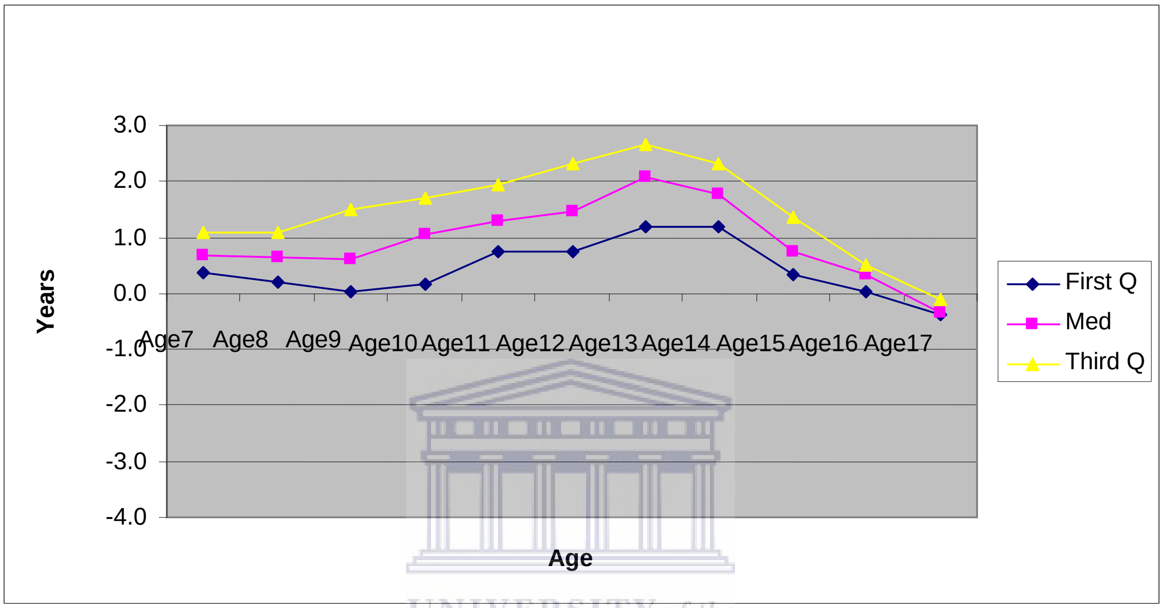


Table 2: Interquartile ranges of age estimation errors using the DGT method (Tygerberg)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-1.5	-1.2	-2.1	-2.1	-1.4	-1.0	-4.6	-4.6	-0.3	-0.5
First Q	0.4	0.2	0.0	0.2	0.8	0.7	1.2	1.2	0.3	0.0
Med	0.7	0.6	0.6	1.0	1.3	1.5	2.1	1.8	0.7	0.3
Third Q	1.1	1.1	1.5	1.7	1.9	2.3	2.7	2.3	1.4	0.5
Max	3.8	4.0	4.0	3.8	4.3	4.3	3.9	3.0	1.9	0.9

Table 2 and Graph 2 show the interquartile ranges of the age estimation errors on the Tygerberg sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Similar interquartile ranges were calculated for the Indian and Zulu samples. In the Indian sample, using the MFH method, the median error varies as the age increases. The error is small from age 10 to 12, but then increases up to 16 years. (Graph 3, Table 3).

Graph 3: The quartiles for the MFH method compared to the age mid-points (Indian)

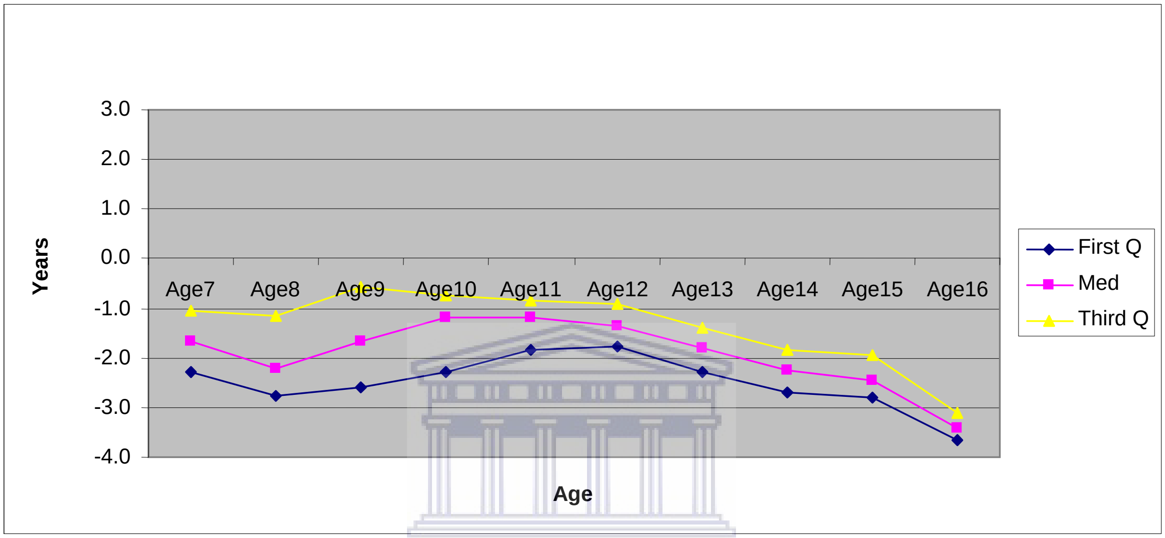


Table 3: Interquartile ranges of age estimation errors using the MFH method (Indian)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-2.5	-3.4	-3.4	-4.7	-4.7	-4.0	-5.4	-5.4	-4.3	-3.9
First Q	-2.3	-2.8	-2.6	-2.3	-1.8	-1.8	-2.3	-2.7	-2.8	-3.6
Med	-1.7	-2.2	-1.7	-1.2	-1.2	-1.4	-1.8	-2.2	-2.5	-3.4
Third Q	-1.0	-1.1	-0.6	-0.7	-0.8	-0.9	-1.4	-1.8	-1.9	-3.1
Max	0.0	0.5	0.6	0.6	0.3	0.3	-0.2	-0.2	-1.4	-1.8

Table 3 and Graph 3 show the interquartile ranges of the age estimation errors on the Indian sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Using the DGT method, the Indian sample showed the median error increases as the age increases to the age of 14 years. The error is small from age 7 to 9 years; the error is progressively larger from 10 to 14 years then decreases towards the age of 16 years (Graph 4, Table 4).

Graph 4: The quartiles for the DGT method compared to the age mid-points (Indian)

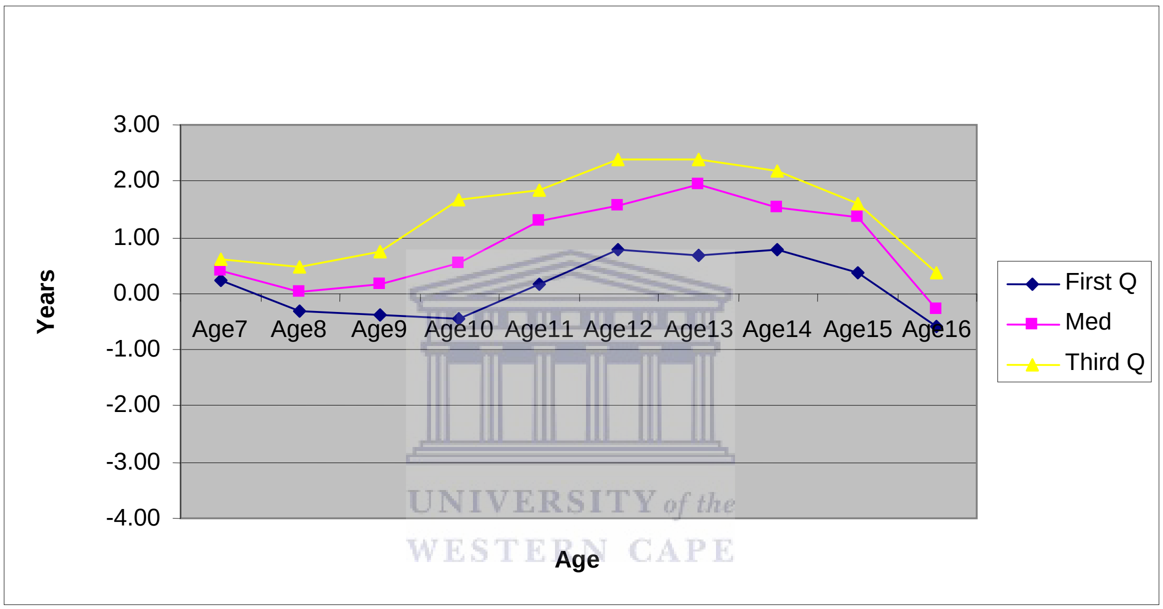


Table 4: Interquartile ranges of age estimation errors using the DGT method (Indian)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	0.07	-0.72	-0.95	-2.38	-2.38	-0.76	-0.76	-2.04	-2.04	-0.67
First Q	0.25	-0.31	-0.37	-0.45	0.17	0.76	0.67	0.80	0.36	-0.57
Med	0.41	0.02	0.15	0.54	1.30	1.55	1.94	1.53	1.37	-0.28
Third Q	0.61	0.47	0.76	1.67	1.82	2.39	2.39	2.18	1.59	0.36
Max	1.14	3.09	3.22	4.14	4.22	4.22	3.45	2.98	1.78	0.97

Table 4 and Graph 4 show the interquartile ranges of the age estimation errors on the Indian sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

The Zulu sample, using the MFH method, showed the median error decreases from 7 to 10 years. The error increases as the age increases from 11 to 16 years (Graph 5, Table 5).

Graph 5: The quartiles for the MFH method compared to the age mid-points (Zulu)

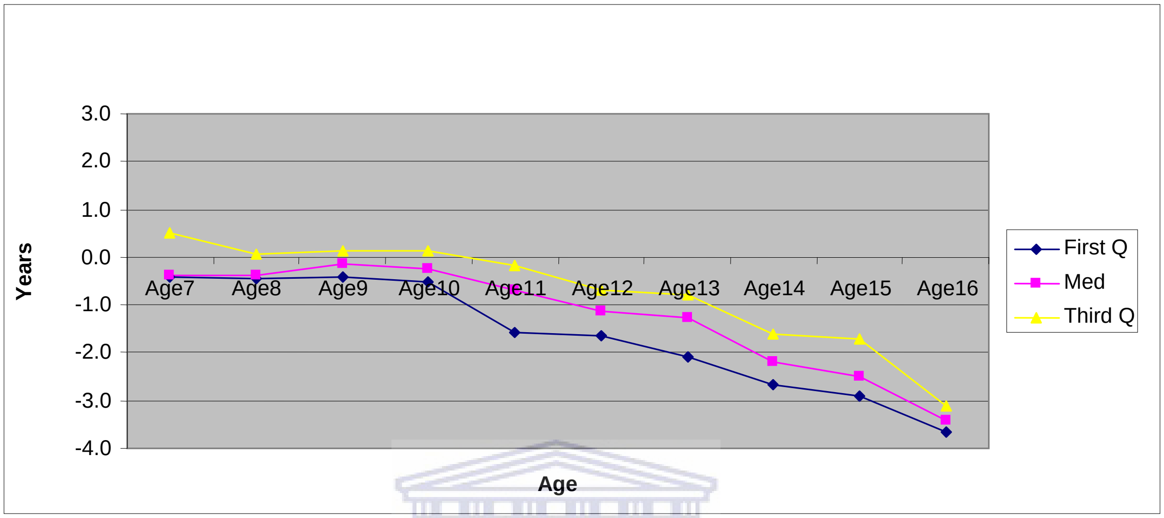


Table 5: Interquartile ranges of age estimation errors using the MFH method (Zulu)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	-0.5	-0.6	-0.9	-1.6	-2.9	-3.3	-3.3	-4.4	-4.4	-3.9
First Q	-0.4	-0.5	-0.4	-0.5	-1.6	-1.6	-2.1	-2.7	-2.9	-3.6
Med	-0.4	-0.4	-0.1	-0.2	-0.7	-1.1	-1.3	-2.2	-2.5	-3.4
Third Q	0.5	0.1	0.1	0.1	-0.2	-0.7	-0.8	-1.6	-1.7	-3.1
Max	1.4	1.4	0.9	0.9	0.7	0.0	-0.1	-0.9	-1.5	-1.8

Table 5 and Graph 5 show the interquartile ranges of the age estimation errors on the Zulu sample utilizing the Moorrees *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

This sample of Zulu children, using the DGT method, showed the median error increases as the age increases to the age of 13 years, then decreases to the age of 16 years. The error is largest between the ages of 10 and 15 years (Graph 6, Table 6).

Graph 6: The quartiles for the Demirjian *et al* method compared to the age mid-points (Zulu)

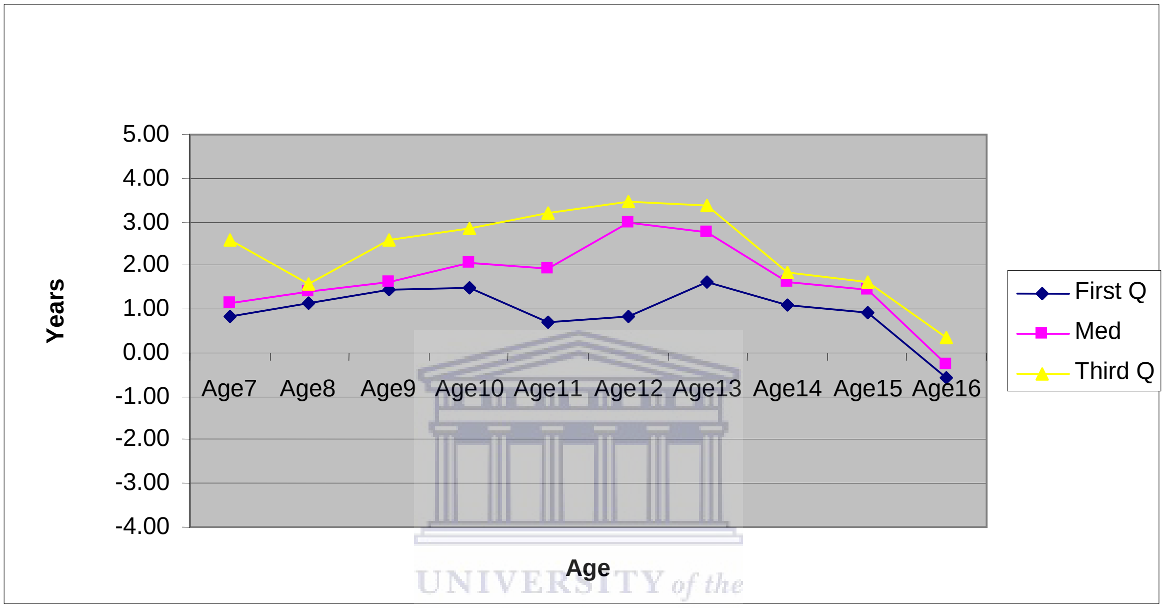


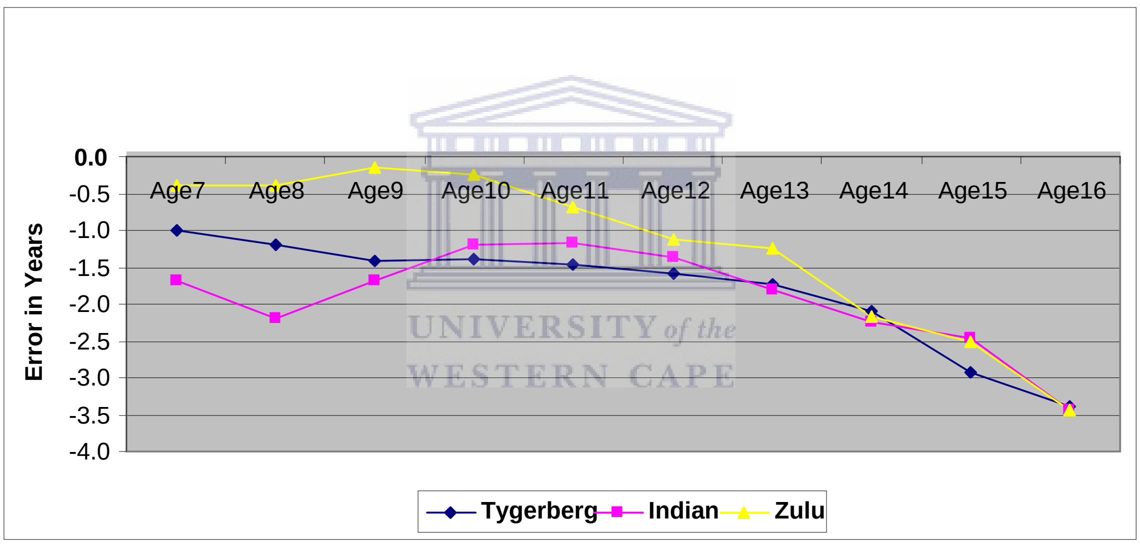
Table 6: Interquartile ranges of age estimation errors using the Demirjian *et al* method (Zulu)

	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Min	0.57	0.57	1.27	0.03	-1.53	-1.71	-1.71	-2.05	-2.05	-0.67
First Q	0.84	1.12	1.44	1.50	0.68	0.81	1.64	1.09	0.92	-0.57
Med	1.12	1.40	1.62	2.05	1.94	2.97	2.77	1.61	1.45	-0.28
Third Q	2.59	1.59	2.60	2.83	3.21	3.47	3.39	1.84	1.62	0.36
Max	4.06	4.06	3.87	4.59	4.59	3.95	3.69	2.86	1.84	0.97

Table 6 and Graph 6 show the interquartile ranges of the age estimation errors on the Zulu sample utilizing the Demirjian *et al* method of age estimation. The minus sign indicates under-estimation of the age in years.

Graph 7 shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups together, using the Moorrees *et al* age determination method. The errors vary in magnitude in the 3 samples in the younger ages; at age 8 years the error is 2.2 years for Indians, 1.2 years for the Tygerberg group and 0.4 years for Zulu children. From 12 to 16 years the errors increase, but are of similar magnitude for the 3 sample groups. This method has a small degree of error for Zulu children between 7 and 11 years of age.

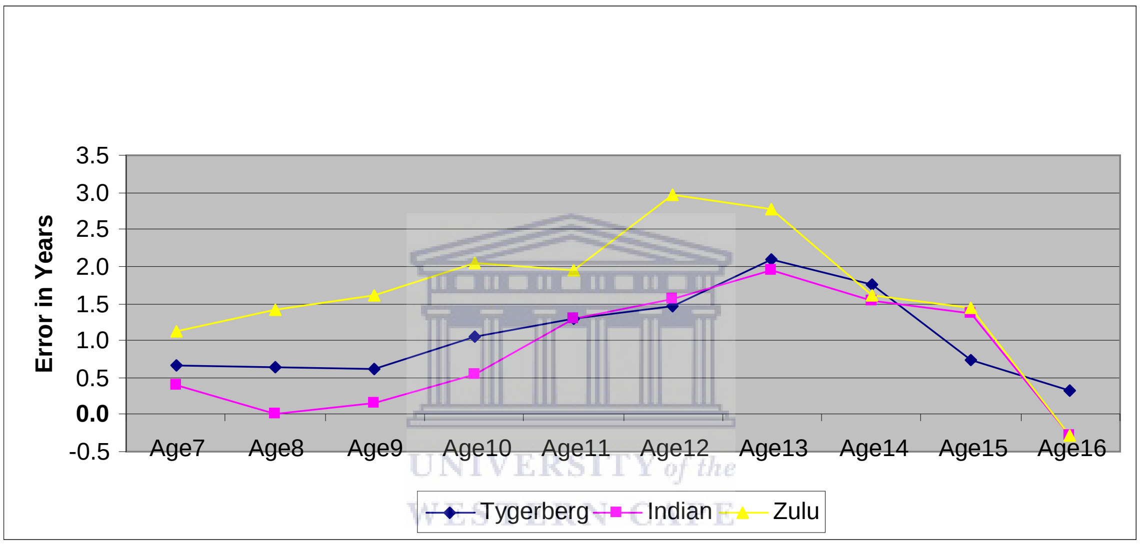
Graph 7: Median Errors made by the MFH method compared to the Real Age



This graph shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the MFH age determination method. The errors vary in magnitude between the 3 samples. At age 8 years the error is 2.2 years for Indians, 1.2 years for the Tygerberg group and 0.4 years for Zulu children. At age 12 to 16 years the errors increase from 1.5 to 3.5 years, but are of similar magnitude for the 3 sample groups.

Graph 8 shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the Demirjian *et al* age determination method. The errors vary in magnitude between the three samples. There is a large error in the 10 to 14 year old Zulu children, which is similar, but not as great in the Tygerberg and Indian groups. The error decreases towards the older ages.

Graph 8: Median Errors made by the Demirjian Method compared to the Real Age



This graph shows the median of the errors of the age estimation of the Tygerberg, Indian and Zulu sample groups using the DGT method. The errors vary in magnitude between the three samples. There is a large error in the 10 to 14 year old Zulu children compared to the Tygerberg and Indian children.

The median errors were used to construct a table of correction factors for each of the age estimation methods of MFH and DGT for the children of the Tygerberg, Indian and Zulu sample groups (Table 7).

Table 7: CORRECTION TABLES FOR DENTAL AGE ESTIMATION ON SOUTH AFRICAN CHILDREN

Moorrees	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Tygerberg	1	1.2	1.4	1.4	1.5	1.6	1.7	2.1	2.9	3.4
Indian	1.7	2.2	1.7	1.2	1.2	1.4	1.8	2.2	2.5	3.4
Black	0.4	0.4	0.1	0.2	0.7	1.1	1.3	2.2	2.5	3.4

Age estimation of lower teeth of left or right quadrant (Canine to 3rd molar). Estimate average age by adding the estimated ages of each tooth and divide by the number of teeth. Add the compensation factor (years)

Demirjian	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15	Age16
Tygerberg	-0.7	-0.6	-0.6	-1	-1.3	-1.5	-2.1	-1.8	-0.7	-0.3
Indian	-0.4	0.0	-0.2	-0.5	-1.3	-1.6	-1.9	-1.5	-1.4	0.3
Black	-1.1	-1.4	-1.6	-2.1	-1.9	-3.0	-2.8	-1.6	-1.5	0.3

Age estimation of lower teeth of left or right quadrant (Central incisor to 2nd molar). Estimated age from weighted tables of Demirjian *et al*. Add the compensation figure (years)

Table 7 shows the age correction factors applicable to the Tygerberg, Indian and Zulu age midpoints from 7 to 16 years of age when using the MFH and DGT methods.

Discussion

The Moorrees, Fanning and Hunt (1963) method under-estimates the dental age of the three sample groups, but by different amounts over the age range of 7 to 16 years (Tables 1, 3 & 5). The Demirjian, Goldstein and Tanner (1973) method over-estimates the ages of the sample groups in similar patterns, but by dissimilar amounts of over-estimation for the same age range (Tables 2, 4 & 6). The data from the calculation of the errors of the age estimations from the interquartile ranges were used to calculate the median error for each of the age estimation methods (Tables 1 to 6). The median error from each of these tables was used to construct a correction factor table for both the MFH and the DGT methods respectively (Table 7). This correction table supplies a correction factor in years for each age midpoint from 7 to 16 years for the Tygerberg, Indian and Zulu samples.

The accuracy of these age correction factors are dependant on knowing the ethnic origin of the individual on whom the age estimation is being exercised using either the MFH or the DGT method.

At either end of the age range for each group, i.e. at age 7 and 16, the dispersion of the errors of age estimation appear smaller than within the central area; this is probably due to the small number of young and older children in the sample groups. If the age of a child is estimated by using either the MFH method or the DGT method, then the correction factor for that age group is added to the estimated age. No distinction is made between males and females as their dental developmental stages related to the real age are very similar.

CHAPTER 7

TESTING OF THE CORRECTION TABLES FOR THE MOORREES *ET AL* & DEMIRJIAN *ET AL* METHODS OF AGE ESTIMATION ON THE TYGERBERG, INDIAN AND ZULU SAMPLES.

Due to the consistent age estimation errors using the methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) on South African children of different population origins, correction factors were derived for both these methods of age estimation. In the calculation of these correction figures it was necessary to derive a correction factor for each age midpoint from 7 to 16 years for the Tygerberg, Indian and Zulu sample groups. These correction figures were specific for each age mid-point of the sample groups (Chapter 8).

The aim was to use the estimated ages of the Tygerberg, Indian and Zulu sample groups using the MFH and DGT methods, then add the correction factors, and compare the results with the chronological ages of the samples.

Materials and methods

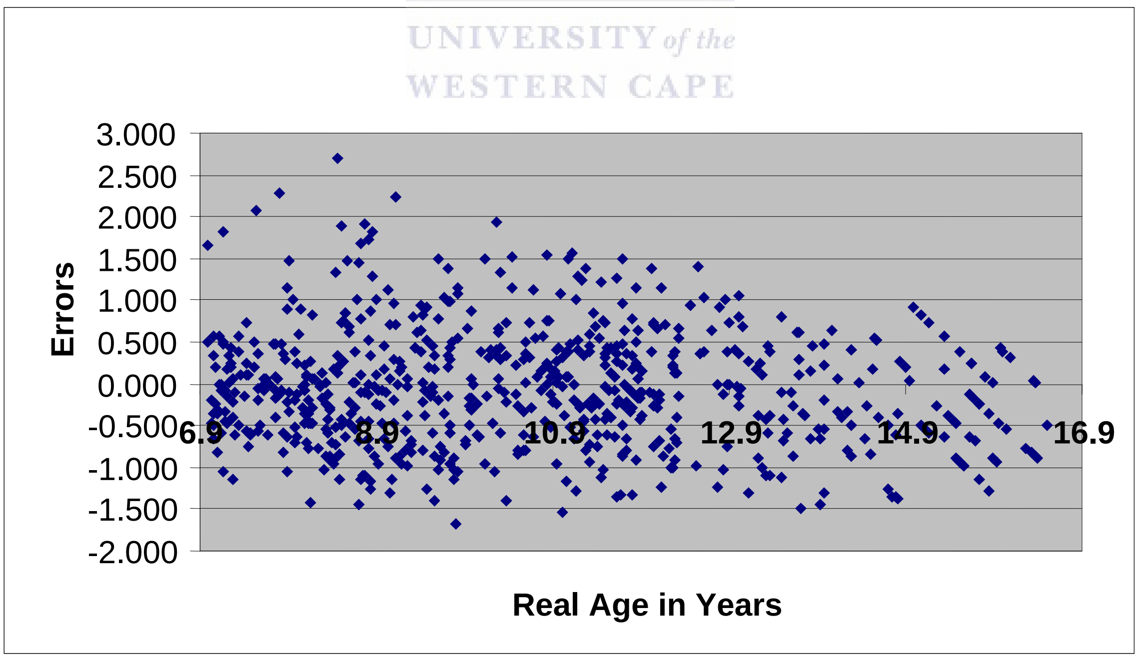
The dental developmental age data from the Tygerberg, Indian and Zulu samples were used to calculate age correction figures for each age group from 7 to 16 years for the age estimation methods of MFH and DGT (Chapter 8, Table 7). The correction figures were positive in the case of the MFH method where there was constant under-estimation of the age. The correction figures were negative in the case of the DGT method as this method over-estimated the ages. The correction figure was added to the estimated age of each individual to produce corrected age estimation. The error of the corrected age was calculated by subtracting the corrected age from the real age (chronological age) and testing it against the real age [Real Age vs Real Age – Corrected Age]. These errors were depicted graphically for each age estimation method on the three sample groups (Graphs 1 to 6).

The percentage of each sample group in which the age was estimated to be within ± 1 year of the real age was calculated for both the MFH and DGT methods. The differences between the uncorrected and corrected age estimations were then tabulated (Tables 1 & 2).

Results

The testing of the Tygerberg sample using the MFH method showed that the ages of 85.86% of the sample, between the ages of 7 to 17 years, were estimated to within 1 year of the chronological age after the application of the correction figures (Graph 1).

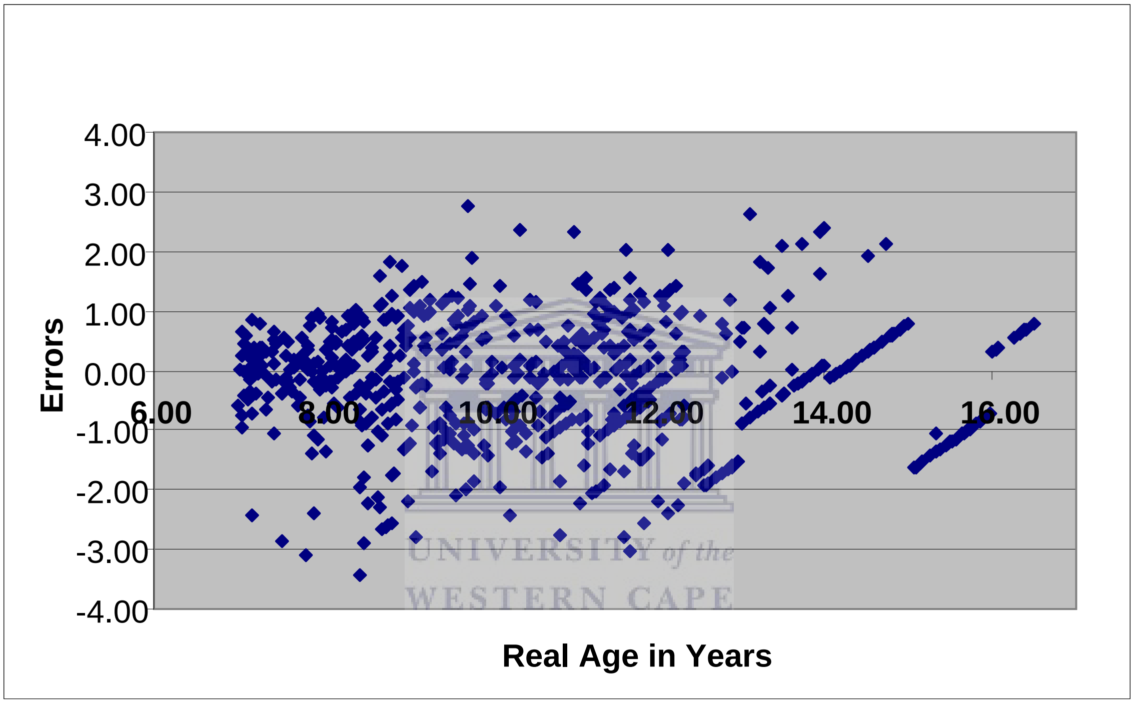
Graph 1: The errors of the corrected age using the MFH method on the Tygerberg sample



Graph 1 shows 85.86% of the Tygerberg sample, between the ages of 7 to 17 years, lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

The testing of the Tygerberg sample using the DGT method showed that 71.88% of the sample, between the ages of 7 to 17 years, was estimated to within 1 year of the chronological age after the application of the correction figures (Graph 2).

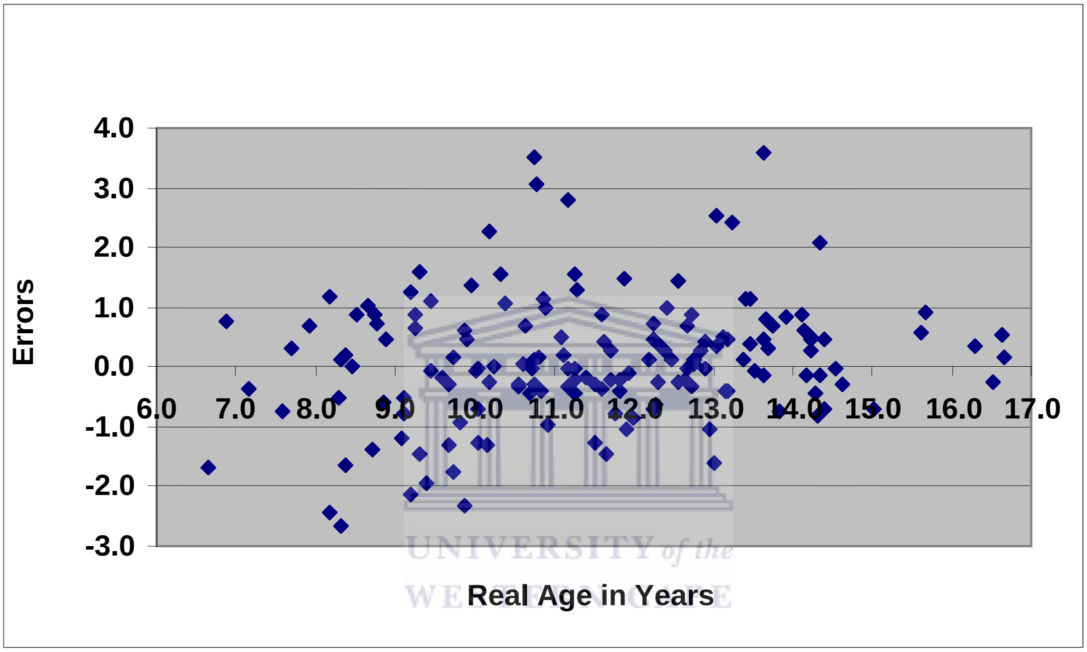
Graph 2: The errors of the corrected age using the DGT method on the Tygerberg sample



Graph 2 shows 71.88% of the Tygerberg sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the DGT method.

The Indian sample, applying the correction figures to the MFH method, showed that 73.88% of the individuals, between the ages of 7 to 17 years, were within 1 year of the chronological age (Graph 3).

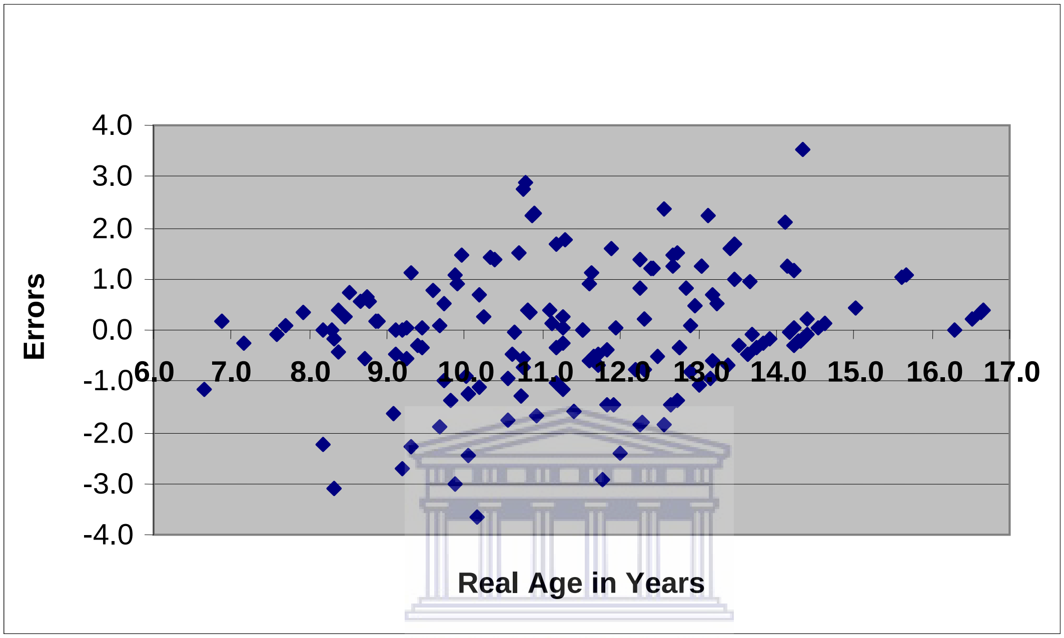
Graph 3: The errors of the corrected age using the MFH method on the Indian sample



Graph 3 shows 73.88% of the Indian sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

After the correction figures for the DGT method were applied to the Indian sample, it showed that 61.14% of the sample was within 1 year of the chronological age (Graph 4).

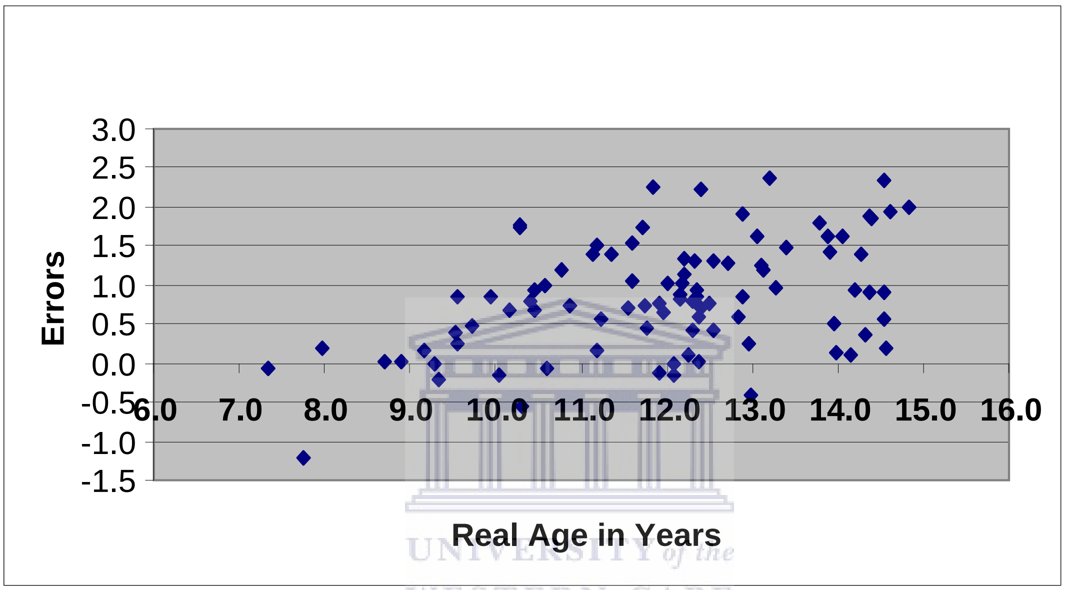
Graph 4: The errors of the corrected age using the DGT method on the Indian sample



Graph 4 shows that 61.14% of the Indian sample between the ages of 7 to 17 years is within ±1 year of the chronological age after the application of the correction factors to the DGT method.

Applying the correction figures to the MFH method on the Zulu sample showed that 61.95% of the individuals, between the ages of 7 to 17 years, were within 1 year of the chronological age (Graph 5).

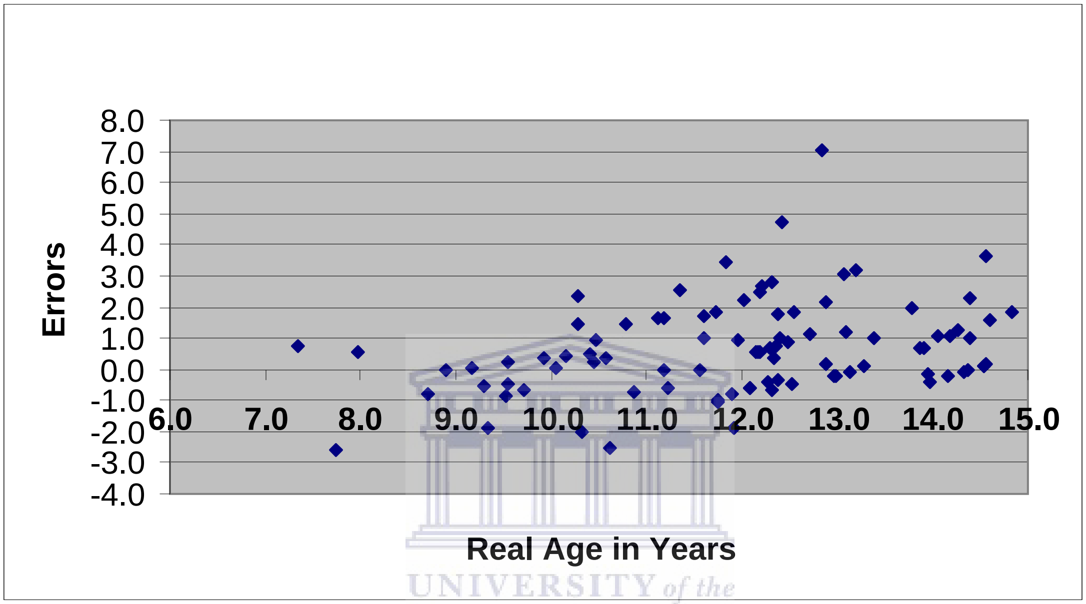
Graph 5: The errors of the corrected age using the MFHl method on the Zulu sample



Graph 5 shows that 61.95% of the Zulu sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the MFH method.

The application of the correction figures to the DGT method on the Zulu sample resulted in 59.78% of the children being within 1 year of their chronological age (Graph 6).

Graph 6: The errors of the corrected age using the DGT method on the Zulu Sample



Graph 6 shows the error between the real age and the corrected age. 59.78% of the Zulu sample between the ages of 7 to 17 years lies within ±1 year of the chronological age after the application of the correction factors to the DGT method.

The percentage of the Tygerberg, Indian and Zulu samples where the age is estimated to within 1 year of the chronological age *using the Correction Tables* for the MFH and DGT methods is shown in Table 1. The Tygerberg sample, using the corrected MFH method, resulted in 85.86% of the group lying within 1 year of the real age; using the DGT corrected method, 71.88% were within 1 year of the real age. The Indian sample, using the corrected MFH method, showed 73.88% of the group within 1 year of the real age; the DGT corrected method resulted in 61.14% within 1 year of the real age. The Zulu sample showed 61.95% of the group within 1 year of the real age for the MFH corrected method and 59.78% for the DGT corrected method. (Table 1)

Table 1: The percentage of the Tygerberg, Indian and Zulu samples that were estimated to within 1 year of the chronological age using the Correction Tables for the MFH and DGT methods

	MFH	**DGT**
Tygerberg	**85.86%**	**71.88%**
Indian	**73.88%**	**61.14%**
Zulu	**61.95%**	**59.78%**

Table 2: The percentage of the Tygerberg, Indian and Zulu samples that were estimated to within 1 year of the chronological age using the un-corrected methods of MFH and DGT.

	Moorrees *et al*	**Demirjian *et al***
Tygerberg	**32.7%**	**55.3%**
Indian	**26.4%**	**45.9%**
Zulu	**45.6%**	**20.6%**

Table 2 shows the results of the age estimation of the Tygerberg, Indian and Zulu samples without the correction factors. The percentage of the samples estimated to within 1 year of the real age showed that the MFH method had 32.7% and the DGT method 55.3% for the Tygerberg group. The Indian sample resulted in 26.4% for the MFH method and 45.9% for the DGT method. The Zulu sample resulted in 45.6% for the MFH method and 20.6% for the DGT method.

Conclusion

The correction factor improved the age estimation to within ± 1 year of the real age of the Moorrees, Fanning and Hunt [MFH] (1963) method from 32.7% to 85.9% for the Tygerberg sample. Similarly the improvement between the uncorrected and corrected age estimation on the Indian sample was from 26.4% to 73.88%. The Zulu sample improved the age estimation from 45.6% to 61.95% of the sample.

The age estimation of the Tygerberg sample by the Demirjian, Goldstein and Tanner [DGT] (1973) method improved the age estimation to within ±1 year from 55.3% to 71.88% by using the correction factors. In the Indian sample the improvement was from 45.9% of the group to 61.14% of the individuals being estimated to within ±1 year of their real age. The Zulu sample group improved from 20.6% to 59.78%.

From these results it is seen that the corrected age estimation methods of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) improved the age estimation markedly for each of the South African sample groups.

CHAPTER 8

TESTING THE CORRECTION FACTORS FOR THE MOORREES *ET AL* AND DEMIRJIAN *ET AL* METHODS ON NEW SAMPLES OF TYGERBERG, INDIAN AND ZULU CHILDREN.

The correction figures that were derived for the age estimation methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) were tested on the original samples of Tygerberg, Indian and Zulu children (Chapter 9). The results showed that the correction factor improved the age estimation of these children significantly. The question was whether this corrected method was accurate when applied to new samples of these children.

The aim was to test the accuracy of the correction figures for the MFH and DGT methods on new samples of children from the Tygerberg records, Indian and Zulu children from the Orthodontic practice in Durban.

Materials and Methods

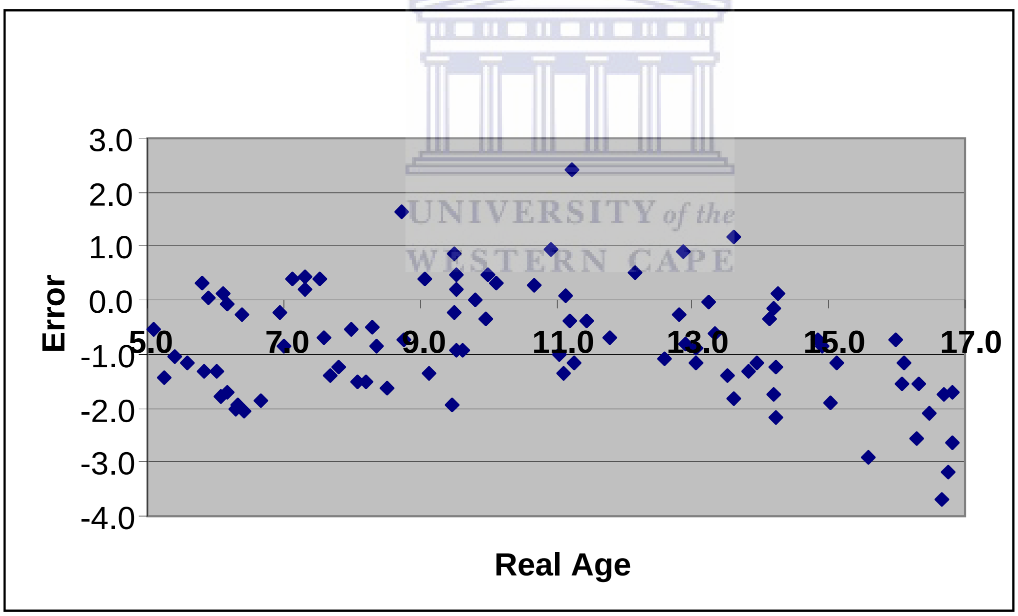
The Pantomographic radiographs from the archived records of children treated at Tygerberg Dental Faculty were accessed and an additional 97 radiographs not used in the original sample were selected for age estimation. An orthodontic practice in Durban was used to acquire Pantomographs of Indian and Zulu children who had undergone recent treatment. The Indian sample consisted of 73 boys and girls; the Zulu sample consisted of 90 individuals. Each of the three samples had an age range of 7 to 16 years.

The age of each individual was estimated using the MFH and DGT methods and the appropriate correction figure was added to the result. The age estimation error was compared to the real age of each individual and represented graphically. The error of the age estimation was recorded to within 1 year of the real age. These results were compared to the results of the previous corrected age estimation by MFH and DGT methods on the original samples of children. These new samples were labelled Tygerberg II, Indian II and Zulu II respectively. There was no separation into sexes.

Results

The age estimation of the Tygerberg II sample using the corrected MFH method resulted in 52.6% of the sample being within ± 1 year of the real age (Graph 1).

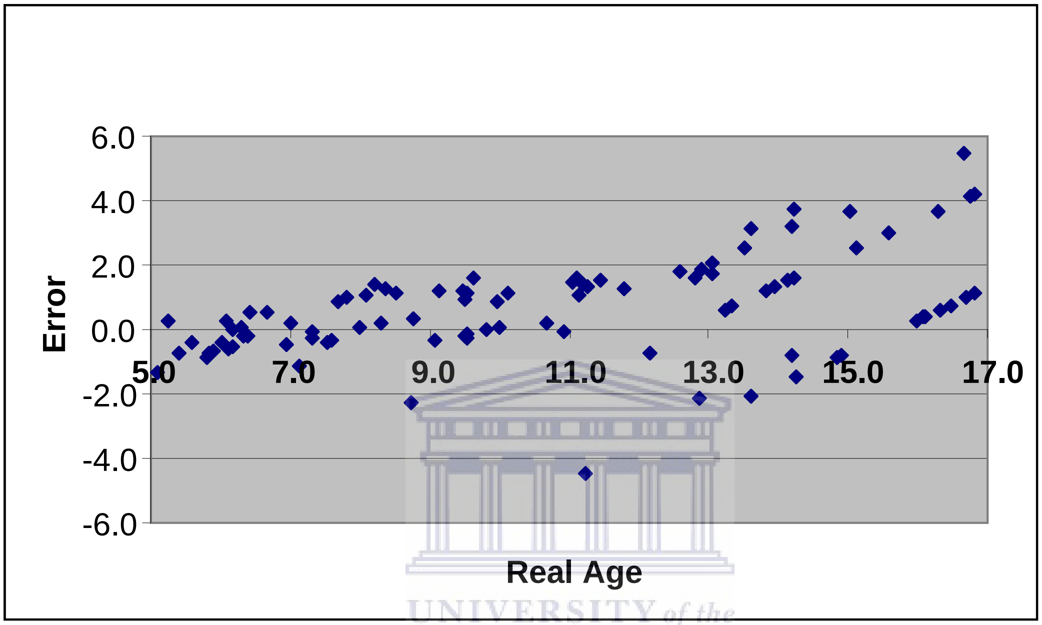
Graph 1: Tygerberg II sample: Age estimation using the corrected MFH method



This graph shows 52.6% of the Tygerberg sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT resulted in 53.68% of the ages of the Tygerberg II sample being estimated to within ± 1 year of the real age (Graph 2).

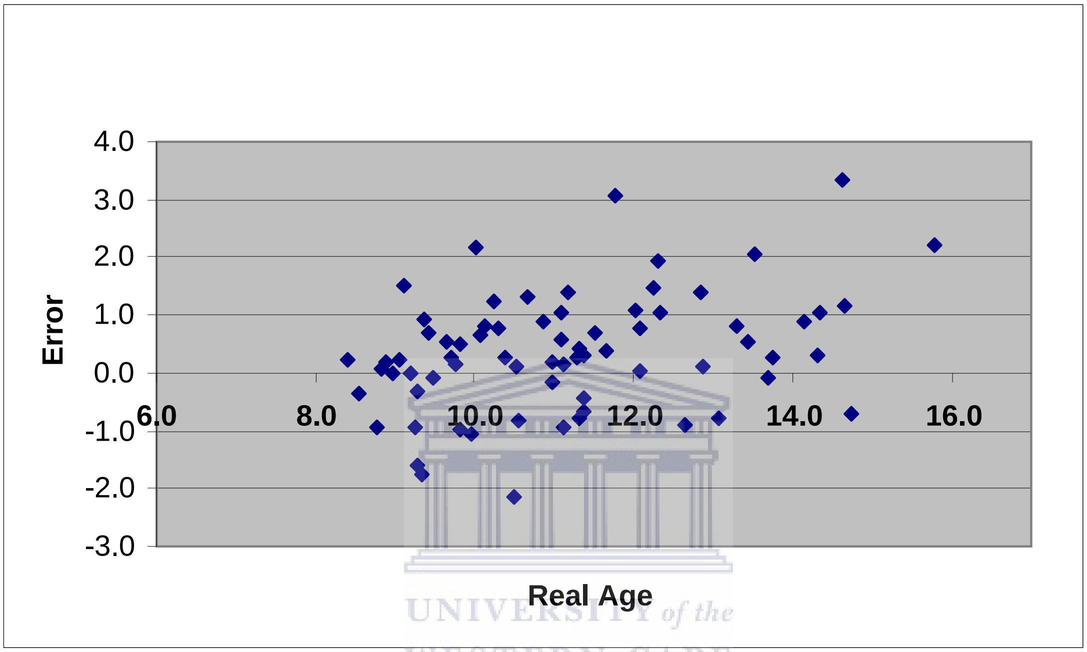
Graph 2 Tygerberg II sample: Age estimation using corrected DGT method



This graph shows 53.68% of the Tygerberg sample was within 1 year of the real age using the corrected DGT method.

The Indian II sample using the corrected MFH method resulted in the ages of 70.8% of the sample being estimated to within ± 1 year of the real age (Graph 3).

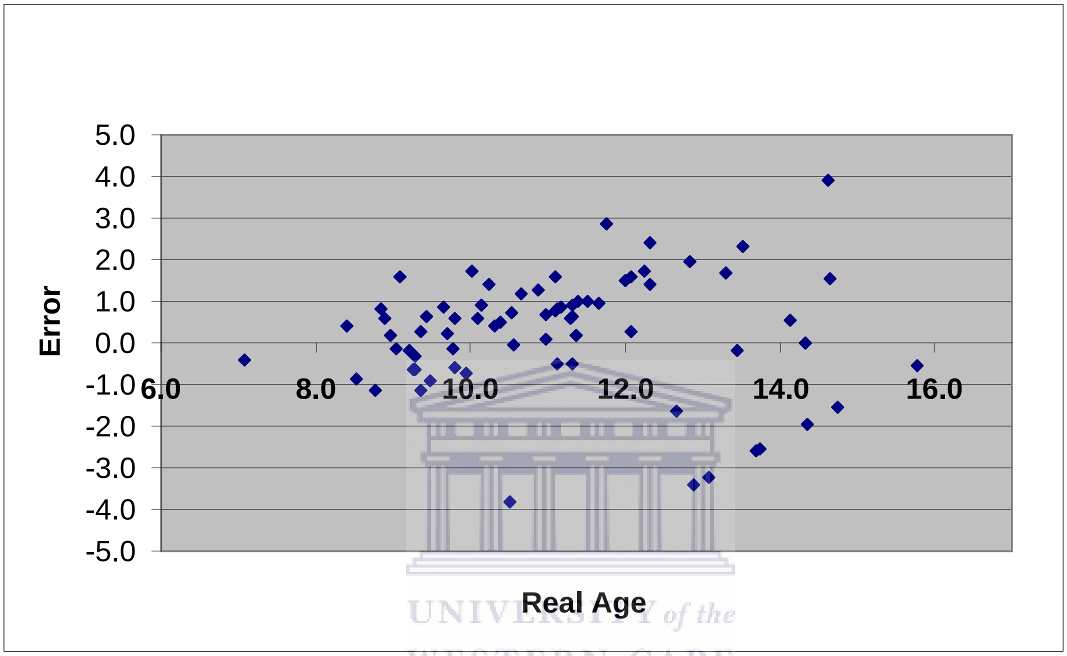
Graph 3 Indian II sample: Age estimation using corrected MFH method



This graph shows 70.8% of the Indian sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT method on the Indian II sample resulted in 61.6% being estimated to within ± 1 year of the real age (Graph 4).

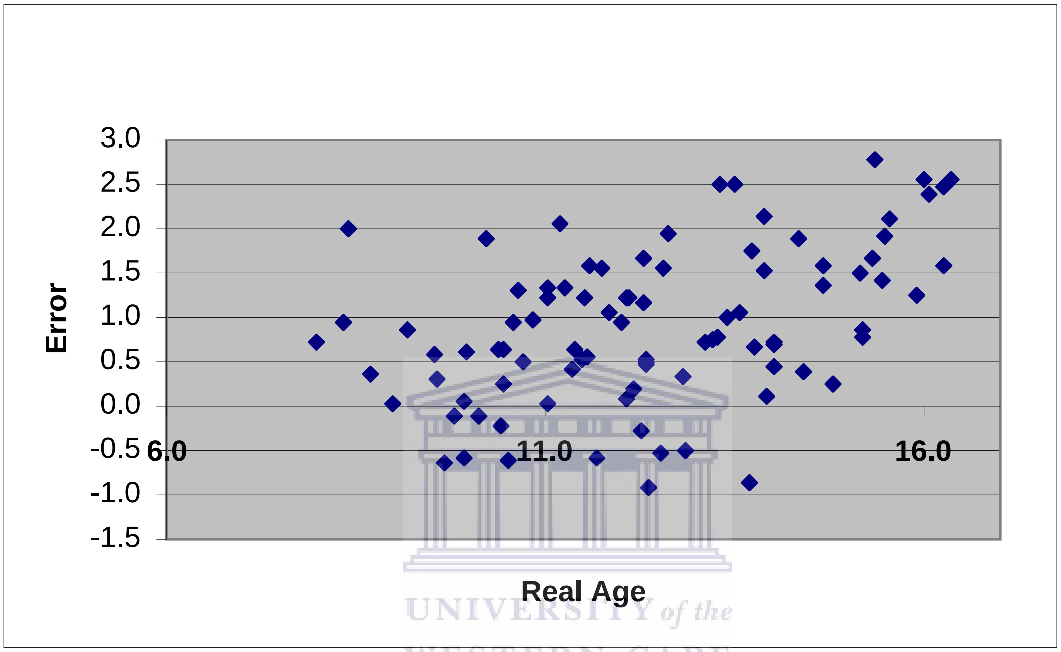
Graph 4 Indian II sample: Age estimation using corrected DGT method



This graph shows 61.6% of the Indian sample was within 1 year of the real age using the corrected DGT method.

The Zulu II sample using the corrected MFH method resulted in 58% being estimated to within ± 1 year of the real age (Graph 5)

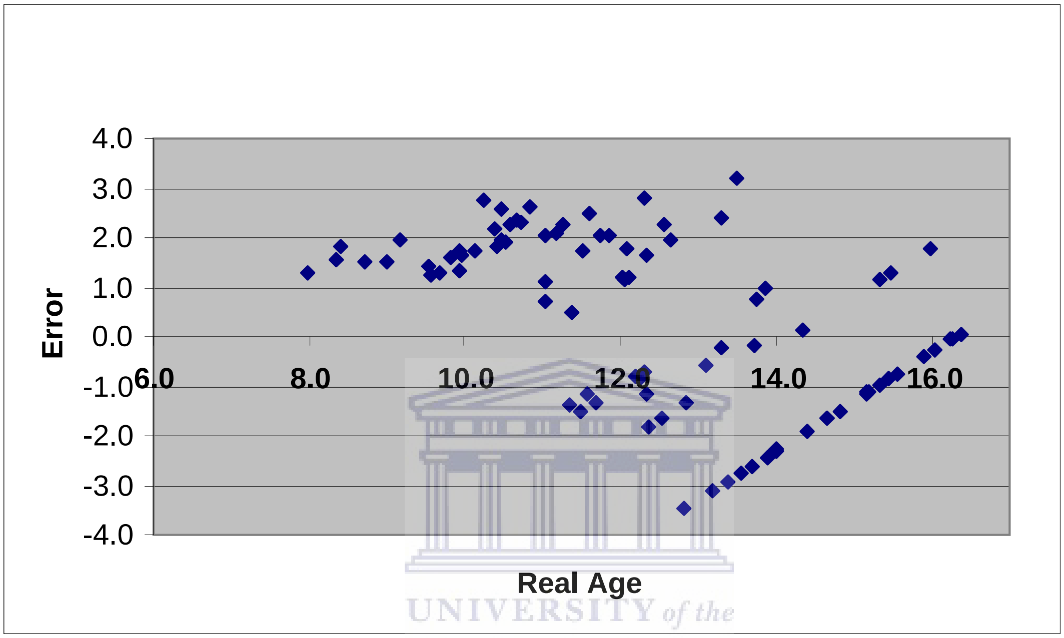
Graph 5: Zulu II sample: Age estimation using corrected MFH method



This graph shows 58% of the Zulu sample was within 1 year of the real age using the corrected MFH method.

The corrected DGT method of the Zulu II sample resulted in 21% being estimated to within ± 1 year of the real age (Graph 6).

Graph 6: Zulu II sample: Age estimation using corrected DGT method



This graph shows 21.0% of the Zulu sample was within 1 year of the real age using the corrected Demirjian *et al* method.

The comparison of the results of the application of the correction factor for age estimation of the 1st and 2nd samples of Tygerberg, Indian and Zulu children by the MFH and DGT methods are shown in Table 1.

Table 1: Comparison between the corrected MFH and DGT methods on samples I and II of Tygerberg, Indian and Zulu children

Samples	Corrected MFH method	Corrected DGT method
Tygerberg I	**85.86%**	**71.88%**
Indian I	**73.88%**	**61.14%**
Zulu I	**61.95%**	**59.78%**
Tygerberg II	**52.6%**	**53.68%**
Indian II	**70.8%**	**61.6%**
Zulu II	**58%**	**21%**

The correction factor for MFH method on the Tygerberg I sample resulted in an age estimation of 85.86% of the sample to within 1 year of the real age. In the Tygerberg II sample the correction factor resulted in 52.6% of the sample being estimated to within 1 year of the real age. The correction of the MFH method in the Indian I and Indian II samples showed a slight change in the age estimation from 73.88% to 70.8% respectively. The Zulu samples, the age estimation using the MFH correction, changed from 61.95% for the 1st sample to 58% for the 2nd sample.

The correction factor for the DGT method on the Tygerberg I sample resulted in age estimation of 71.88% to within 1 year of the real age and 53.68% of the Tygerberg II sample. The Indian samples using the DGT correction showed very little difference between the two samples, changing from 61.14% in sample I to 61.6% in sample II. The Zulu samples, however, showed marked differences between the two samples; the DGT corrected method on the Zulu I sample resulted in 59.78% being estimated to within 1 year of the real age; the Zulu II sample resulted in 21% being within 1 year of the real age.

Discussion

The results show that the correction factor using both the MFH and DGT methods are equally applicable to the Indian children and the age estimation improved markedly. The dramatic decrease from 85.86% for the Tygerberg I to 52.6% of the Tygerberg II children using the corrected MFH method may be due to 2 factors. The Tygerberg II sample was much smaller than the Tygerberg I sample and the error may be due to the sample size discrepancy. Alternately the Tygerberg I sample consisted of mainly 'White' children whereas the Tygerberg II sample, due to the demographic change in patient intake at the Dental School, consisted mainly of 'Coloured' children. This decrease in the percentage of children estimated to within 1 year of their real age was also seen in the Tygerberg samples when using the DGT corrected method; the Tygerberg I sample showed 71.88% and the Tygerberg II sample 53.68%.

The MFH corrected method on the Zulu group remained relatively the same for both samples; 61.95% for the first sample and 58% for the second sample, but the corrected DGT method failed significantly in the second sample with only 21% of the estimated ages being within 1 year of the real age. The explanation for this could be due to the second sample of Zulu children being of a different socio-economic background to the Zulu I group and the correction factor that was derived from the first group was not applicable to the second group. The Zulu I group of children were from records obtained from the archives of the orthodontic practice and were all patients treated prior to 1990. These children were from a socio-economic background where their parents could afford private orthodontic treatment. The Zulu II group were from recent cases still undergoing treatment and from a different socio-economic background and whose parents were working class people covered by medical aid insurance.

Conclusion

The dental age estimation method of Moorrees, Fanning and Hunt (1963) using the correction factor, when applied to White-Coloured, Indian and Black South African children, will improve the accuracy of this method as shown in both the samples of children. The corrected Demirjian, Goldstein and Tanner (1973) method is applicable but less accurate than the MFH method when applied to the same samples of South African children. The correction factor, however, when used with the DGT method on Black children is inaccurate.

CHAPTER 10

TESTING THE PHILLIPS AGE ESTIMATION TABLES ON SAMPLES OF TYGERBERG, INDIAN AND XHOSA CHILDREN

The previous chapter showed the derivation of dental age related tables for a Tygerberg sample of children of White and Coloured origin. Tables were also derived for Indian and African (Nguni) children. These tables will be described as Phillips Tables for this chapter. Phillips Table 1 is the table for age estimation of White and Coloured children (Tygerberg); Phillips Table 2 is the table derived for Indian children and Phillips Table 3 is for African (Nguni) children.

The aim of this study was to compare the estimated ages of the three sample groups using the MFH and DGT methods with the dental age related tables of Phillips and to analyse the results statistically.

Materials and methods

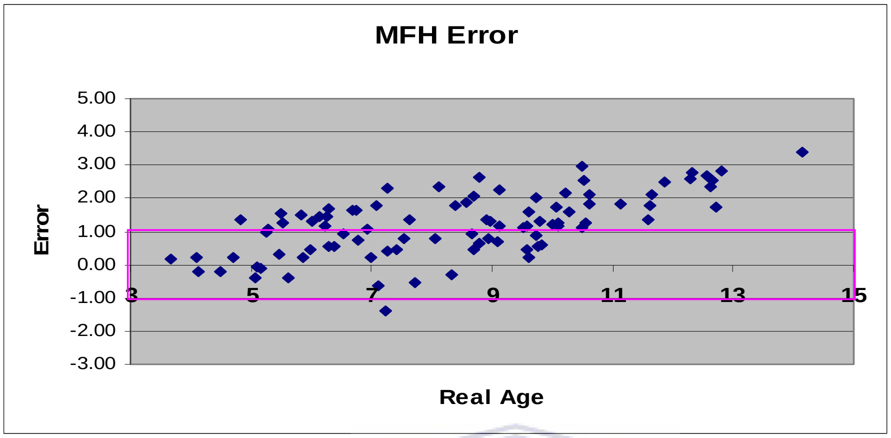
The new Tygerberg sample used for this part of the study was an additional set of individuals obtained from the files of children currently undergoing dental treatment at the Dental Faculty of the University of the Western Cape. The Tygerberg sample consisted of 91 children, 70 White, 21 Coloured. The Indian and Xhosa samples were a random selection of children from the original data bases used in this study. There were 112 Indian and 62 Xhosa children respectively. The Tygerberg, Indian and Xhosa samples were analysed in the following manner: the age of each child was estimated using the MFH, the DGT methods. Then the ages of the samples were estimated using the Phillips Tables applicable for each sample. (Phillips Table 1 was used for the Tygerberg sample, Phillips Table 2 was used for the Indian sample and Phillips Table 3 was used for the Xhosa sample). The age estimation error for each method was calculated and depicted graphically. The real ages and the errors of the estimated ages of each method were subjected to regression analysis. All r-correlation coefficients were tested for significance and in every case the p-value was significant at the $p< 0.05$ level.

Results

THE NEW TYGERBERG SAMPLE

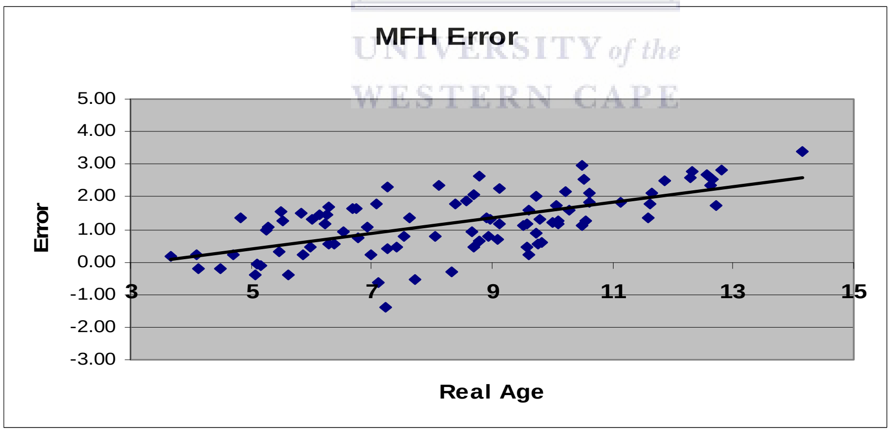
The MFH method of age estimation of the new Tygerberg sample resulted in 38.4% of the sample being estimated to within 1 year of the real age (Graph 1). Regression analysis of the MFH method showed an R-value of 0.63 with a p-value of 1.6376×10^{-11}(Table 1).

Graph 1a: The age estimation error of the MFH method. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00. *The alignment* of the sample (Graph 1a) shows that 38.4 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample. [If the error is positive then the estimated age is less than the real age]

Graph 1b: The age estimation error of the MFH method. Tygerberg (n = 91)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 1b). The R-value (R = 0.633) indicates that the MFH method is strongly predictive. The regression correlation is significant ($p<0.05$)

Table 1: Regression analysis of MFH method on the Tygerberg sample

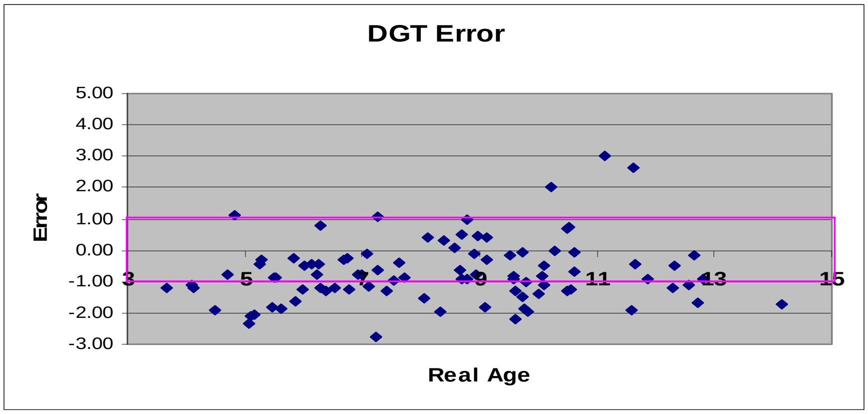
Regression Statistics	
R	0.633
R Square	0.401
Observations	91

ANOVA

	df	Significance F
Regression	1	1.6376E-11
Residual	89	
Total	90	

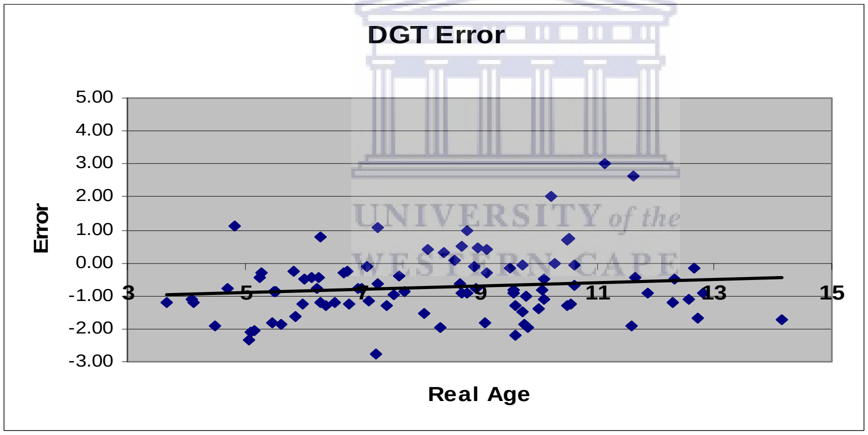
The DGT method of age estimation of the Tygerberg sample resulted in 53.8% of the sample being estimated to within 1 year of the real age (Graph 2). Regression analysis of the DGT method showed an R-value of 0.91 with a p-value of 2.40489×10^{-36} (Table 2).

Graph 2a: The age estimation error of the DGT method. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00.*The alignment* of the sample (Graph 2a) shows that 53.8 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 2b: The age estimation error of the DGT method. Tygerberg (n = 91)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 2b). The R-value (R = 0.913) indicates that the DGT method is strongly predictive. The regression correlation is significant ($p<0.05$)

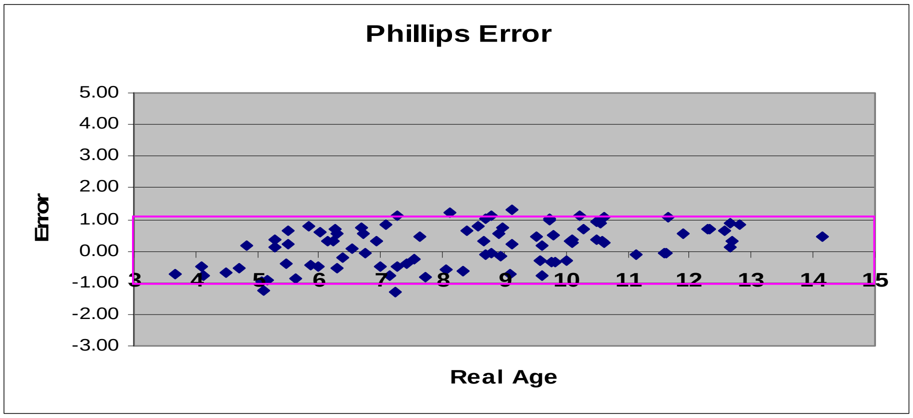
Table 2: Regression analysis of the DGT method on the Tygerberg sample

Regression Statistics		
R	0.913	
R Square	0.833	
Observations	91	
ANOVA		
	df	Significance F
Regression	1	2.40489E-36
Residual	89	
Total	90	

The R correlation is significant ($p<0.05$) and strongly predictive. This method is more accurate than the MFH method, but over-estimates the ages of 46.8% of the Tygerberg sample.

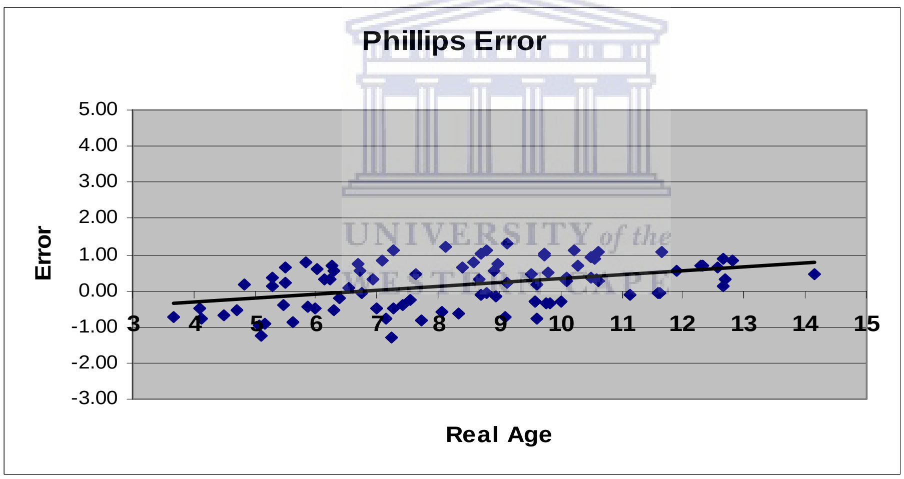
The Phillips Table 1 used for age estimation of the Tygerberg sample resulted in 88.4% of the sample being estimated to within 1 year of the real age (Graph 3). Regression analysis of the Phillips Table 1 showed an R-value of 0.966 with a p-value of 3.18422 x 10^{-54} (Table 3)

Graph 3a: The age estimation error of the Phillips Table 1. Tygerberg (n = 91)



The scale of the error is from -3.00 to 5.00. *The alignment* of the sample shows that 88.4 % of the sample is within 1 year of Real Age.

Graph 3b: The age estimation error of the Phillips Table 1. Tygerberg (n = 91)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 3b). The R-value (R = 0.966) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 3: Regression analysis of the Phillips Table 1 on the Tygerberg sample

Regression Statistics	
R	0.966
R Square	0.934
Observations	91

ANOVA

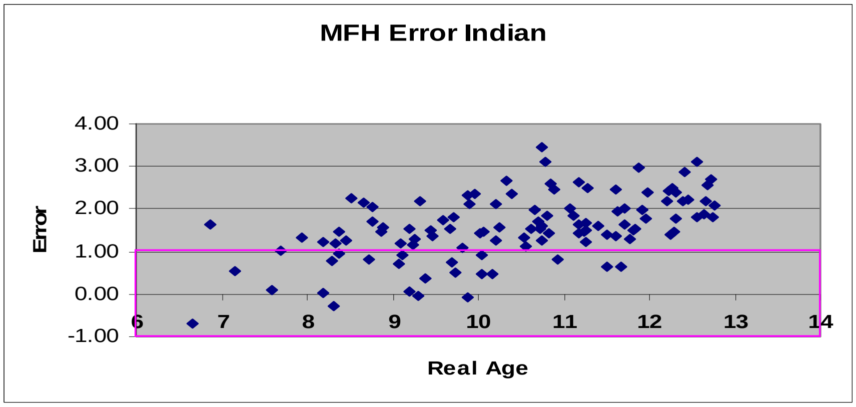
	df	Significance F
Regression	1	3.18422E-54
Residual	89	
Total	90	

The Phillips method is more accurate than the MFH and the DGT methods for ageing Tygerberg children.

THE INDIAN SAMPLE

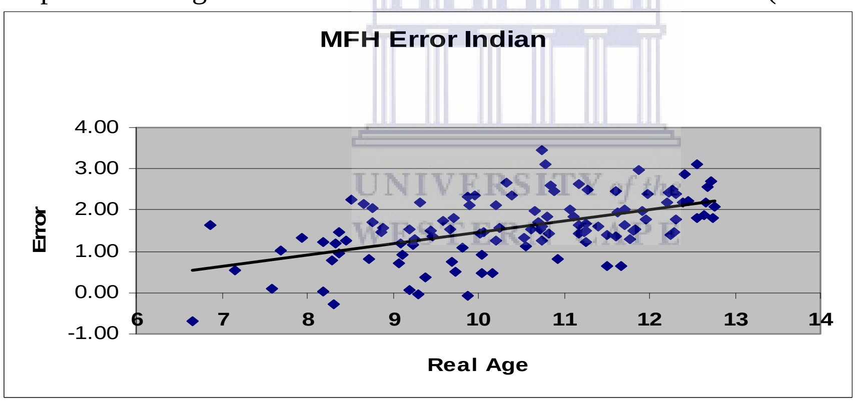
The MFH method of age estimation of the Indian sample resulted in 19.6% of the sample being estimated to within 1 year of the real age (Graph 6). Regression analysis of the MFH method showed an R-value of 0.54 with a p-value of 7.70422×10^{-10} (Table 4).

Graph 4a: The age estimation error of the MFH method. Indian (n = 112)



The scale of the error is from -1.00 to 4.00. *The alignment* of the sample (Graph 6a) shows that 19.6 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 4b: The age estimation error of the MFH method. Indian (n = 112)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 4b). The R-value (R = 0.540) indicates that the MFH method is predictive. The regression correlation is significant ($p<0.05$)

Table 4: Regression analysis of the MFH method on the Indian sample

Regression Statistics	
R	0.540
R Square	0.292
Observations	112

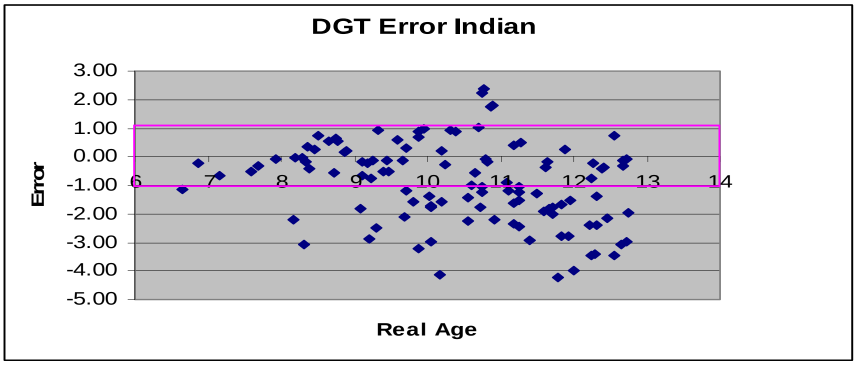
ANOVA

	df	Significance F
Regression	1	7.70422E-10
Residual	110	
Total	111	

The R correlation is significant ($p<0.05$) and predictive, but the MFH method under-estimates the ages of 80.4% of the Indian sample.

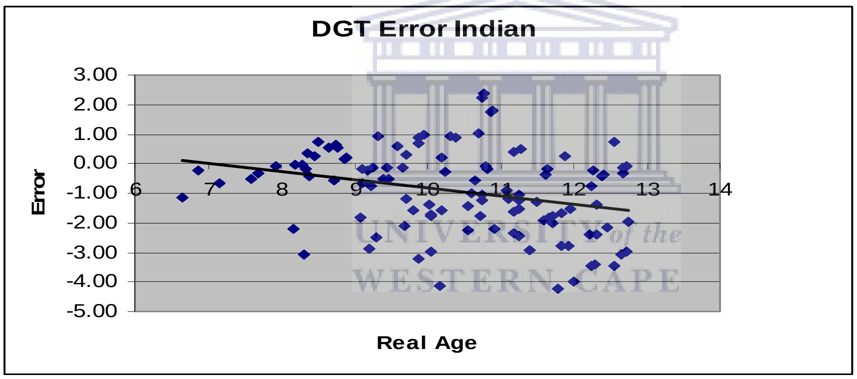
The DGT method of age estimation of the Indian sample resulted in 46.4% of the sample being estimated to within 1 year of the real age (Graph 7). Regression analysis of the DGT method showed an R-value of 0.306 with a p-value of 0.001022 (Table 5).

Graph 5a: The age estimation error of the DGT method. Indian (n = 112)



The scale of the error is from -5.00 to 3.00.*The alignment* of the sample (Graph 7a) shows that 46.4 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 5b: The age estimation error of the DGT method. Indian (n = 112)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 5b). The R-value (R = 0.306) indicates that the DGT method is predictive, but there is a significant amount of scatter around the trend line. The regression correlation is significant (p<0.05)

Table 5: Regression analysis of the DGT method on the Indian sample

Regression Statistics	
R	0.306
R Square	0.094
Observations	112

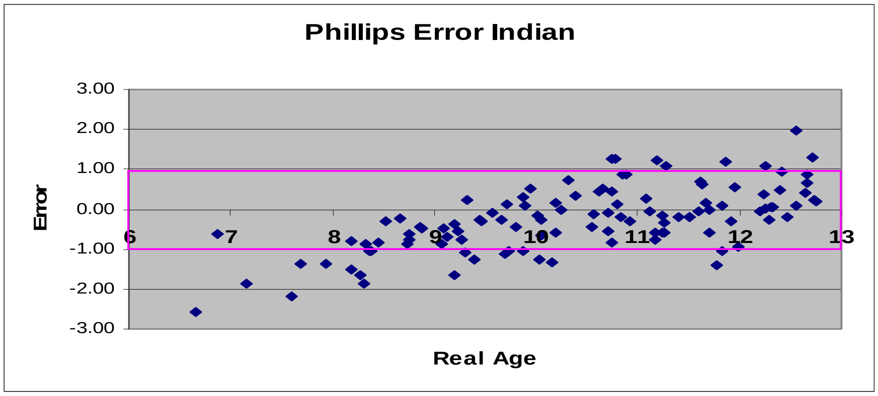
ANOVA

	df	Significance F
Regression	1	0.001022684
Residual	110	
Total	111	

The regression correlation is significant (p<0.05) for the DGT method. The method overestimated the ages of 53.6% of the Indian sample.

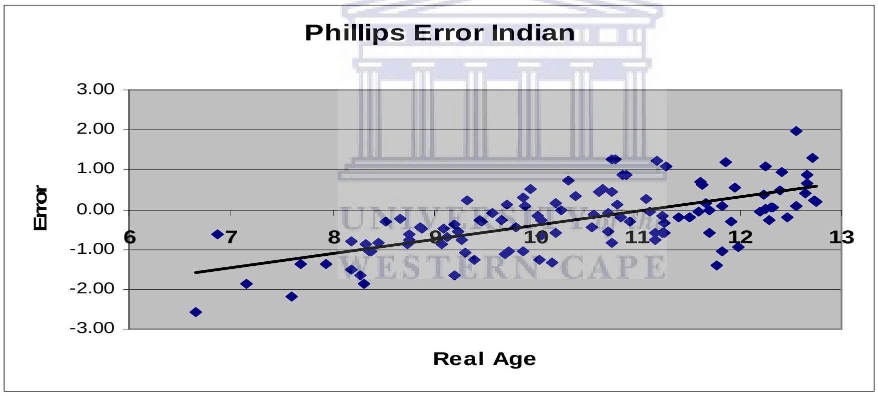
The Phillips Table 2 used for age estimation of the Indian sample resulted in 75% of the sample being estimated to within 1 year of the real age (Graph 8). Regression analysis of the Phillips Table 2 showed an R-value of 0.65 with a p-value of 8.22195×10^{-15} (Table 6).

Graph 6a: The age estimation error of the Phillips Table 2. Indian (n = 112)



The scale of the error is from -3.00 to 3.00. *The alignment* of the sample shows that 75 % of the sample is within 1 year of Real Age.

Graph 6b: The age estimation error of the Phillips Table 2. Indian (n = 112)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 6b). The R-value (R = 0.651) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 6: Regression analysis of Phillips Table 2 on the Indian sample

Regression Statistics	
R	0.651
R Square	0.423
Observations	112

ANOVA

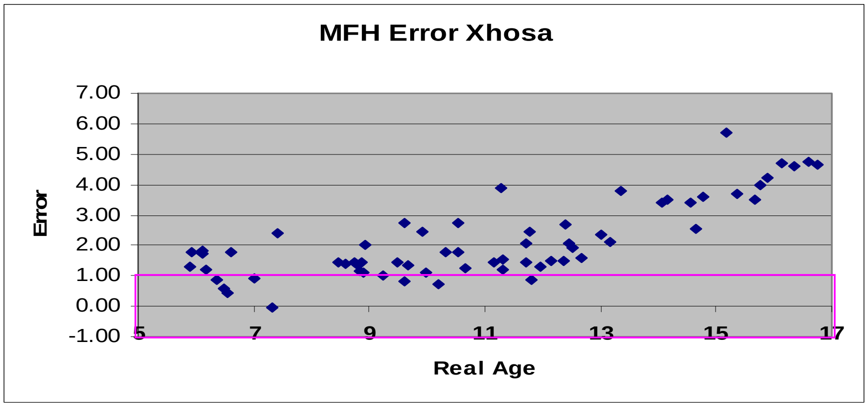
	df	*Significance F*
Regression	1	8.22195E-15
Residual	110	
Total	111	

The Phillips method is more accurate than the MFH and the DGT methods for ageing Indian children.

THE XHOSA SAMPLE

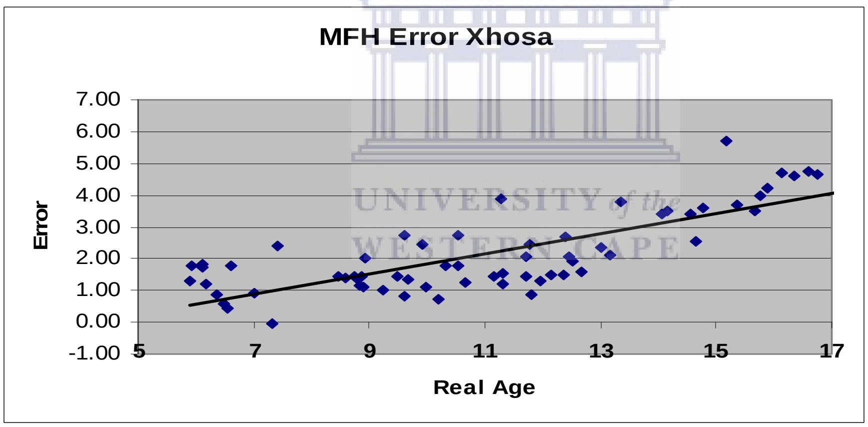
The MFH method of age estimation of the Xhosa sample resulted in 13.8% of the sample being estimated to within 1 year of the real age (Graph 11). Regression analysis of the MFH method showed an R-value of 0.784 with a p-value of 1.06964×10^{-14} (Table 7).

Graph 7a: The age estimation error of the MFH method. Xhosa (n = 65)



The scale of the error is from -1.00 to 7.00. *The alignment* of the sample (Graph 11a) shows that 13.8 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 7b: The age estimation error of the MFH method. Xhosa (n = 65)



The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 7b). The R-value (R = 0.784) indicates that the MFH method is strongly predictive. The regression correlation is significant ($p<0.05$)

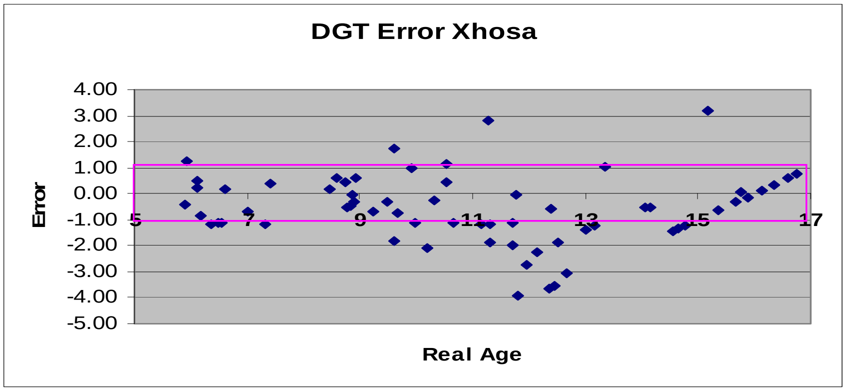
Table 7: Regression analysis of the MFH method on the Xhosa sample

Regression Statistics		
R		0.784
R Square		0.615
Observations		65
ANOVA		
	df	Significance F
Regression	1	1.06964E-14
Residual	63	
Total	64	

The R correlation is significant ($p<0.05$) and predictive, but the MFH method under-estimates the ages of 86.2% of the Xhosa sample.

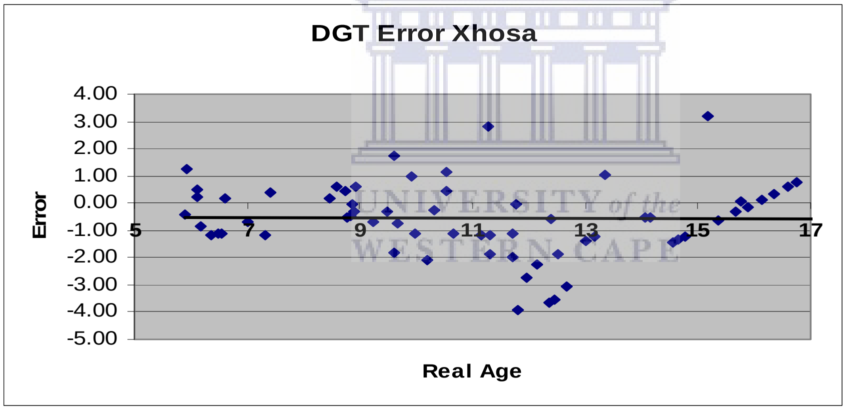
The DGT method of age estimation of the Xhosa sample resulted in 49.2% of the sample being estimated to within 1 year of the real age (Graph 12). Regression analysis of the DGT method showed an R-value of 0.013 with a p-value of 0.912053379 (Table 8).

Graph 8a: The age estimation error of the DGT method. Xhosa (n = 62)



The scale of the error is from -5.00 to 4.00.*The alignment* of the sample (Graph 12a) shows that 49.2 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 8b: The age estimation error of the DGT method. Xhosa (n = 62)



The accuracy of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 8b). The R-value (R = 0.014) indicates that the DGT method is not predictive because there is a significant amount of scatter around the trend line even though this line is parallel to the X-axis. The regression correlation is not significant (p=0.912)

Table 8: Regression analysis of the DGT method on the Xhosa sample

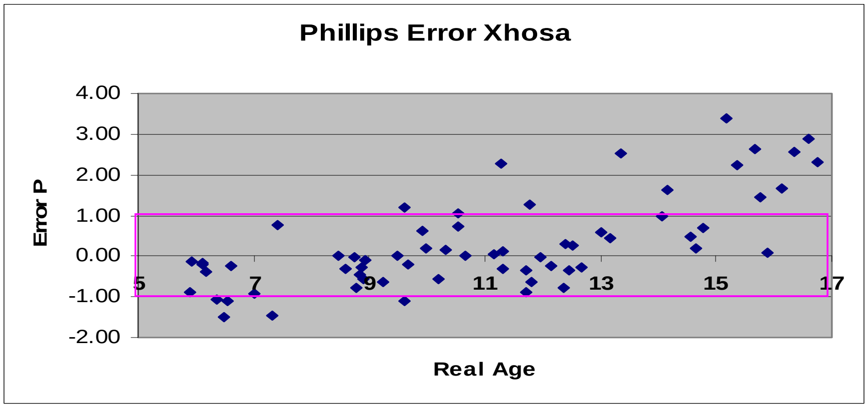
Regression Statistics	
R	0.014
R Square	0.0001
Observations	65

ANOVA		
	df	Significance F
Regression	1	0.912053379
Residual	63	
Total	64	

The DGT method is not applicable for age estimation of the Xhosa sample.

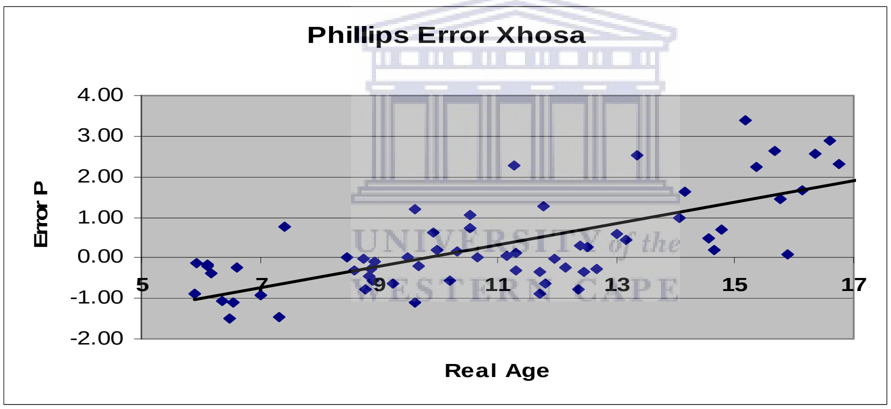
The Phillips Table used for age estimation of the Xhosa sample resulted in 69.2% of the sample being estimated to within 1 year of the real age (Graph 13). Regression analysis of the Phillips Table 3 showed an R-value of 0.71 with a p-value of 2.10552×10^{-11} (Table 9)

Graph 9a: The age estimation error of the Phillips Table 3. Xhosa (n = 62)



The scale of the error is from -2.00 to 4.00. *The alignment* of the sample shows that 69.2% of the sample is within 1 year of Real Age.

Graph 9b: The age estimation error of the Phillips Table 3. Xhosa (n = 62)



The accuracy of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 9b). The R-value (R = 0.716) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 9: The Regression analysis of Phillips Table 3 on Xhosa sample

Regression Statistics	
R	0.716
R Square	0.512
Observations	65

ANOVA

	Significance F
Regression	2.10552E-11
Residual	
Total	

The Phillips method is more accurate for the age estimation of Xhosa children than the MFH and DGT methods.

The age estimation errors for the Tygerberg sample using the MFH, DGT and the Phillips Table 1 resulted in 38.4%, 53.8% and 88.4% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Tygerberg sample showed that the r-value of 0.966 (Table 11) and the p-value of 3.18×10^{-54} indicate that the Phillips Table 1 for White and Coloured children is more accurate than the methods of MFH and DGT.

The age estimation errors for the Indian sample using the MFH, DGT and the Phillips Table 2 resulted in 19.6%, 46.4% and 75% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Indian sample showed that the r-value of 0.651 (Table 11) and the p-value of 8.22×10^{-15} indicate that the Phillips Table 2 for Indian children is more accurate than the methods of MFH and DGT. The age estimation errors for the Xhosa sample using the MFH, DGT and the Phillips Table methods resulted in 13.8%, 49.2% and 69.2% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 10). The regression analysis of the estimated ages of the Xhosa sample showed that the r-value of 0.716 (Table 11) and the p-value of 2.106×10^{-11} indicate that the Phillips Table 3 for Xhosa children is more accurate than to the methods of MFH and DGT.

Table 10: The percentages of the Tygerberg, Indian & Xhosa samples estimated to within 1 year of the chronological age using the methods of MFH, DGT and Phillips

	Tygerberg	Indian	Xhosa
MFH	**38.4**	**19.6**	**13.8**
DGT	**53.8**	**46.4**	**49.2**
Phillips	**88.4**	**75.0**	**69.2**

Table 11: The regression correlation of the ageing errors for the MFH, DGT & Phillips methods on the Tygerberg, Indian and Xhosa samples

	Tygerberg	Indian	Xhosa
MFH	**R = 0.633**	**R = 0.540**	**R = 0.784**
DGT	**R = 0.913**	**R = 0.306**	**R = 0.014**
Phillips	**R = 0.966**	**R = 0.651**	**R = 0.716**

Discussion and Conclusion

The MFH method consistently under-estimated the age of the South African children. The performance of the MFH method for the White and Coloured children was poor as it only estimated the ages of 38% of the sample to within 1 year of the chronological age. The MFH method performed very poorly for the Indian and Xhosa children. The DGT method over-estimated the ages of the samples. The performance of the DGT method was relatively constant for all three samples, estimating the ages to within 1 year in approximately 50% in all cases. The Phillips Tables for White and Coloured, Indian and African (Nguni) children was found to be more accurate than the MFH and DGT methods when estimating the ages of South African children.

CHAPTER 11

DISCUSSION AND CONCLUSIONS

This study has encountered various problems in the estimation of age using radiographic images and the application of dental age related tables to children of different population groups by using the standard age estimation methods. This discussion will highlight these problems and suggest further investigation.

Radiographic images:

Pictorial images of the various stages of tooth development were taken to illustrate the calcification of crowns and roots of the teeth as they age. The examination of the Pantomographic images of the developing teeth highlighted some areas of difficulty in interpreting the developmental stages. Firstly it is difficult in numerous cases to visualise the root apical calcification stages of the incisors due to the superimposition of the cervical spine on the radiograph. The difference in the formation of the root apex between 'A½' and 'Ac' is not always clear in the radiographic images of all the teeth and makes this stage of calcification difficult to evaluate. The 'A½' stage is easier to visualise and is more reliable for age evaluation. The alternative radiographic image for apical calcification evaluation is the periapical radiograph that provides a much clearer image and would possibly facilitate the visualizing of the Ac stage.

The calcification stages of the crown are fairly easy to distinguish except for the stages of 'crown complete' (Crc) and 'root initiation' (Ri). These stages are especially difficult to determine in the molars. It is suggested that the stage of 'root initiation' (Ri) in molars be abandoned and that the stage of 'cleft initiation' (Cli) be used. This stage is much easier to visualise and depicts a definitive stage between crown and root formation.

The stages of calcification of the roots of the canine and the premolars need intermediate stages from the 'root ¼' to 'root ½' stage and between 'root ½' and 'root ¾'stages. There are images of root lengths that appear to be between these stages and suggest 'root ⅓' and 'root ⅔' stages; this was suggested by Smith (1991). These intermediate stages warrant investigation and appropriate ages determined for each tooth in the left mandibular quadrant.

Although some of the roots of the maxillary teeth are difficult to visualize on Pantomographic radiographs, the corresponding developmental stages of the maxillary teeth need to be investigated and ages derived for these stages in comparison to their mandibular counterparts.

The population groups

This study investigated the prediction of age of children and juveniles from four population groups. The Tygerberg sample which consisted of White and Coloured children was used as a group because it was not possible in most cases to derive the ethnicity of the individual from the dental records. The Tygerberg I sample consisted of mostly White children with a small number of Coloured children. The second sample (Tygerberg II) from more recent records consisted of mainly Coloured children due to the change in the demographic intake of patients at the Dental Faculty after 1994. The correction factor that was derived from the first sample of Tygerberg children attained a more accurate result in age estimation compared to the second Tygerberg sample. The components of the two samples were different and suggest that there is a dental developmental difference in the White and Coloured child populations which needs to be investigated. Dental age related tables therefore need to be derived for White and Coloured children and compared to the Tygerberg dental age related table.

The Zulu samples, however, showed a different result. The first sample was obtained from archival records of children who had orthodontic treatment during the Apartheid era and who came from an upper socio-economic background that was able to afford private dental treatment. The second Zulu sample was from current files of patients in the process of orthodontic treatment. These patients are mainly from a lower socio-economic class of Zulus who have recently had access to medical insurance and therefore could afford orthodontic treatment for their children. The two samples behaved differently when the correction factors were applied, especially when the correction factors were applied to the Demirjian *et al* (1973) method. The low percentage of children estimated to within 1 year of their real age in the Zulu II sample was possibly due to differences in the nutritional status of this sample.

Genetic vs. socio-economic status

This study has shown there are genetic differences in the development of teeth which is indicated in by the differences in the ages at which the teeth develop in the South African children within the three sample groups. There is evidence, despite the work of Lavelle (1976) who stated that nutritional factors played an insignificant role in tooth development, that socio-economic factors do affect tooth development as was seen in the difference in the two samples of Zulu children. A sample of 65 Xhosa speaking children mainly from the informal settlement (Khayelitsha) were obtained from recent records. These children come from a very poor socio-economic background. The age related table derived for this sample group showed that there was a delay in the development of the teeth in these children compared to the Zulu children. This indicates that there is an influence of nutritional status on tooth development.

Correction factors were derived for the MFH and DGT methods for South African children; these corrections can be applied if either the MFH or DGT method to estimate the age of a South African child. These correction factors improved the age estimation for the White-Coloured and Indian samples but were inaccurate for the African children when using the DGT method.

Application of this study

This study demonstrated that the ages at which the various teeth attained their developmental stages in the different sample groups were not exactly the same but never-the-less within 6 months to 1 year of each other. The Tygerberg sample consisted of approximately 1000 individuals of mixed population origin and suggests that in the estimation of the age of a juvenile skeleton of South African origin, the Phillips Table 1 could be used with relative confidence.

Dental age related tables (Phillips Tables) were created for the sample groups from Tygerberg, Indian and Nguni origin and represent the majority of South African children with regard to the estimation of ages. The further application of these age related tables need to be applied to the other population groups in South Africa.

In Chapter 10 samples of Tygerberg, Indian and Xhosa children were subjected to age estimation using the MFH, DGT and the Phillips Tables. The regression analysis of these methods indicated that the Phillips Tables for White-Coloured, Indian and African children are more accurate for age estimation compared to the MFH or the DGT methods.

Conclusion

The hypotheses of this study were firstly, that the standard dental age estimation tables of Moorrees, Fanning and Hunt (1963) and that of Demirjian, Goldstein and Tanner (1973) were not applicable to the South African child population, and secondly that specific dental age related tables were needed to estimate the ages of South African children. This study has shown that the dental age related tables developed for South African children (Phillips Tables) are more accurate and applicable for age estimation of White-Coloured, Indian and Nguni children.

In the age estimation of skeletal remains of South African juveniles of unknown population origin, it is suggested that the Phillips Table 1 could be used as this sample consisted of approximately 1000 children. This would provide a better age estimation than either MFH or DGT. If, however, the population origin of the individual is known to be White, Coloured, Indian or Negroid then the appropriate table should be used for more accurate age estimation.

Proposals for possible areas of future investigation suggested by the results of this study:

- Compare the various age related stages of tooth development of children with their nutritional / socio-economic status [There has been no study on the effect of malnutrition on the calcification of teeth and the relation to chronological age]
- Investigated and compared the corresponding age related developmental stages of the maxillary teeth to their counterparts in the mandible [There has been no extensive study of the equivalent dental age related stages of maxillary teeth compared to the mandibular teeth]

- Testing the dental age related tables derived in this study on other population groups within South Africa [The dental age related tables of this study need to be tested on other South African tribes and refugees from beyond the South African borders]
- Investigate the ages at which the roots of the mandibular teeth reach ⅓ and ⅔ of their final length when viewed radiographically as interim stages would make the age related tables more accurate.
- Investigate the rate of root development of the 2^{nd} mandibular molar where the 1^{st} molar is lost early due to extraction and the influence this may have on dental age estimation.

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