DENTAL AGE ESTIMATION IN CHILDREN ATTENDING A UNIVERSITY DENTAL HOSPITAL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTERS IN HUMAN ANATOMY IN THE DEPARTMENT OF HUMAN ANATOMY IN THE UNIVERSITY OF NAIROBI

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DECLARATION

"This thesis is my original work and has not been presented for a degree in any other University".

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DEDICATION

Dedicated to my lovely daughter, Christine and wonderful sons, Tim and Nathan.

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LIST OF ABBREVIATIONS

BMPs--------------------Bone morphogenetic proteins

CA----------------------Chronological age

C-------------------------Canine

CI-----------------------Confidence interval

DA----------------------Dental age

DOB---------------------Date of birth

DOP---------------------Date of panoramic radiograph

F-------------------------Female

FGFs--------------------Fibroblast growth factors

I_1---------------------------------- Central incisor

I_2-----------------------------------Lateral incisor

ICC----------------------Intraclass correlation coefficient

KNH/UON-ERC-------Kenyatta National Hospital/ University of Nairobi - Ethics and Research Committee

M_1----------------------------------First molar

M_2-----------------------------------Second molar

MAD----------------------Mean age difference

M--------------------------Male

PM_1--------------------------------First premolar

PM_2--------------------------------Second premolar

PR-------------------------Panoramic radiographs

SCEP---------------------Separated Children in Europe Programme

Shh-----------------------Sonic hedge hog

UNDH-------------------University of Nairobi Dental Hospital

UNICEF-----------------United Nations Children's Emergency Fund

Wnt3---------------------Wingless

ABSTRACT

Background: There are various circumstances when the chronological age of a child needs to be verified but due to lack of legally approved documentary evidence, age has to be conventionally estimated. Determination of age provides an important biological data which plays a vital role in the identification of victims of mass disasters and crimes. Additionally, it is an important requirement during school admission, marriage, child-adoption, in determination of criminal responsibility, imprisonment of minors and in management of various orthodontic as well as pediatric conditions and pathologies. Various methods have been applied to estimate the age of children mainly through the assessment of developmental and morphological changes of bone and teeth. However, in Kenya there is hardly any approved method that can be used to achieve this purpose. Hence, the need to determine the applicability of the available methods in estimating the age of a given Kenyan population.

Objective: To determine the performance of Willems' model of age estimation in children visiting the University of Nairobi Dental Hospital.

Materials and method: A cross sectional study was done at The University of Nairobi Dental Hospital. It involved examination of panoramic radiographs of 401 children aged 3.0 – 16.99 years old who had previously visited the pediatric and orthodontic clinic. The sample was divided into one year age cohorts from age 3 – 16 years. The radiographs were assessed in order to determine the tooth maturity stages for the first 7 mandibular teeth. In addition, each maturity stage was assigned a corresponding score as described in Willems' tables. The age difference was calculated through subtraction of the dental age from the chronological age. Descriptive and inferential statistics were done using SPSS 20.0 and presented in tables and various types of figures.

Results: A sample of 401 radiographs was included in the study, 188 (46.9) belonged to females while 213 (53.1%) were for males. The mean chronological age was 9.73±3.60 years. The mean chronological age for girls and boys was 9.83±3.65 and 9.65±3.56 years respectively.

The overall dental age was 10.01±3.60 years. Willems' method overestimated overall age by -0.27±1.30 years. There was statistically significant difference between the overall CA and DA, (t (400) = -4.185, p= 0.000). The 95% confidence interval was -0.40 - -0.14 years. Overall, there was a strong, positive correlation between the chronological and estimated age, r=0.935, n=401 p=0.000.

The overall dental age for the girls was 9.93±3.60 years. The study found that the girls had a mean age difference of -0.10±1.37 which was not statistically significant, (t (187) = -1.017, p= 0.311) with 95% confidence interval of -0.30 - 0.10 years. The boys had an overall dental age of 10.07 ± 3.60 years. The mean age difference was -0.42±1.22 years which was statistically significant (t (212) = -5.041, p= 0.000) with a 95% confidence interval of -0.26 - -0.59 years.

The most accurately estimated age by Willems' method was for age cohort 9 which had a mean age difference that was less than a month (-0.07 years). About a third (150, 37%) of the children had their age estimated within 6 months of their chronological age while about two thirds (258, 64%) were within one year.

There was complete development of about 50% of the teeth which had already achieved the final maturity stage H. The youngest boy and girl with fully matured 7 mandibular teeth were aged 12.91 and 13.02 years respectively. In general, there was no statistical difference between the maturity for girls and boys in most tooth stages. However, girls were significantly ahead in crown development of the lateral incisor and root development of the 1st premolar and canine. The maturity of the children in the same age group revealed variations in tooth stages.

Conclusion and recommendation: Use of Willems' method resulted in statistically significant overestimation of the age. The method performed better in estimating the age of the girls as compared to boys who were significantly over aged. Majority of the children had their age estimated within one year of their actual age. Generally, there was no statistical difference between the tooth maturity for girls and boys in most of the maturity stages. However, girls were significantly ahead of the boys in the root development of the canine. There existed different patterns of tooth maturity in children of the same age group. The current findings should be validated with a larger sample size that is representative of the Kenyan population. This will inform whether there is a need to modify Willems' method.

1. INTRODUCTION

The age of an individual forms an important part of their biological data and plays a vital role in the identification of not only the living but also the deceased persons. It can be ascertained through legal documents including birth certificate and personal identification cards or passport. However, there are situations when such identification documents are not available, hence, chronological age cannot be established but has to be estimated (UNICEF, 2013). The determination of an individual's age is often practiced in various disciplines including, anthropology, archeological studies, forensic medicine and odontology (Márquez-Grant, 2015; Ritz-Timme et al., 2000; Senn and Weems, 2013). In dentistry, the knowledge of a patient's age and level of teeth maturity guides in treatment planning in pedodontics and orthodontic management of different types of dental and skeletal malocclusion (Grabber, 2001; Panchbhai, 2011; Tandon, 2008).

At UNDH, the stage of tooth maturity and dental age, have to be determined routinely when assessing dental growth and development for every pediatric patient. This plays a role in definitive treatment planning. The level of maturity guides in deciding about the right time to extract a tooth or to initiate orthodontic treatment. Age can also be combined with other maturity indicators such as bone and sexual development in the diagnosis and follow up of pediatric endocrinopathies and growth disorders (Demirjian et al., 1973; Tandon, 2008). Often, chronological age is an important prerequisite during admission in a school, employment, marriage and child-adoption (Constitution of Kenya, 2010; Senn and Weems 2013; Willems et al., 2001a). Furthermore, asylum seekers especially unaccompanied minors require age determination in order to decide whether a person qualifies to receive benefits such as acquiring citizenship, free care and education (Larsen et al., 2012; Panchbhai, 2011; Senn and Weems, 2013). Worldwide, age plays a role in sports especially when participants have to be categorized into age groups for example under 17 years old soccer groups. Sometimes the age has to be confirmed through imaging (Dvorak et al., 2007).

Last but not least, age guides in deciding whether a minor has attained the age for criminal responsibility as well as whether one should be subjected to adult or juvenile imprisonment (UNICEF, 2013). The Kenyan constitution assumes that 8 years old and below who are unaccompanied and are of unknown nationality are Kenyan citizens by birth. Further, the eight years old and below are presumed not to be criminally responsible. However, the 12 years old and below are only criminally responsible if they are found to have the capacity to know that they should not have done or omitted a particular act. Additionally, a male of 12 years and below is presumed to be incapable of carnal knowledge. Further, the constitution refers to a person who is below 18 years as a child, while those who are above this age have the rights and responsibilities of an adult including the right to marry. Therefore, children of unknown age who find themselves in the above mentioned situations would definitely need to have their age determined before benefiting from their constitutional rights or taking their corresponding legal responsibilities (Constitution of Kenya, 2010).

The biological age of a child is mainly determined through the assessment of physical, skeletal and dental developmental. Estimation of age is done through a multidisciplinary procedure that considers the physical appearance of a person, sexual development, psychological behavior, state of health, environmental and cultural background (Schmeling, 2016; Senn and Weems, 2013; UNICEF, 2013). This helps in identifying any developmental abnormalities and behavioral factors that may influence the appearance of an individual and hence confound the determination of age. In Europe, non-medical and medical methods have been used to estimate age. Non-medical methods involve evaluation of documentary evidence, interviews and psychosocial assessment while medical methods involve physical examination and imaging techniques. Imaging techniques include use of x-rays to obtain radiographs of the hand and wrist, dentition and the clavicles. MRI is also gaining popularity since it does not expose patients to ionizing radiation (SCEP, 2012).

Further, the choice of an age estimation method depends on the state of the individual, whether living or dead, child or adult, the available tissues when one is assessing human remains and the availability/accessibility of age determination techniques (Senn and Weems, 2013). Once the age has been determined, the American Board of forensic odontology (2016) age estimation committee recommends that the estimated age should be presented with an error rate which includes 2 standard deviations so as to include 95% of the population. Further, UNICEF, (2013) recommends that the error should be used in ruling in favour of a child hence the lowest age limit can be considered as long as it will benefit the child.

Age estimation methods that can be used in forensic medicine are required to fulfill certain criteria. First, the method should have been published in journals which are peer-reviewed. Then, the methodology should be well outlined while the results should have been tested with the appropriate statistical methods. The method should also be accurate enough to estimate the age of a given sample. Finally, during its utilisation the appropriate ethical and legal standards should be applied (Ritz-Timme et al., 2000, UNICEF, 2013). To this end, several age estimation methods have been published. They mainly rely on the developmental and morphological status of teeth and epiphyseal plates of bone. Skeletal age has been assessed through the examination of the developing bones of the hand and wrist, clavicle, iliac crest, ribs, sacrum and cervical vertebrae. However, skeletal ossification has been found to be significantly affected by endocrine and environmental factors as compared to dental calcification. Additionally, the dentition is stable and particularly very useful because it's resistant to fire and has ability for postmortem survival (Amselem et al., 2007; Márquez-Grant N, 2015; Ritz-Timme et al., 2000; Senn and Weems, 2013; Wehkalampi et al., 2008).

Dental age estimation in children is mainly done through visual examination of the erupted teeth and radiographic examination of the calcification stages of developing teeth. Visual examination has been found to be unreliable since eruption of teeth may be significantly affected by environmental factors (Cameriere et al., 2007; Senn and Weems, 2013; Tandon, 2008). Radiographic study of developing teeth provides a more reliable indication of chronological age as compared to recording a one-time occurrence of tooth eruption (Gleiser and Hunt 1955; Graber, 2001; Tandon, 2008). The most common radiographic method of age estimation was developed by Demirjian et al., (1973). It has been modified by Willems et al., (2001a) who came up with Willems' model of age estimation. Due to different rates of dental growth in different populations, authors such as Demirjian and Willems recommends testing of their methods in other populations in order to verify their applicability in other foreign populations (Demirjian et al., 1973; Willems et al., 2001a).

In Kenya, there is scarcity of publication on dental maturity as well as utilisation of scoring radiographic dental age estimation methods. At UNDH, estimation of dental age is done through the use of eruption times and chronological age tables published by Hassanali, 1985, Hassanali and Odhiambo, 1982 and Ngassapa et al., 1996. Further, newer age estimation methods such as Willems' method have not been studied. Therefore, in the pursuit of establishing national standards in dental age estimation in Kenya, there is need for further assessment of the available age estimation methods in order to find the most applicable in the Kenyan population. This study was specifically carried out in order to determine the performance of Willems' method of age determination in a select Kenyan population.

2. LITERATURE REVIEW

Developmental, morphological and regressive characteristics of teeth have been utilized in determination of tooth maturity and biological age. Several methods have been useful in achieving this purpose. Demirjian's (1973) method has been widely utilized. It has now been modified by Willems et al., (2001a) and found to have better accuracy as compared to other methods. Imaging has played an important role in age estimation and panoramic radiographs of the jaws are frequently used in most age estimation methods.

2.1 TEETH DEVELOPMENT

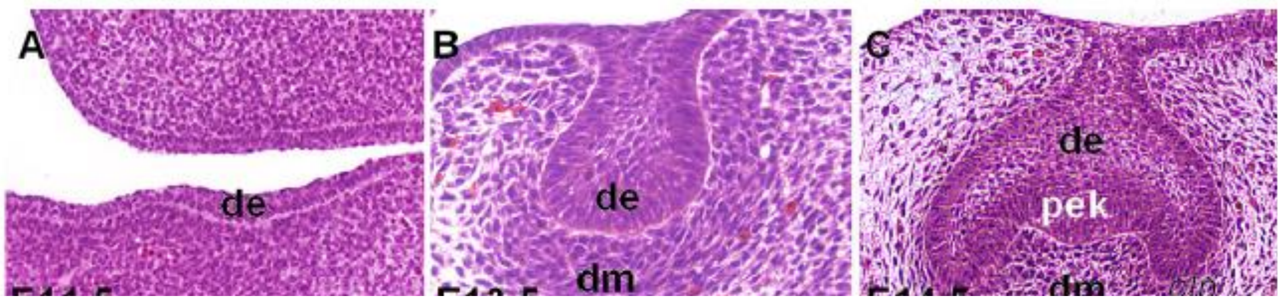
The teeth develop on the alveolar segment of the jaws which usually form from the first pharyngeal arch. The arch subdivides into mandibular and maxillary processes which then develop into lower and upper jaw respectively. The development of the teeth starts by early migration of neural crest cells into the mandibular and maxillary processes where they settle beneath the oral ectoderm (Moore et al., 2013). Growth and development of the teeth depends on molecular ectodermal-mesenchymal interaction. It occurs through several signaling pathways mediated by bone morphogenetic proteins (BMP), fibroblast growth factors (FGF), Sonic hedgehog (Shh), and Wingless (Wnt)/β-catenin. Initially, the expression of transcription factor Pitx-1 outlines the ectodermal dental field while expression of Homeobox genes (Dlx-1, Dlx-2) leads to tooth formation. The human teeth are arranged in one row which is patterned by a buccal-lingual gradient of molecules whereby there is high BMP expression on the buccal side and a high expression of Osr-2 on the lingual side. Expression of BMP-4 leads to activation of Msx-1 and Msx-2 to initiate development of incisors while FGF-8 restricts expression of Dlx-1 and Barx-1 posteriorly leading to formation of molars. Further, the ectodysplasin (Eda) gene plays a role in regulating normal tooth morphogenesis and tooth number (Carlson, 2014; Jheon et al., 2013; Suryadeva et al., 2015; Wang et al., 2012; Yuan et al., 2015).

Development of the teeth occurs in stages starting from the crown progressing towards the root. The stages include, bud, cap and bell stage, (Fig.1) then appositional growth, calcification and eruption. As the teeth grow within the jaw bones, they are enclosed in dental crypts which can be recognized on radiographs; initially as radiolucent areas which later become radiopaque as the teeth develop and calcify (Carlson, 2014; Demirjian et al., 1973; Suryadeva et al., 2015).

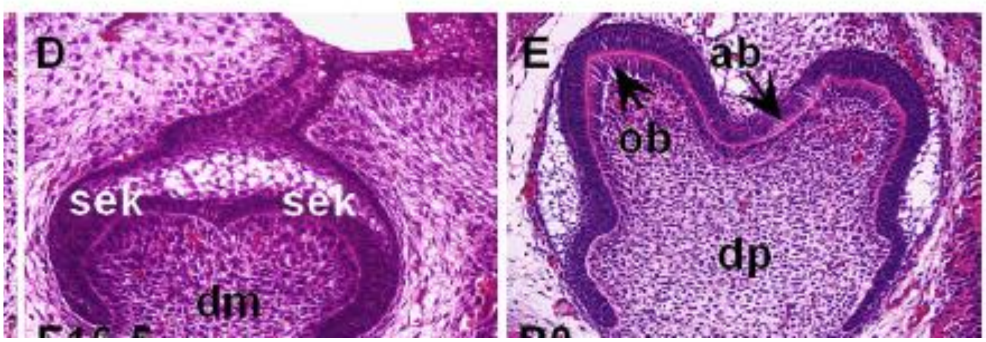
During the sixth week of embryo development, cells in the basal layer of the oral epithelium proliferate to form an epithelial thickening which grows to form the dental lamina. The dental lamina then grows towards the underlying mesenchyme, it enlarges and encompasses a condensation of mesenchyme leading to formation of a tooth bud. At the tip of the tooth bud, a regulating center namely enamel knot appears, it expresses FGFs, BMPs, Shh and Wnt3 genes which regulates the patterning of tooth crown into various shapes. The expression of genes at the enamel knot is influenced by the transcription factor Lef1. This leads to downwards proliferation of the cells surrounding the enamel knot causing the tooth bud to transform into the cap stage. Usually, the anterior teeth have got one center while the posterior ones have secondary centers since they are multicusped (Figure 1) (Lan et al., 2014; Suryadeva et al., 2015).

Next is the bell stage where morphodifferentiation starts. The ectodermal cells and underlying neural crest derived epithelial cells form the enamel organ and dental papilla respectively. The inner cells of the enamel organ differentiate into ameloblasts and secrete enamel while the dental papilla cells differentiate into odontoblasts and secrete dentine. Initially, there is deposition of tissue matrix and subsequent precipitation of inorganic calcium salts. As growth proceeds, through various molecular interactions, the teeth take their characteristic shape. Early calcification starts at the tips of the cusps and forms one of the earliest stages that can be identified on radiographs during age estimation (Carlson, 2014; Demirjian et al., 1973; Simmer and Hu, 2001). Calcification occurs in rhythmic variations thus creating incremental lines which can be assessed histologically. More importantly, due to physiological disturbances during birth, a distinct neonatal incremental line forms which can be assessed to determine whether a child died before or after birth (Senn and Weems, 2013).

Once the tooth crown is completely developed, enamel formation ceases then cementum starts to form along with dentine which marks the start of root development. Eruption of the teeth occurs before completion of root development and proceeds through a well predetermined sequence with a specific timing for each tooth. Growth and development of teeth continues from prenatal life up to early adult life resulting into two sets of teeth, namely, the deciduous (primary) and permanent (secondary) dentition. As a result, dental age can be assessed up to early adult life (Carlson, 2014; Tandon, 2008).



A. Dental lamina B. Bud stage C. Cap stage



D. Early bell stage E. Late bell stage

ab – ameloblast, de - dental epithelium, dm - dental mesenchyme, dp - dental pulp,

ob – odontoblast, pek - primary enamel knot, sek - secondary enamel knot

Figure 1. Histology of the first molar tooth development in mice.

Adopted from: Suryadeva et al., (2015)

Once the teeth are fully developed, with time they start to undergo ageing through regressive changes which are either gross or microscopic changes. The gross anatomical changes that may be visualised include recession of the periodontium, apical root resorption, dentin coloration and tooth wear through attrition, abrasion or erosion. Microscopic changes can be demonstrated through histological staining of extracted teeth, these include apposition of secondary dentine and cementum. Such postformation tooth changes have been utilized in age estimation in adults (Kvaal and Solheim, 1994; Slootweg, 2007; Senn and Weems, 2013; White and Pharoah, 2004).

Teeth development has been shown to occur at about the same time for the European and a few other populations despite their location in different geographical areas. A meta-analysis study consisting of data from 9002 children aged 2–16.99 years whose origin was mostly European (Finland, England, Belgium, Sweden, France, South Korea, Quebec and Australia) showed no significant differences in dental maturity. Most of the teeth seemed to develop at around the same time. More importantly, it has been observed that the dental maturity for girls is usually ahead of that of boys' hence dental maturation/age estimation studies usually present data for boys and girls separately (Liversidge et al., 2006; Macdonald et al., 2004; Tandon, 2008).

2.2 DEVELOPMENTAL ANOMALIES OF TEETH

The development of teeth can be affected by diverse abnormalities which can affect the number, structure, size, shape and position of the teeth. Thus, causing a challenge in dental age estimation. Anomalies that affect the number of teeth may manifest with missing (hypodontia) or extra (hyperdontia) teeth. There are also structural genetic abnormalities of teeth that lead to defective formation of dentine and enamel leading to dentinogenesis and amelogenesis imperfecta respectively. Others include dentin dysplasia and odontodysplasia (ghost teeth) which manifest with abnormally short roots and grossly enlarged pulp chambers respectively. The size of the teeth may also be affected during development causing them to appear either larger or smaller than normal.

Abnormalities that can interfere with the normal shape of the teeth may either affect the whole tooth, crown or the root. They include but are not limited to, gemination, concrescence, dens invaginatus, fusion of teeth, dilacerations, extra roots and taurodontism. Others comprise of syphilitic teeth which present as notched Hutchinson's incisors and dome-shaped mulberry molars (Farman et al., 1993; Whaites, 1996). A majority of the abnormalities have got features which can be easily recognized on dental radiographs. This is helpful in determining whether to include or exclude a radiograph from age estimation studies. Willems' method depends on the shape of the crowns and the roots hence teeth with altered morphology should be excluded in order to avoid misinterpretation of the results (Willems et al., 2001a).

2.3 DENTAL AGE ESTIMATION METHODS

Several dental age estimation methods for children have been developed and are based on various developmental stages of teeth. The methods can be applied during both the prenatal and postnatal period. This is due to the fact that development of the teeth can be observed from the sixth week while crown calcification of the primary incisors and 1st molar begins as early as 13 – 15 weeks of embryonic life (Macdonald et al., 2004; Tandon, 2008). Dental development progresses until about 16 – 25 years (AlQahtani et al., 2010; Ngassapa et al., 1996). Age estimation methods that are based on developmental characteristics include gravimetric observation of the mineral content of teeth as well as histological approach through microscopic observation of incremental lines. Other techniques include visual examination of the number and type of the erupted teeth and radiographic examination of the developing dentition. The last two methods are commonly applied in assessing age in children and adolescents (Tandon, 2008, Willems, 2001b).

Eruption of teeth has been found to be affected by various factors including, nutritional modifications, endocrine status, exogenous factors such as infection, traumatic injury, tissue obstruction, crowding and early extraction of deciduous teeth (Seen and Weems, 2013; Tandon, 2008). These factors can lead to delayed or failed eruption of the teeth. However, tooth calcification is not greatly influenced by these factors. For instance, impacted teeth still progress to full maturity while lodged within the jaw bones. The effect of the nutrition has previously been assessed by comparing timing of teeth mineralization for well- and undernourished Peruvian children. The results revealed that nutrition did not cause any significant differences in the development of teeth in both groups (Cameriere et al., 2007). A similar study done in North Sudan did not find any significant tooth developmental differences between normal and severely malnourished children (Elamin and Liversidge, 2013).

Radiographic study of developing teeth has been found to provide a more reliable indication of chronological age as compared to recording a one-time occurrence of tooth eruption (Graber, 2001; Tandon, 2008; Willem, 2001b). Stages of tooth development that have been identified on panoramic radiographs (PR) include absence or presence of a dental crypt in the alveolar process of the maxillary and mandibular bone, levels of crown and root formation/calcification as well as whether the tooth apices are open or closed. A number of authors have divided tooth development into different stages such as, 10 stages by Gleiser and Hunt (1955) and modified by Kohler et al., (1994), 8 stages by Demirjian et al., (1973), 14 stages by Moorrees et al., (1963) and 10 stages by Nolla, (1960). The Demirjian's (1973) tooth stages are popularly used since they are easier to identify. Once the stages have been identified, different methods of age estimation can then be applied to convert the tooth stages into a dental age.

Two radiographic age estimation methods have been studied, namely 'atlas approach' and 'scoring system' (Willems, 2001b). The atlas approach relies on radiographic diagrams of the entire developing dentition demonstrating how a child of a certain age would present. The atlas approach can also be presented as dental maturity tables that can be used to directly determine the dental age depending on the radiographic appearance of the teeth. Examples include age tables by Moorrees, Anderson, Logan and Kronfeld as well as Schour and Massler (Senn and Weems, 2013). In addition, there are recently developed atlases that include one by Ubelaker and London atlas of tooth development by AlQahtani (AlQahtani et al., 2010; Senn and Weems, 2013; Willems, 2001b). Nonetheless, the atlas approach is associated with high error rate and tooth pattern variability (Senn and Weems, 2013).

The radiographic scoring method is commonly used and involves identification of the stage of tooth maturity from a radiograph. Then, an age score is allocated to a particular stage and total scores are eventually converted into an age (Demirjian et al., 1973; Senn and Weems, 2013; Willems et al., 2001a). The most common scoring method of age estimation was developed by Demirjian et al., (1973). It has been modified by Willems et al., (2001a) who came up with Willems' model of age estimation. Due to population differences in dental growth, authors such as Demirjian and Willems recommends testing of their methods in other populations in order to verify their applicability in other foreign populations (Demirjian et al., 1973; Willems et al., 2001a).

2.3.1 DEMIRJIAN'S (1973) METHOD

The most widely used scoring method is that developed by Demirjian et al., (1973) which was based on a large French Canadian population. The method has three steps whereby at step one the developmental stage of the tooth is identified. In step two, the teeth are assigned maturity scores while in the final step the scores are converted into an age.
Demirjian's (1973) method is based on assessment of radiographic appearance of two permanent teeth located on the left side of the mandible which are usually at different stages of development in children. The mandibular teeth were preferred because they are usually clear than the maxillary teeth on PR. Inevitably, the maxillary teeth are usually superimposed on the maxillofacial bones (White and Pharoah, 2004).

The PR of a French-Canadian population consisting of 2928 children aged 2-20 years were used to assess the stages of tooth calcification of the seven teeth (first and second molars, both premolars, canine, lateral and central incisors). A developmental chart and a tooth stage description table were created as shown in appendix B and C. Dental maturation was divided into eight stages (A - H) and the criteria for each have been clearly defined. Subsequently, each stage was assigned a weighted maturity score. Finally, the total score for the seven teeth is matched with the corresponding dental age using age tables (Demirjian et al., 1973). Demirjian's method (1973) is easy to use since it relies on the morphological appearance of the teeth rather than particular measurements of the teeth which could be affected by geometric distortions of panoramic images (Whaites, 1996). The use of Demirjian technique has been shown to result in high inter- and intraexaminer reproducibility (Altalie et al., 2014; Javadinejad et al., 2015; Yusof et al., 2013).

Demirjian's method (1973) was initially developed to assess the dental maturity of children but it has also been used to estimate age. However, various studies have found it to mainly overestimate the dental age (Hedge et al., 2015; Phillips and Kotze, 2009; Yan et al., 2013). Dental age estimation of a South Indian population resulted into statistically significant underestimation (DA-CA) of 0.23 years for males and an overestimation of 0.43 years for girls (Mohammed et al., 2015). In another Indian population study, the method was used to estimate the age of 6-12 years old Mumbai children. There was significant overestimation (CA-DA) of 0.1 years, insignificant overestimation of 0.004 for boys and significant overestimation of 0.096 years for girls (Hegde et al., 2015). In a South African study, estimation of dental age by Demirjian's (1973) method revealed that the age of more than 75% of the 3 – 16 years old was overestimated (Phillips and Kotze, 2009).

An overall overestimation of the mean age was also observed following a study of European children from a Portuguese and Spanish sample. However, estimation of age in the 8 year olds and below was found to be the most accurate (Tomas et al., 2014). A different study involving 5 – 16 years old from a mixed population of Euro-Canadian and First Nations/Aboriginal in Sudbury, showed statistically significant overestimation (Gilbert et al., 2014). A further European study involving 4 – 9 years old British children composed of two ethnic groups (Bangladesh and white Caucasian) revealed an overall mean age overestimation of 0.73 ± 0.73 years and 0.51± 0.79 years for boys and girls respectively. The mean difference between the chronological and dental age in most of the age cohorts was statistically significant (Liversidge et al., 1999). A recent study of 198 Western Saudi children aged 4 – 16 years revealed a mean age difference (CA-DA) for girls which ranged from -1.44 to 0.81 years and -0.66 to 0.77 years for boys. Statistically significant differences were noted in 7 and 11 years old girls as well as 8 and

13 years old boys (Alshihri et al., 2015).

Willems et al., (2001a) used the Demirjian's method to estimate the dental age of a Belgian Caucasian population. There was overestimation of the age and the mean difference between the chronological and estimated age (CA-DA) was 0.5 and 0.9 years for boys and girls respectively. In order to improve the accuracy of Demirjian's (1973) method, Willems et al, 2001a modified the Demirjian's method to generate a new scoring system for age estimation. However, he retained the staging technique by Demirjian et al., (1973) but introduced new scores as shown in appendix D.

2.3.2 WILLEMS' MODEL OF AGE ESTIMATION

Willems et al., (2001a) utilised a part of Demirjian's (1973) method to create a new method for dental age estimation based on a Belgian Caucasian reference population. The new method uses the same A-H tooth staging technique of Demirjian et al., (1973) based on the seven left mandibular teeth. After identifying the developmental stage for the seven teeth, new maturity scores corresponding to each tooth stage were formulated through weighted ANOVA. The scores (appendix D) were presented as fractions of dental age which have to be summed up to find the dental age of a given individual. Hence, Willems et al, (2001a) did not use Demirjian's (1973) scores but came up with different tables for boys and girls showing age scores which were expressed in years. They were validated using another Belgian sample and found to be more accurate than Demirjian's (1973) method. Willems' method performed very well and resulted into a mean age difference of 0.0 and 0.2 years for boys and girls respectively. The Demirjian's (1973) method had resulted into a higher overestimation 0.5 years and 0.9 years for boys and girls respectively (Willems et al., 2001a).

Willems' model of age estimation has been tested in other populations and has been found to perform better than Demirjian et al., (1973) method.In an effort to find out the best method of age estimation, Liversidge et al., (2010a) used eleven methods (Nolla, Demirjian, Willems, Chaillet, Moorrees, Haaviko, Anderson, 3 Liversidge methods and 2

Nystrom methods) to study 946 children aged 3-16 years old children of a Bangladesh and white ethnic origin. The Willems' method was found to be the best since the estimated age had the smallest mean and standard deviation as compared to the other methods. Willems' method also performed better in estimating the age of Macedonian children as compared to Demirjian's method (Ambarkova et al., 2014). In Egypt, Willems' method performed better and revealed a mean age difference of -0.15 years as compared to Cameriere method which resulted into a higher mean difference of -0.29 years (El-Bakary et al., 2010).

The performance of Willems model on age estimation of 6-13 years old Bosnian-Herzegovian children resulted into a mean age difference of 0.24 years ($p<0.001$) and 0.42 years ($p<0.001$) in girls and boys respectively (Galic et al., 2011)Age estimation of 4 – 14.99 years old 485 UAE children by Willems model resulted into an overall mean error of -0.01 years, while the mean age difference for girls and boys was 0.12 and -0.08 years respectively (Altalie et al., 2014). Further, the verification of Willems model of age estimation on Brazillian, Malay and Japanese children showed a mean error of -0.28, -0.02 and 0.45 years respectively (Franco et al., 2013; Ramanan et al., 2012; Yusof et al., 2013). The three studies (Franco et al., 2013; Ramanan et al., 2012; Yusof et al., 2013) show that the under/overestimation of age was less than six month.

2.4 OVERVIEW ON SKELETAL AGE ESTIMATION

The assessment of the skeletal age for the children is sometimes done in combination with the dental age. It has been commonly done through the review of the hand and wrist radiographic images. Ultrasound and MRI have also been utilised instead of the radiographs in order to avoid use of the harmful ionizing radiation (Dvorak et al., 2007; Karami et al., 2014). Age is then determined using different methods such as, the Greulich and Pyle atlas, Tanner Whitehouse method or Gilsanz and Ratib atlas. It involves the assessment of ossification centers of the carpal bones, epiphysis of metacarpals, phalanges, distal radius and ulna which appear and fuse at different growth periods. They can be used to determine age from birth to about 15 – 16 years in females and 18 – 19 years in males (Gilsanz and Ratib, 2005; Johnson, 2008; Mughal et al., 2014; Satoh, 2015).

Skeletal age can also be estimated through the assessment of the ossification centers in the clavicle. It is the first and last long bone to ossify and ossification centers appear as early as 5th - 6th week of intrauterine life. In addition, a secondary ossification center appears on its sternal end during late puberty or early 20s and it fuses completely at about 22 years. Therefore, it can be used to determine age in early adulthood when the dental development has ceased (Carlson, 2014; Johnson, 2008; Mughal et al., 2014; Schmeling, 2016). Other bones that have been utilized include the iliac crest, femoral bone, ribs, sacrum and cervical vertebrae (Choi Y et al., 2016; Giri et al., 2016; Márquez-Grant, 2015). Skeletal ossification has been found to be significantly affected by endocrine and environmental factors such as nutrition when compared to dental calcification (Cardoso, 2007). Secular treads have influenced bone growth and children reach their adult height earlier than previously observed. However, the dentition is stable and particularly very useful because it's resistant to fire and has ability for postmortem survival (Amselem et al., 2008; Márquez-Grant N, 2015; Ritz-Timme et al., 2000; Senn and Weems, 2013; Wehkalampi et al., 2008).

2.5 THE ROLE OF IMAGING IN DENTAL AGE ESTIMATION

Dental and maxillofacial diagnostic imaging constitutes an invaluable tool in the assessment of the dental age. Various imaging techniques including panoramic, intraoral periapicals, lateral oblique of the mandible and cone beam computed tomography, have been utilized in age determination (Agarwal et al., 2012; Demirjian et al., 1973; Panchabhai, 2011; Willems, 2001a; Yang et al., 2006). In particular, PR has been widely used in age estimation. It shows a single tomographic image of the facial structures that includes both the maxillary and mandibular dental arches and their supporting structures. It is used as the initial evaluation image that can provide a general overview of the upper and lower jaws plus their associated dentition. Additionally, it plays a role in assisting in determining the need for other radiographic projections (White and Pharoah, 2004). A study done at UNDH by Kihara et al., (2012) revealed that PR was the commonest radiographic examination requested at the radiology section.

Panoramic images are principally useful in children for assessing the development of the dentition. They are used to study the deciduous teeth root resorption, development of the permanent teeth and path of tooth eruption. Further, they are used in assessing the presence or absence of developmental anomalies, ankylosed and impacted teeth. Further to that, PR is used to diagnose the presence and extent of oral pathology and evaluation of traumatic injuries (Graber, 2001; Tandon, 2008; White and Pharoah, 2004). At UNDH, children commonly undergo a panoramic examination in order to assess and monitor growth and development of the teeth.

American Dental Association Council on Scientific Affairs (2006) recommends PR for the children who have evidence of eruption of the first secondary tooth which may occur at 5 – 7 years (AlQahtani et al., 2010; Ngassapa et al., 1996). The guidelines further recommend periapical or panoramic examination for adolescents for the assessment of developing third molars. Hence, it is not unusual to find PR being routinely done for children. However, in view of these recommendations and other technical aspects associated with PR, clinicians may not routinely request for panoramic views of the very young i.e. 5 years and below. This is evident in previous studies that assess age through PR of children whereby such examinations of the younger age groups were not commonly available (Alshihri et al., 2015; Galic et al., 2011; Liversidge et al., 2006).
Radiographic examination involves use of ionizing radiation; hence, it should be done judiciously (Whaites, 1996). The United Nations recommends that age should first be determined through other non-medical methods and one should only undergo radiographic examination as a last resort. The ethical standards of taking radiographs should be adhered to including giving of consent before exposure to radiation (Koppenberg, 2014; UNICEF, 2013). However, the dental as well as the hand and wrist radiographs requires a very low dose of radiation which is comparable to natural radiation (Schmeling, 2016; Whaites, 1996).

2.6 STUDY OBJECTIVES

2.6.1 BROAD OBJECTIVE

To determine the performance of Willems' model of dental age estimation in children attending the University of Nairobi dental hospital.

2.6.2 SPECIFIC OBJECTIVES

1. To describe the distribution of the chronological age in the select population.
2. To determine the teeth maturity for the girls and boys from the select population
3. To estimate the dental age for girls and boys according to the Willems' method.
4. To correlate age estimated by Willems' method with the chronological age.

2.7 STUDY VARIABLES

1. Socio-demographic data including, chronological age and gender
2. Independent variables - Crown calcification, root development, tooth morphology and tooth type.
3. Dependent variables - Maturity stage, maturity score, estimated dental age

2.8 JUSTIFICATION

There are numerous situations when the age of a child is required to be determined especially due to lack of documentary evidence. For example, during the investigation of crimes such as child defilement, trafficking or murder. There is usually a need to either identify the age of the victim (dead or living) and the perpetrator. Age is important in deciding whether a perpetrator has reached the age of criminal responsibility (CdeBaca and Sigmon, 2014; Constitution of Kenya, 2010; U.S. department of state, 2013; UNICEF, 2013). There are other common situations when age has to be determined including, application for a national identity card. The application could be for children who may not have been registered at birth, for example, a survey done in Kwale County in Kenya revealed that more than half of the children did not possess a birth certificate (Pelowski et al., 2016). Other children whose DOB may not be registered are those who have grown up either in the streets or children's homes or unaccompanied minors such as immigrants, refugees or asylum seekers. Further, a child's age may need to be determined prior to condemning a convict to serve in an adult or juvenile imprisonment (Koppenberg, 2014; SCEP, 2012). Other occasional situations include identification of victims of terrorist attacks, mass disasters for example after fire from oil spills or in shopping malls as has previously been witnessed in Kenya (Young et al., 2010).

Despite the dire need for age estimation in Kenya, there is hardly any approved age estimation method that is applicable to the Kenyan population. The dentists are very often requested to determine the age of an individual. Sometimes the legal officers question the credibility of the methods used querying whether they are population specific or not. Unfortunately, the clinicians who have no access to panoramic imaging have to rely on methods such as observation of eruption pattern which has been found to be highly unreliable due to influence by environmental and local factors. Besides, even if they were to use published age estimation techniques, such methods have been developed using foreign populations which may not have a similar tooth maturity pattern as Kenyans. Therefore, there is need to explore the performance of the available methods and come up with the most appropriate method for the Kenyan population.

This study will specifically determine the performance of Willems method in estimating the age of a select Kenyan population. This method is a modification of the commonly utilized age estimation method by Demirjian et al., (1973). Willems' method has revealed good performance in various populations including London, Belgium, Japan, Malay and United Arab Emirates (Altalie et al., 2014; Liversidge et al., 2010a, Ramanan et al., 2012; Willems et al., 2001a; Yusof et al., 2013). The method is easy to apply with minimal training and the required developmental and scoring charts have been published and are freely available online. Age estimation involves initial analysis of the tooth maturity which reveals the tooth maturity pattern for the children in a particular population. At UNDH, this has not been previously described. However, there is need to come up with tooth maturity tables which can essentially be used as a reference at the UNDH which usually provides national referral and teaching services. In addition, the findings of the study will be used as baseline data for further studies which will eventually lead to the development of a specific Kenyan model for age estimation. Once developed, the Kenyan method can be used locally and abroad especially when settling young Kenyan asylum seekers and immigrants.

3. RESEARCH METHODOLOGY

3.1 STUDY AREA

The study was done at The University of Nairobi Dental Hospital (UNDH) which is located in Nairobi, Kenya. It serves as a referral center for management of dental and maxillofacial diseases and conditions.

3.2 STUDY POPULATION AND SAMPLING METHOD

The study population consisted of 401 children aged between 3.0 to 16.99 years who had visited the radiology unit since the installation of the digital panoramic imaging machine in 2009. Purposive sampling method was utilized (Polit and Beck, 2012). All the radiographs that fulfilled the inclusion criteria were included in the study (figure 2). The sample size was calculated using the formula for sample size determination while estimating mean in a finite population. The confidence level was set at 95%. Standard deviation and margin of error were assumed to be 0.5 and ±5% respectively (Kothari and Garg, 2014). From previous records, 3360 children had digital panoramic imaging at the UNDH radiology unit from April, 2009 to May, 2016.

The following formula was used;

$$n = \frac{(Z_{a/2})^2\, \sigma^2 N}{e^2 (N - 1) + (Z_{a/2})^2\, \sigma^2}$$

Where;

n = Size of the sample

$Z_{\alpha/2}$ = Z score is the value of standard variate at 95% confidence level (CI) which is 1.96

σ = Standard deviation of 0.5 was used.

e = Margin of error (confidence interval) of 0.05 was used.

N= estimated population size = 3360

$$n = \frac{(1.96)^2 (0.5)^2 (3360)}{0.05^2 (3360 - 1) + (1.96)^2 0.5^2}$$

$$n = \frac{3225.6}{8.4 + 0.96}$$

$$n = 345$$

The proposed study population was a minimum of 345 participants.

3.3 STUDY DESIGN

The research was a cross-sectional study with retrospective collection of data.

3.4 SELECTION CRITERIA

Previously done PR were retrospectively collected and selected as outlined in figure 2. They had to be diagnostically acceptable and at least the images of the teeth on one side of the mandible had to be clear so as to allow assessment of the developmental stages. Any blurred images that had lost the normal tooth outline due to geometric distortion or technical errors were excluded. Besides, radiographs which had bilaterally missing mandibular teeth as well as dentition with features of developmental anomalies were left out. Further, panoramic images of patients aged above 16.99 years and those below 3.00 years were also eliminated. The incomplete dental records which lacked the date of birth (DOB) and the date of panoramic radiograph (DOP) were not useful to the study hence they were also eliminated. Finally, any other form of dental imaging which was found in the patients' file such as intraoral periapicals, bitewings and cephalograms were not collected.

3.5 STUDY PROCEDURES: TRAINING, DATA COLLECTION

Study procedures included various activities which were undertaken in order to fulfill the research objectives.

3.5.1 TRAINING AND PREPARATION FOR DATA COLLECTION

The principal investigator and the research assistants were trained and calibrated before data collection and analysis. This involved explanation of the variables which needed to be collected and how to extract the necessary data. It also involved examination of several radiographs and training on how to identify the seven developmental stages as outlined by Demirjian et al., (1973). Additionally, there was training on how to use the Willems' age scores in order to calculate the dental age. Pre-testing of the data collection form was done to minimize errors. When analyzing the radiographs, there was blinding whereby, the observer was not aware of the chronological age and gender of the patient.

3.5.2 RETRIEVAL OF RADIOGRAPHS AND PATIENTS'FILES

A pre-designed data-collection form was used to collect data which was obtained from the patient's past clinical records. The sequence of events is outlined in figure 2. Retrieval of the archived clinical records began by examination of manual patients' registration records at the division of radiology. Names of children who had undergone PR examination were recorded together with their file numbers. The patients' names were then used to retrieve the PR from a digital archive i.e. from a computer which was connected to the main digital panoramic x-ray machine.

The retrieved images were saved in a desktop folder and later they were copied onto a compact Disc Read-only memory (CD-ROM). During the retrieval, the DOP was noted and entered on the data collection form. The images were saved as JPEG files of 186 KB with width x height of 2190 x 1536 pixels. The identity of every image was coded and assigned Arabic numerals in order to conceal any patient identifiers. The radiographic examination had been performed at the UNDH radiology division using a digital panoramic x-ray machine, CS 9000C manufactured by Kodak, New York. The digital machine had been installed in 2009. Later, the file numbers were used to retrieve manual patients' files from where the DOB and gender of the patient were extracted. The recording of the dates involved recording the day, month and year of birth.

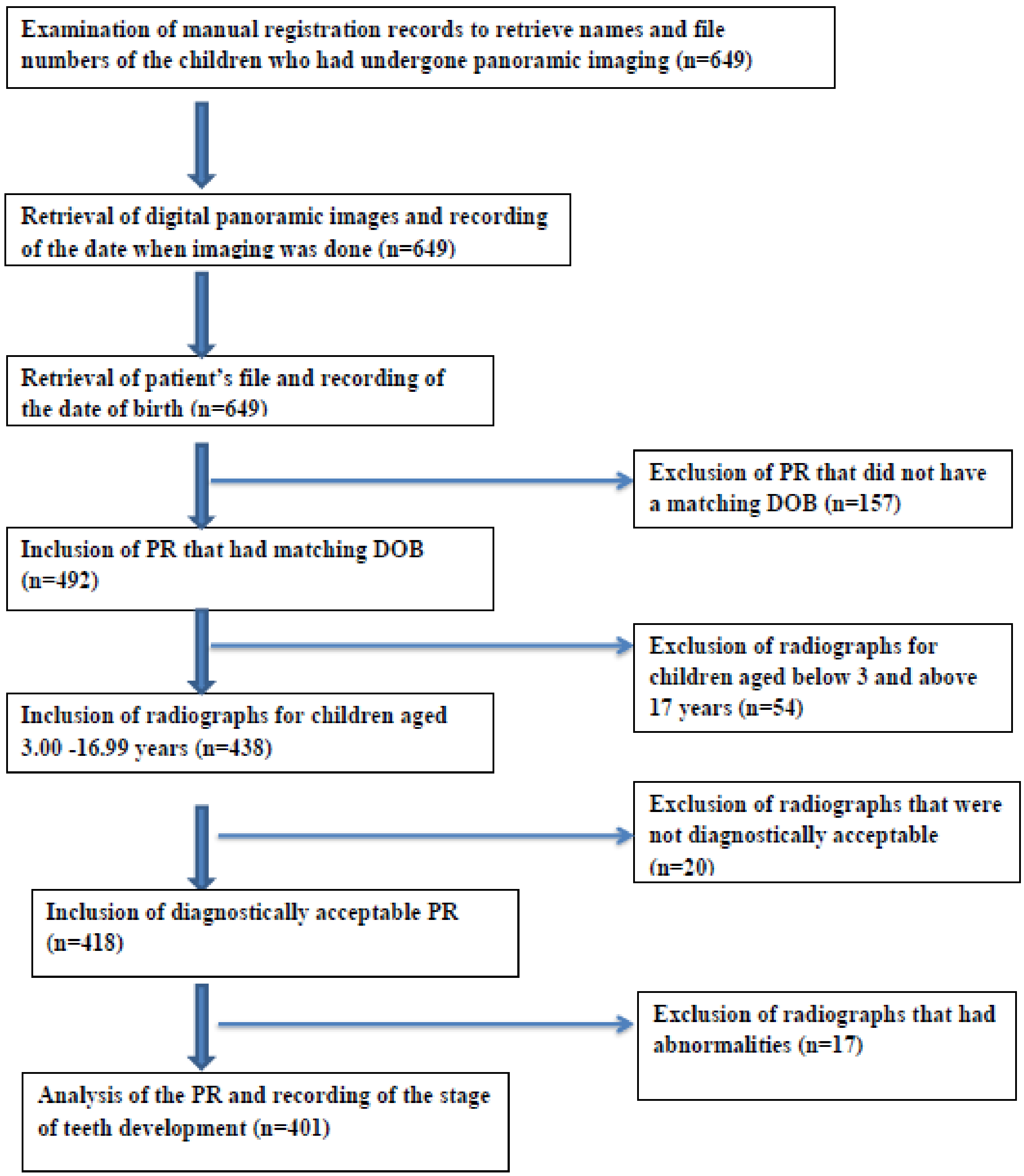


Figure 2. Flow diagram for data collection

3.5.3 DETERMINATION OF THE CHRONOLOGICAL AGE

The data collection forms were checked for completeness. Data was edited and any omitted information was rechecked and entered. Any missing information which could not be obtained led to exclusion of the incomplete data. The DOB and DOP were entered on a Microsoft 2010 excel worksheet. The chronological age of the patient at the time of undertaking the radiograph was then calculated. This resulted into an age which was presented in years which were expressed into two decimal points. The children were then classified into inclusive type class intervals of one year i.e. from (3 – 3.99 years) up to (16 – 16.99 years).

3.5.4 DETERMINATION OF TOOTH MATURITY

Each PR was coded and given Arabic numerals, any patient identifiers were cropped out and the radiographs were saved in one folder. All the radiographs were assessed by the principal investigator and tooth maturity was determined by assessing the morphological appearance of the teeth on PR. Then, they were staged according to the Demirjian's (1973) maturity chart and tooth description table (appendix B and C). Tooth maturity was registered by applying Demirjian's (1973) stages A to H on the seven mandibular left permanent teeth as shown in figure 3. In radiographs where there were missing teeth or blurred images on the left side, the teeth on the right mandibular jaw were assessed as recommended by Demirjian et al., (1973). The teeth which were in developmental stages E, F and H had two characteristics; they qualified to be in those particular stages if they fulfilled one of the descriptions. Additionally, stage C and D had three descriptions but a tooth had to fulfill at least two of them. The following guidelines as outlined in appendix B were followed.

1. Stage A marked the initial stage of crown calcification which appeared as single or multiple inverted cone(s) which were located within the bony dental crypt.
2. Stage B was indicated by fusion of the calcified parts of the crown.
3. Stage C had three characteristics, namely, enamel formation was complete, there was evidence of dentine formation and the superior part of the pulp chamber had a curved appearance.

4. In stage D, the crown of the tooth was completely formed. Secondly, the walls of the pulp chamber were curved. In the uniradicular teeth (incisors and premolars) there was a pulp horn which projected into the crown giving the pulp chamber the shape of an umbrella top but the pulp chambers of the molars had a trapezoid shape. Thirdly, there was evidence of root formation which was represented by a spicule on the lower border of the crown.
5. In stage E, the walls of the pulp chamber of the single-rooted teeth were straight with a pulp horn at the center while in the molars there was evidence of development of the bifurcation which was indicated by a semilunar or a minute calcification at the inferior border of the pulp chamber. The root was longer than in stage D and had reached a third of the crown height.
6. Teeth that were in stage F had a root which was the same size or longer than the crown. The walls of the pulp chamber in the uniradicular teeth had a triangular shape while the apices of all the teeth were funnel-shaped.
7. Stage G was marked by straight walls of the pulp chamber which ended up with open apices.
8. Teeth in stage H were completely developed, the stage was marked by either a closed apex or the periodontal ligament space had uniform thickness all-round the root. It is recommended that for the molars which have two roots (mesial and distal) the distal root should be assessed.

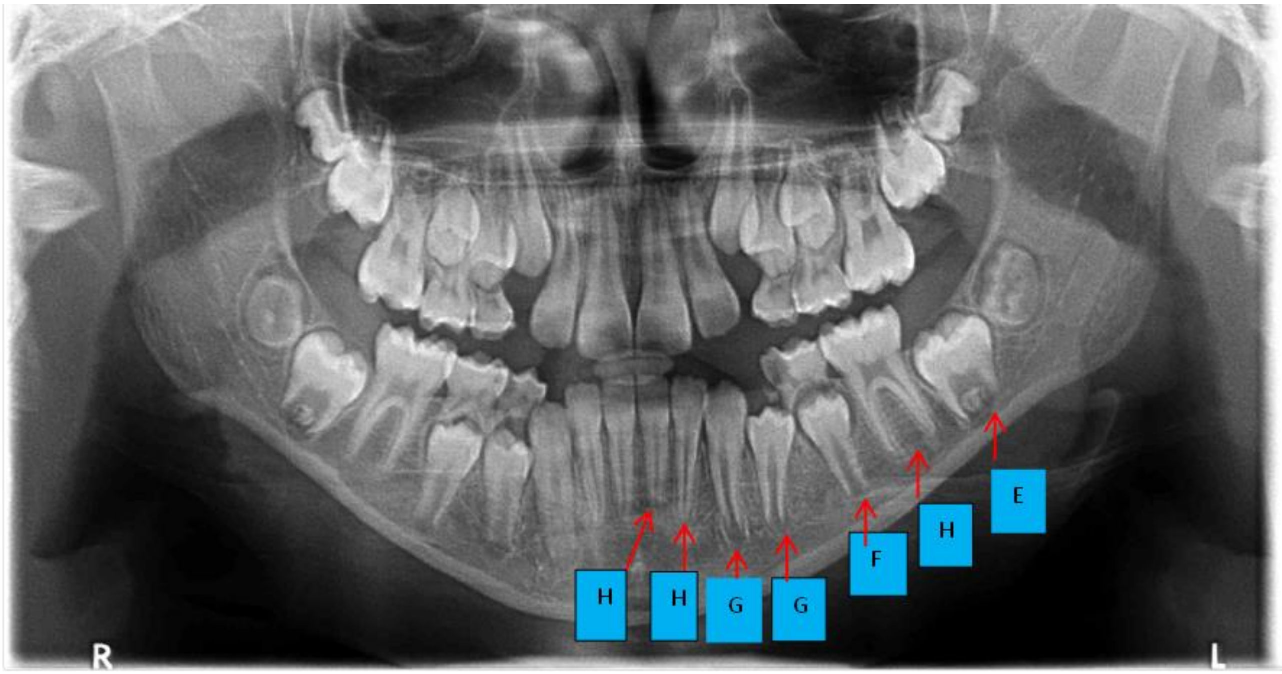


Figure 3. A PR of a 10.27 years old girl showing mixed dentition and tooth maturity stages of the 7 left mandibular teeth.

3.5.5 ESTIMATION OF THE DENTAL AGE

The tooth stages that were previously identified were then assigned the corresponding age scores using the Willem's age score tables (appendix D). It is worth noting that there are different scores for girls and boys. The scores for the seven teeth were summed up to give the estimated dental age for a particular individual as demonstrated in table 1.

Table 1. Staging, scoring and determination of the dental age of the panoramic radiograph in figure 3.

Tooth	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**TOTAL**
Maturity Stage	H	H	G	G	F	H	E	
Maturity Score	3.14	0.7	1.72	1.58	0.35	2.21	0.66	10.36
Estimated age	10.36 years							
Chronological age	10.27 years							
Gender	Female							

3.5.6 DETERMINATION OF THE CORRELATION BETWEEN THE ESTIMATED AND CHRONOLOGICAL AGE

The data regarding the chronological age and gender were merged together with the corresponding data for tooth stages, scores and dental age in a Microsoft excel worksheet. The data was cleaned up and any inappropriately filled or missing data was corrected. The difference between the chronological age (CA) and dental age (DA) was calculated by subtracting the DA from the CA i.e. (CA - DA). Study subjects who had their DA perfectly estimated i.e. DA=CA resulted into an age difference of 0. A positive or a negative mean age difference indicated an underestimation or overestimation of the child's age respectively. Relationship between the estimated and chronological age was also determined as well as the statistical significance as outlined under data analysis.

3.5.7 DATA ANALYSIS

The data was transferred from Microsoft excel to the Statistical Packages for Social Sciences (SPSS) version 20.0 for further analysis. Analysis was categorised as descriptive and inferential statistics. Descriptive statistics included measures of central tendency such as median and mean while dispersion was measured in range, maximum, minimum and standard deviation. Inferential statistics consisted of CI, standard error, parametric and non-parametric tests. The statistical significance of the mean difference between chronological and estimated age was measured using the paired-samples t-test and 95% CI. The mean age for male and females were compared using the independent-samples t-test. Non-parametric tests were used to compare the means for age groups which had a few participants and data was not normally distributed. They included, Mann-Whitney U test for measuring mean differences between independent samples of females and males while Wilcoxon signed rank test was used to compare CA and DA.

The results were reported as follows; t (degrees of freedom [df]) =t-value, p= significance level. P value of less than 0.05 indicated statistical significance. The interval estimate for the mean difference between the chronological and age estimated by Willems' model was measured with a confidence interval of 95%. A CI that did not include 0 in its range also indicated statistical significance (Polit and Beck, 2012).

The measure of relationship between the chronological and dental age was tested using the Pearson product-moment correlation coefficient (Pearson's r). Inferential statistics were presented as point and interval estimate. Tables and figures such as bar charts, box plot, scatter plots and line graphs were used to present the results according to different age cohorts (Kothari and Garg, 2014). The data for boys and girls were presented separately as well as a combination of both.

3.6 RELIABILITY

There was random selection of 40 (10%) images which were assessed again by the principal investigator after 2 months in order to measure the intraexaminer reliability. Besides, the interexaminer reliability was also carried out by examination of the same 10% of the radiographs by a different observer. Intra- and interexaminer reliability was then measured using the one way random intraclass correlation coefficient (ICC) for continuous data.

3.7 ETHICAL CONSIDERATIONS

The proposal was presented to the Kenyatta National Hospital/University of Nairobi (KNH/UON)-Ethics and Research Committee (ERC) for approval. The approval was granted under approval number P130/02/2016. Authority to carry out the study was sought from the Dean of the School of Dental Sciences, University of Nairobi. Data was corrected retrospectively from clinical records that had already been consented to be used for research since UNDH is a research and teaching hospital. Besides, the study did not involve examination of patients. All the information obtained was kept confidential. The data was anonymised by removal of patients' identifiers from the radiographs. Each PR was given Arabic numeral codes and stored under password to enhance confidentiality.

4. RESULTS

The results of the chronological and dental age as well as their correlation was analysed as shown in figures 4 – 9 and tables 2- 8. The teeth maturity for the select sample was also determined as shown in figures 10 - 18 and tables 9 – 17.

4.1 CHRONOLOGICAL AGE

A total of 649 PR were collected but only 401, 61.8% fulfilled the inclusion criteria hence they were all included in the analysis. Most (157, 63.3%) of the rejected PR did not have the corresponding date of birth in terms of day, month and year while a few (20, 8.1%) were not diagnostically acceptable. Bilaterally missing and impacted teeth were found in 16, 6.5% PR while 1, 0.4% had features of amelogenesis imperfecta. After computing the chronological age, it was realized that some (54, 21.8%) radiographs were for children aged either below 3.00 or above 16.99 years, therefore, they were excluded.

4.1.1 OVERALL DISTRIBUTION OF THE CHRONOLOGICAL AGE

Panoramic radiographs of 401 children were assessed. They belonged to 188 (46.9%) females and 213 males (53.1%). The mean chronological age was 9.73±3.60 years with a standard error of ±0.18. The median age was 9.43 years while the minimum and maximum ages were 3.24 and 16.90 years respectively (Table 2). There was unequal representation of children in different age cohorts. They ranged from 10 to 46 children per age cohort. The 8 years old were the majority (11.47%) while the 3 years old were the least (2.49%). The 9 and 8 years old age cohorts had the most boys and girls respectively (figure 4 and Table 2).

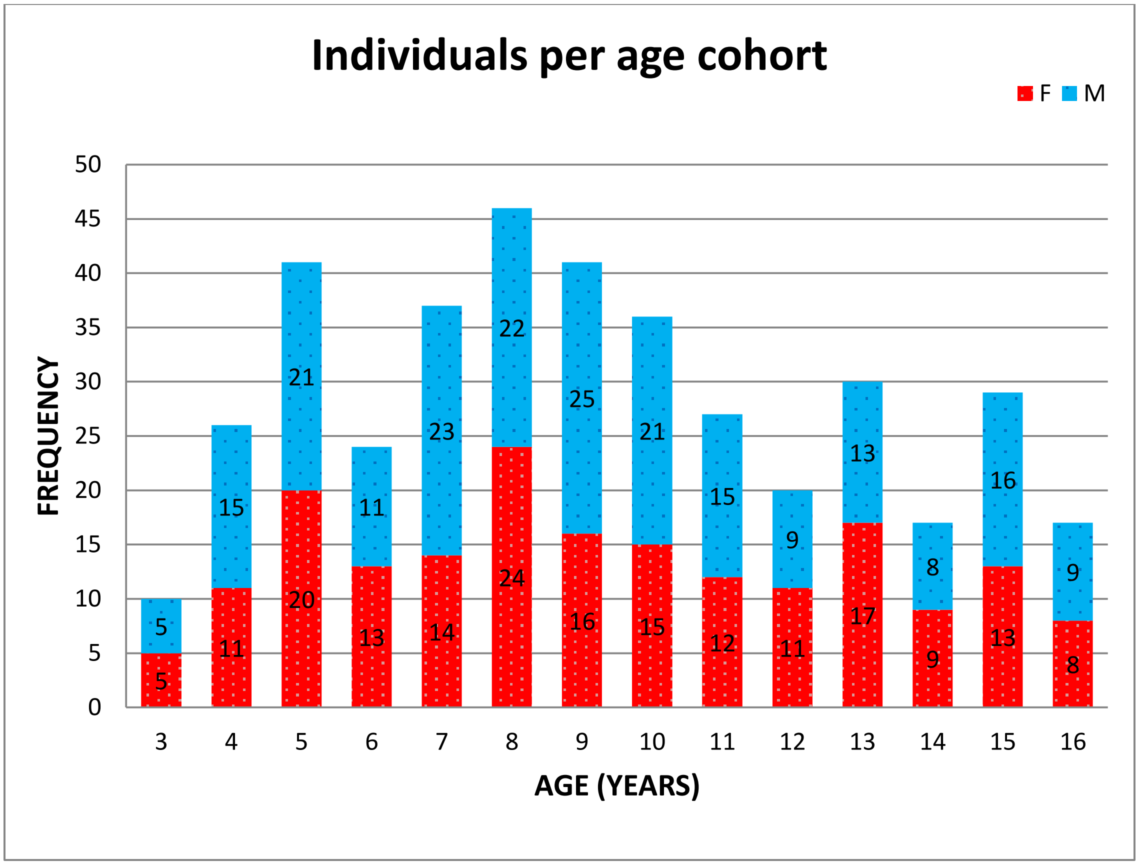


Figure 4. Distribution of children by age cohort

Table 2. Overall distribution of the chronological age

Age cohort (yrs.)	n	Mean (yrs.)	SD (yrs.)	SE (yrs.)	Min. (yrs.)	Max. (yrs.)	Median (yrs.)
3	10	3.64	0.21	0.07	3.24	3.96	3.67
4	26	4.53	0.31	0.60	4.07	4.97	4.58
5	41	5.50	0.32	0.05	5.00	5.99	5.52
6	24	6.41	0.30	0.06	6.01	6.98	6.32
7	37	7.45	0.31	0.51	7.01	7.97	7.44
8	46	8.45	0.28	0.41	8.01	8.89	8.46
9	41	9.47	0.28	0.44	9.00	9.98	9.48
10	36	10.50	0.30	0.05	10.01	10.99	10.48
11	27	11.48	0.26	0.50	11.04	11.93	11.42
12	20	12.50	0.32	0.72	12.05	12.94	12.52
13	30	13.42	0.35	0.63	13.01	13.99	13.35
14	17	14.57	0.33	0.80	14.01	14.97	14.67
15	29	15.46	0.26	0.49	15.01	15.94	15.52
16	17	16.51	0.24	0.06	16.23	16.90	16.51
3-16	401	9.73	3.60	0.18	3.24	16.90	9.43

SD- standard deviation, SE- standard error, Min- minimum, Max- maximum

4.1.2 DISTRIBUTION OF THE CHRONOLOGICAL AGE BETWEEN GIRLS AND BOYS

The mean age for girls was 9.83±3.65 years with a standard error of ±0.27 years. The boys had a slightly lower mean age of 9.65±3.56 years with a standard error of ±0.24 years (Table 3). There was no statistically significant difference between the mean chronological age for girls and boys ($t(399) = 0.486$, $p = 0.627$).

Table 3. Distribution of the chronological age between girls and boys

Age cohort (yrs.)	Girls						Boys					
	n	Mean (yrs.)	SD (yrs.)	SE (yrs.)	Median (yrs.)	Range (yrs.)	n	Mean (yrs.)	SD (yrs.)	SE (yrs.)	Median (yrs.)	Range (yrs.)
3	5	3.69	0.21	0.09	3.74	0.49	5	3.60	0.22	0.10	3.61	0.57
4	11	4.47	0.36	0.11	4.58	0.88	15	4.57	0.27	0.07	4.58	0.82
5	20	5.56	0.33	0.07	5.62	0.94	21	5.44	0.31	0.07	5.37	0.93
6	13	6.50	0.34	0.10	6.41	0.97	11	6.29	0.19	0.06	6.24	0.63
7	14	7.41	0.33	0.09	7.34	0.91	23	7.48	0.30	0.06	7.47	0.95
8	24	8.44	0.28	0.06	8.44	0.82	22	8.47	0.28	0.06	8.48	0.83
9	16	9.45	0.32	0.09	9.47	0.98	25	9.48	0.27	0.05	9.51	0.93
10	15	10.48	0.30	0.08	10.41	0.96	21	10.52	0.30	0.06	10.49	0.98
11	12	11.48	0.27	0.08	11.48	0.80	15	11.47	0.26	0.07	11.39	0.89
12	11	12.52	0.36	0.11	12.64	0.89	9	12.47	0.29	0.10	12.43	0.76
13	17	13.40	0.36	0.09	13.30	0.97	13	13.46	0.34	0.10	13.48	0.98
14	9	14.75	0.21	0.07	14.79	0.70	8	14.36	0.33	0.12	14.20	0.85
15	13	15.45	0.33	0.09	15.54	0.84	16	15.47	0.21	0.05	15.44	0.75
16	8	16.60	0.30	0.10	16.75	0.67	9	16.43	0.15	0.05	16.43	0.43
3-16	188	9.83	3.65	0.27	9.45	13.43	213	9.65	3.56	0.24	9.35	13.43

SD- standard deviation, SE- standard error, Min- minimum, Max- maximum

4.2 ESTIMATION OF DENTAL AGE BY WILLEMS' MODEL

An excellent degree of reliability was found in staging the teeth. The measure for ICC for intraexaminer reliability was 0.995 with a 95% confidence interval from 0.990 - 0.997 p=0.000. Additionally, the measure for ICC for interexaminer reliability was 0.982 with 95% confidence interval from 0.982 – 0.995 p=0.000. The variability which was noted involved just a one stage difference whereby a stage was rated as D by one examiner while the other rated it as C. The dental age for the select population was determined as outlined here below.

4.2.1 OVERALL DISTRIBUTION OF THE ESTIMATED DENTAL AGE

The mean DA was estimated as 10.01±3.61 years with a standard error of ±0.18 years. The median of the estimated age was 9.57 years while the minimum was 3.14 years and maximum was 16.03 years. The 95% CI of the mean DA was 9.65 – 10.36 years. The 3 years old who were the least had the widest 95% CI of 3.52 - 6.17 years while the 8 years old who were the majority had the narrowest interval of 8.60 - 9.20 years (Table 4). There was an overlap between the 95% CI of the 3 - 4 years old, 8 - 9 years old, 10 - 12 years old and 13 – 16 years old. Analysis of the DA revealed 18 outliers which were distributed within various age cohorts as shown in figure 5. There were only 1 – 3 outliers per age cohort.

Table 4. Overall distribution of the estimated dental age

Age cohort	n=401	Mean (yrs.)	95% CI for Mean (yrs.) Lower Bound	Upper Bound	SD (yrs.)	SE (yrs.)	Min. (yrs.)	Max. (yrs.)	Median (yrs.)
3	10	4.85	3.52	6.17	1.85	0.59	3.14	4.39	9.35
4	26	4.74	4.39	5.08	0.86	0.17	3.44	4.63	7.73
5	41	5.67	5.28	6.06	1.23	0.19	4.03	5.46	11.26
6	24	7.06	6.60	7.52	1.09	0.22	5.00	7.16	9.92
7	37	7.95	7.60	8.29	1.03	0.17	5.36	8.12	10.93
8	46	8.90	8.60	9.20	1.00	0.15	6.55	8.73	11.90
9	41	9.54	9.13	9.95	1.31	0.20	4.99	9.57	12.88
10	36	10.92	10.37	11.47	1.63	0.27	6.94	10.48	14.34
11	27	11.90	11.31	12.48	1.47	0.28	9.41	11.90	13.86
12	20	12.95	12.40	13.50	1.18	0.26	11.26	12.96	16.03
13	30	14.30	13.79	14.80	1.34	0.25	11.46	14.34	16.03
14	17	14.23	13.27	15.19	1.87	0.45	10.24	14.34	16.03
15	29	15.21	14.85	15.57	0.95	0.18	13.59	15.79	16.03
16	17	15.23	14.72	15.74	0.98	0.24	13.59	15.79	16.03
3-16	401	10.01	9.65	10.36	3.61	0.18	3.14	9.57	16.03

CI- confidence interval, SD- standard deviation, SE- standard error, Min- minimum, Max- maximum

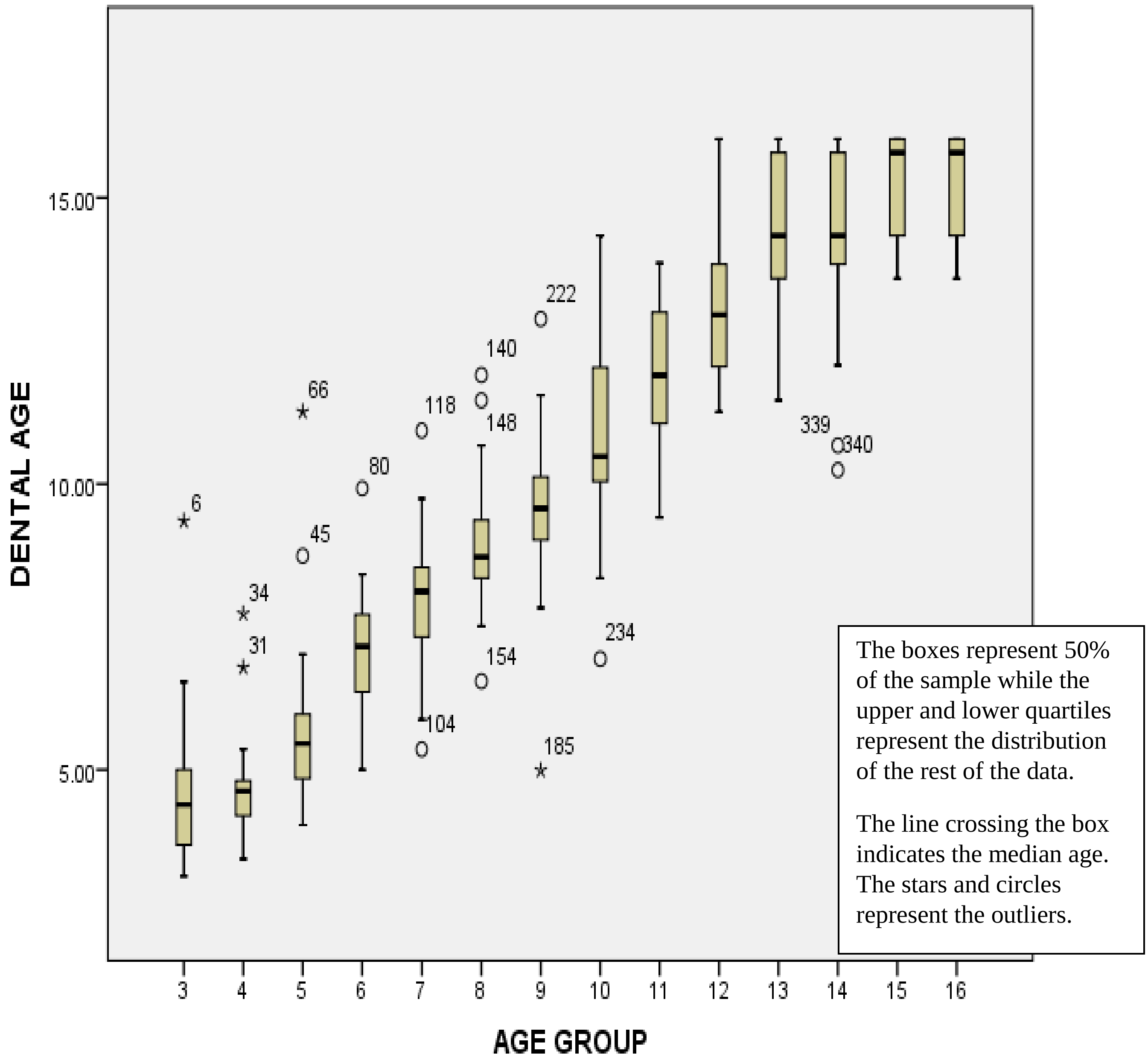


Figure 5 Boxplot showing the distribution of the estimated dental age.

4.2.2 DISTRIBUTION OF THE ESTIMATED DENTAL AGE BETWEEN GIRLS AND BOYS

The mean of the estimated dental age for girls and boys was 9.93±3.60 and 10.07±3.60 years respectively with equal standard error of 0.30 years. The difference between the mean DA for girls and boys was not statistically significant (t (399) = -0.402, p= 0.688). Median dental age for girls and boys was 9.41 and 9.72 years respectively. The minimum and maximum of the estimated dental age was 3.69 – 15.79 years for girls and 3.14 - 16.03 years for boys (Table 5). The maximum estimated age for age 13 – 16 years old girls and boys was the same i.e. 15.79 and 16.03 years respectively. There was year to year overlap of the confidence intervals.

Table 5. Estimated dental age for girls and boys

Age cohort (yrs.)	Girls n	Mean (yrs.)	95% CI for mean (yrs.) Lower Bound	Upper Bound	SE (yrs.)	SD (yrs.)	Range (yrs.)	Boys n	Mean (yrs.)	95% CI for mean (yrs.) Lower Bound	Upper Bound	SE (yrs.)	SD (yrs.)	Range (yrs.)
3	5	4.69	3.33	6.04	0.49	1.09	2.85	5	5.01	1.85	8.17	1.14	2.55	6.21
4	11	4.77	4.09	5.45	0.31	1.01	3.80	15	4.71	4.29	5.13	0.20	0.76	3.35
5	20	5.99	5.23	6.74	0.36	1.61	7.23	21	5.37	5.09	5.66	0.14	0.62	2.08
6	13	6.79	6.23	7.35	0.26	0.93	2.92	11	7.37	6.55	8.19	0.37	1.22	4.24
7	14	7.77	7.28	8.27	0.23	0.86	3.12	23	8.05	7.56	8.54	0.24	1.13	5.57
8	24	8.67	8.24	9.11	0.21	1.04	4.91	22	9.14	8.73	9.55	0.20	0.93	4.07
9	16	9.12	8.22	10.03	0.43	1.70	7.89	25	9.81	9.43	10.19	0.18	0.92	3.70
10	15	10.61	9.64	11.58	0.45	1.75	6.90	21	11.15	10.44	11.85	0.34	1.54	5.40
11	12	11.75	10.60	12.89	0.52	1.81	4.43	15	12.02	11.35	12.68	0.31	1.20	4.17
12	11	12.76	12.09	13.42	0.30	0.99	2.38	9	13.19	12.12	14.26	0.46	1.39	4.77
13	17	14.04	13.27	14.81	0.36	1.50	4.33	13	14.62	13.97	15.28	0.30	1.08	3.25
14	9	13.83	12.46	15.21	0.60	1.79	5.12	8	14.67	13.02	16.33	0.70	1.98	5.79
15	13	15.04	14.44	15.64	0.27	0.99	1.95	16	15.35	14.86	15.84	0.23	0.92	2.44
16	8	15.06	14.22	15.90	0.36	1.01	1.95	9	15.38	14.62	16.15	0.33	0.99	2.44
3-16	188	9.93	9.41	10.45	0.26	3.59	12.10	213	10.07	9.58	10.56	0.25	3.63	12.89

CI- Confidence interval, SE- Standard error, SD- Standard deviation,

4.3 CORRELATION BETWEEN CHRONOLOGICAL AND DENTAL AGE

The performance of Willems' method in the select population was outlined by comparing the CA and DA.

4.3.1 AGE DIFFERENCE BETWEEN CHRONOLOGICAL AND DENTAL AGE

The overall mean age difference (MAD) for the sample was -0.27±1.30 years, 95% CI -0.40 - -0.14. with SE of 0.06 years (table 6). The difference between CA (9.73±3.60 years) and DA (10.01 ±3.61), was found to be highly significant (t (400) = -4.185, P = 0.000). Product-moment correlation coefficient (Pearson's r) was computed and revealed a strong, positive correlation between the chronological and estimated age, r=0.935, n=401 p=0.000.

About a third (150, 37%) of the children were aged within 6 months while about two thirds (258, 64%), were within one year of their chronological age (figure 6). There was a general overestimation of the DA except in the age cohorts 14 - 16 years old which were underestimated. The age group analysis revealed that some of the age cohorts did not show any statistically significant difference between estimated and chronological age except for the 6 - 8, 13 and 16 years old. The most accurately estimated age was for age group 9 which had a mean age difference that was less than a month (-0.07 years) (table 6).

Table 6 Overall mean age difference between chronological and dental age

Age cohort (yrs.)	**n**	**Mean (yrs.)**			**95% CI for Mean (yrs.)**		**SD (yrs.)**	**SE (yrs.)**	**p-value CA vs DA**
		CA	DA	CA-DA	Lower Bound	Upper Bound			
3	10	3.64	4.85	-1.20	-2.48	0.08	1.79	0.57	**0.170**
4	26	4.53	4.74	-0.21	-0.52	0.11	0.78	0.15	**0.404**
5	41	5.50	5.67	-0.17	-0.53	0.18	1.12	0.18	**0.334**
6	24	6.41	7.06	-0.65	-1.08	-0.22	1.02	0.21	**0.005***
7	37	7.45	7.95	-0.49	-0.81	-0.17	0.96	0.16	**0.004***
8	46	8.45	8.90	-0.45	-0.75	-0.14	1.03	0.15	**0.005***
9	41	9.47	9.54	-0.07	-0.48	0.33	1.28	0.20	**0.714**
10	36	10.50	10.92	-0.42	-0.97	0.12	1.61	0.26	**0.124**
11	27	11.48	11.9	-0.42	-1.01	0.17	1.50	0.28	**0.146**
12	20	12.50	12.95	-0.45	-0.95	-0.04	1.07	0.24	**0.100**
13	30	13.42	14.30	-0.87	-1.39	-0.87	1.37	0.25	**0.002***
14	17	14.57	14.23	0.34	-0.65	1.32	1.91	0.46	**0.705**
15	29	15.46	15.21	0.25	-0.11	0.62	0.96	0.18	**0.270**
16	17	16.51	15.23	1.28	0.80	1.77	0.94	0.23	**0.000***
3-16	401	9.73	10.01	-0.27	-0.40	-0.14	1.30	0.65	**0.000***

CI- confidence interval, SE- standard error, SD- standard deviation, Min- minimum, Max- maximum *p<0.05 – significant

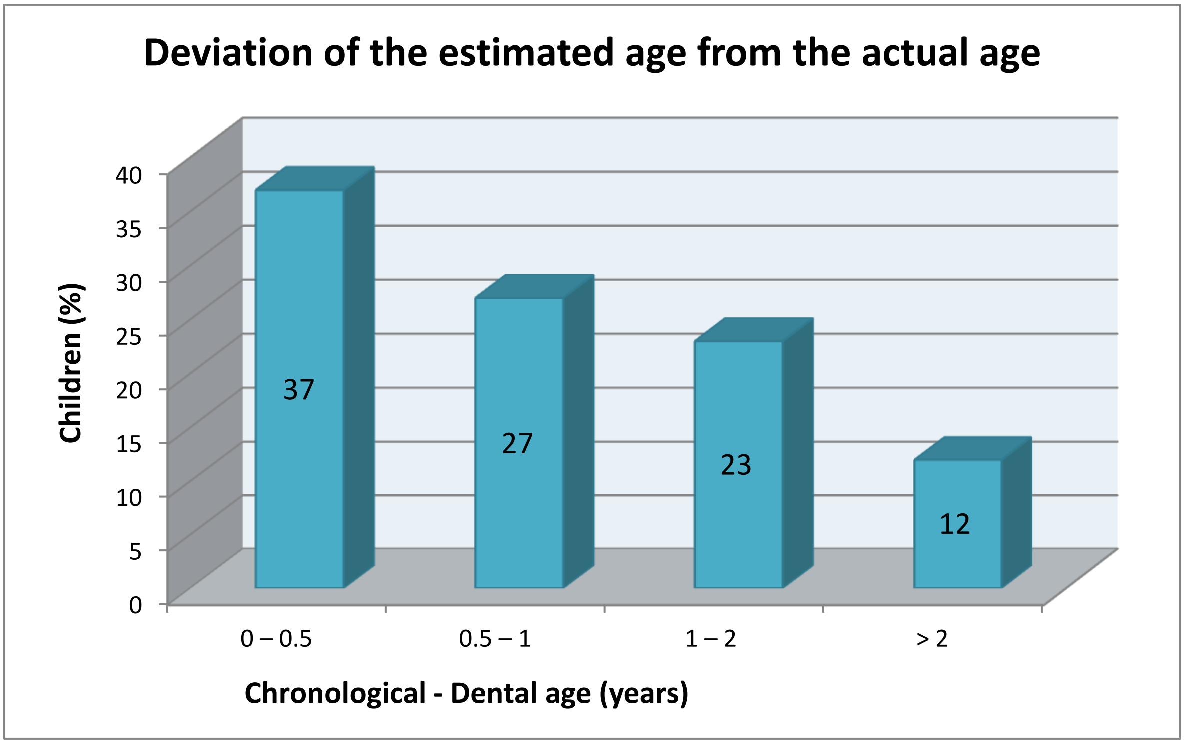


Figure 6. Percentage of children aged within 0.5, 0.5 – 1, 1 - 2 and >2 years of their chronological age.

4.3.2 MEAN AGE DIFFERENCES BETWEEN GIRLS AND BOYS

The MAD for the girls was -0.10±1.37 years, 95% CI of -0.30 - 0.10 years which was not statistically significant. The paired student t-test also revealed that there was no statistically significant difference between CA (9.83±3.65 years) and DA (9.93±3.60), (t (187) = -1.017, p= 0.311). Product-moment correlation coefficient (Pearson's r) was computed to assess the relationship between the chronological and estimated age for girls. Overall, there was a strong, positive correlation between the chronological and estimated age, r=0.929, n=188 p=0.000.

The mean difference between the CA and DA for the girls ranged from -0.99 to 1.54 years. The MAD for most of the age cohorts i.e. 3 – 15 years old was not statistically significant except for the 16 years old. In general, most of the age cohorts were overestimated except the 9 and 14 – 16 years. In addition, most of the age cohorts with the exception of the 3, 14 and 16 years old had an overall under- or overestimation of ≤ six months (Table 7 and figure 7).

Figure 8 shows a positive correlation between mean age differences and chronological age for girls whereby as age advances the difference also increases. Initially, there is a negative difference which shows overestimation of the age of the younger children. Then at around 10 years the estimation is more accurate as the difference between CA and DA approaches 0. Then, it increases to show a positive difference which indicates underestimation of age of the older children.

The boys had a mean age difference of -0.42±1.22 years, 95% CI -0.26 - -0.59 years which was statistically significant. Paired student t-test also revealed that there was statistically significant difference between CA (9.65 ±3.56 years) and DA (10.07 ± 3.60), (t (212) = -5.041, p=0.000). The median MAD was -0.40 years with SE of 0.84 years while the minimum was -5.62 and a maximum of 3.77 years. A Product-moment correlation coefficient (Pearson's r) was computed to assess the correlation between the chronological and estimated age for boys. There was a strong, positive correlation between the chronological and estimated age, r=0.942, n=213 p=0.000.

The mean age differences for about two thirds of the age cohorts were not statistically significant. The age cohorts for the 6 - 8, 13 and 16 years old had confidence intervals which did not include 0 hence indicating a statistical significance. The minimum and maximum MAD was -1.41 and 1.05 years respectively. In general, most of the age cohorts except the 5, 15 and 16 years old were overestimated. Additionally, majority of the age cohorts with the exception of the 3, 6, 13 and 16 years old had an overall under- or overestimation of ≤ 1 year (table 7 and figure 7). Figure 9 shows a general overestimation of the boys' age, the overestimation reduces as age advances but does not reach zero.

Table 7. Mean age differences for girls and boys

Gender	Age Cohort	n	Mean (yrs.) CA	DA	CA-DA	95% CI for mean Lower Bound	Upper Bound	SD. (yrs.)	Min. (yrs.)	Max. (yrs.)	Median (yrs.)	p-value CA vs DA
Girls	3	5	3.69	4.69	-0.99	-2.31	0.32	1.06	-2.80	-0.20	-0.50	**0.043***
	4	11	4.47	4.77	-0.31	-0.92	0.31	0.91	-2.95	0.31	-0.09	**0.533**
	5	20	5.56	5.99	-0.43	-1.10	0.25	1.44	-5.41	1.44	-0.05	**0.444**
	6	13	6.50	6.79	-0.29	-0.75	0.17	0.76	-0.98	1.27	-0.45	**0.196**
	7	14	7.41	7.77	-0.37	-0.83	0.09	0.8	-1.77	0.79	-0.24	**0.140**
	8	24	8.44	8.67	-0.24	-0.69	0.22	1.08	-3.26	2.03	0.07	**0.440**
	9	16	9.45	9.12	0.33	-0.58	1.23	1.70	-3.61	4.48	0.09	**0.278**
	10	15	10.48	10.61	-0.13	-1.09	0.82	1.73	-3.83	3.47	-0.17	**0.650**
	11	12	11.48	11.75	-0.26	-1.38	0.86	1.76	-2.53	2.15	0.40	**0.505**
	12	11	12.52	12.76	-0.24	-0.88	0.40	0.96	-1.78	1.19	-0.24	**0.533**
	13	17	13.4	14.04	-0.65	-1.38	0.09	1.43	-2.77	2.30	-0.54	**0.068**
	14	9	14.75	13.83	0.92	-0.47	2.30	1.80	-1.12	4.30	0.95	**0.235**
	15	13	15.45	15.04	0.41	-0.16	0.99	0.95	-0.78	1.94	0.03	**0.328**
	16	8	16.60	15.06	1.54	0.80	2.28	0.89	0.44	2.86	1.08	**0.012***
	3-16	188	9.83	9.93	-0.10	-0.30	0.10	1.37	-5.41	4.48	-0.11	**0.311***
Boys	3	5	3.60	5.01	-1.41	-4.45	1.62	2.45	-5.62	-0.51	0.35	**0.225**
	4	15	4.57	4.71	-0.14	-0.52	0.25	0.70	-2.21	0.05	0.89	**0.683**
	5	21	5.44	5.37	0.07	-0.22	0.37	0.65	-0.91	0.22	1.39	**0.754**
	6	11	6.29	7.37	-1.08	-1.85	-0.31	1.15	-3.46	-1.34	0.59	**0.013***
	7	23	7.48	8.05	-0.57	-1.03	-0.11	1.06	-3.01	-0.66	1.66	**0.011***
	8	22	8.47	9.14	-0.68	-1.10	-0.25	0.95	-3.67	-0.72	0.97	**0.002***
	9	25	9.48	9.81	-0.33	-0.68	0.03	0.86	-1.68	-0.36	1.49	**0.049**
	10	21	10.52	11.15	-0.63	-1.33	0.07	1.53	-3.50	0.15	1.36	**0.217**
	11	15	11.47	12.02	-0.55	-1.27	0.17	1.30	-2.26	-0.62	2.17	**0.088**
	12	9	12.47	13.19	-0.71	-1.63	0.20	1.19	-3.12	-0.56	0.92	**0.086**
	13	13	13.46	14.62	-1.17	-1.96	-0.38	1.31	-2.99	-1.00	0.88	**0.011***
	14	8	14.36	14.67	-0.31	-1.93	1.30	1.94	-1.96	-0.85	3.77	**0.484**
	15	16	15.47	15.35	0.12	-0.39	0.64	0.97	-0.84	-0.43	1.95	**0.501**
	16	9	16.43	15.38	1.05	0.29	1.80	0.98	0.21	0.53	2.84	**0.008***
	3-16	213	9.65	10.07	-0.42	-0.59	-0.26	1.22	-5.62	-0.40	3.77	**0.000***

CI- confidence interval, SD- standard deviation, Min - minimum, Max – maximum, *p<0.05 – significant

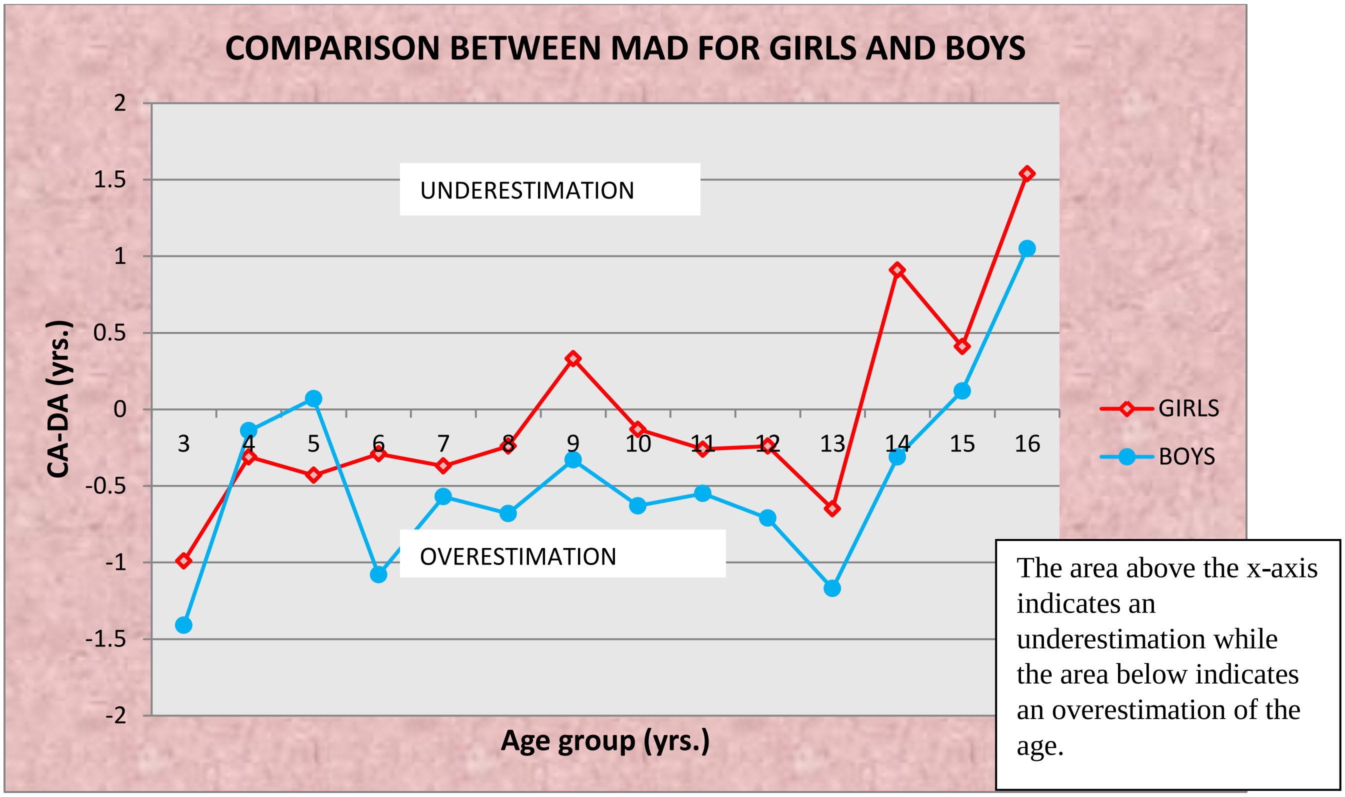


Figure 7 Performance of Willems' model in different age groups

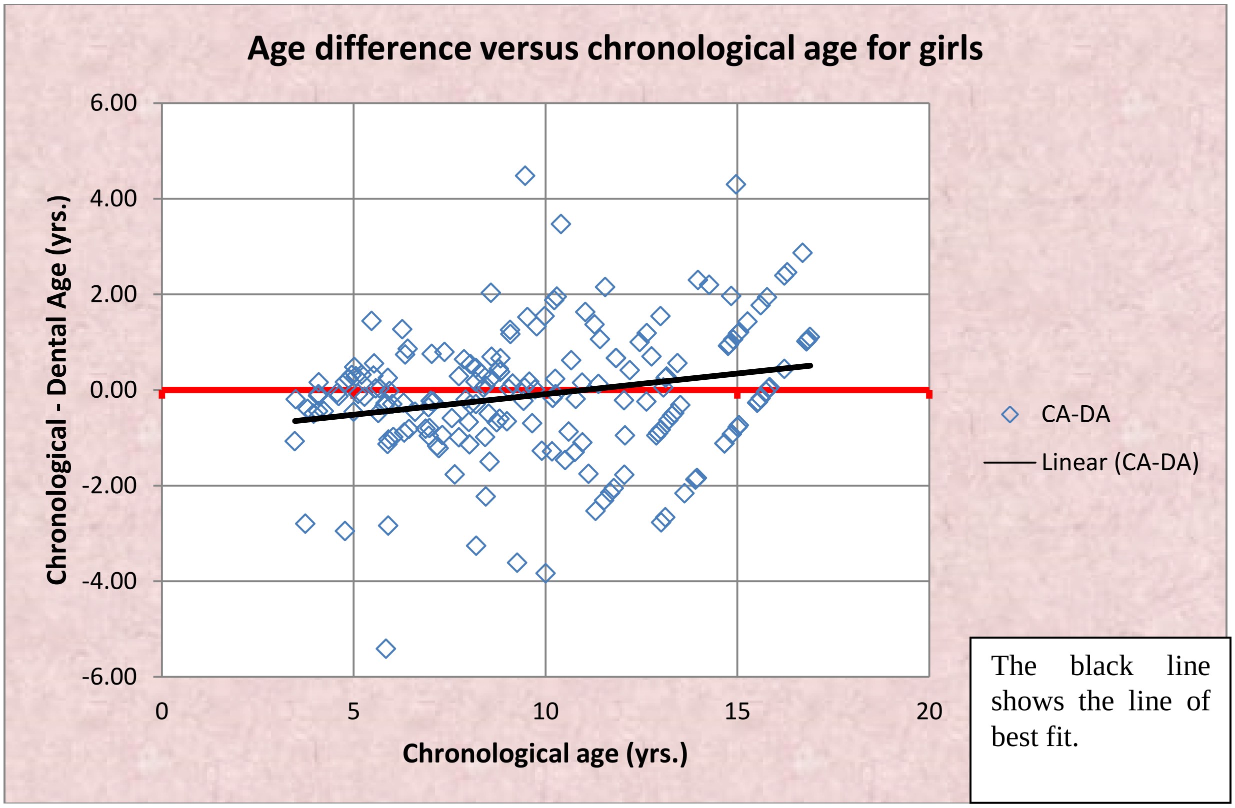


Figure 8. Scatter plot showing mean age differences versus chronological age for girls.

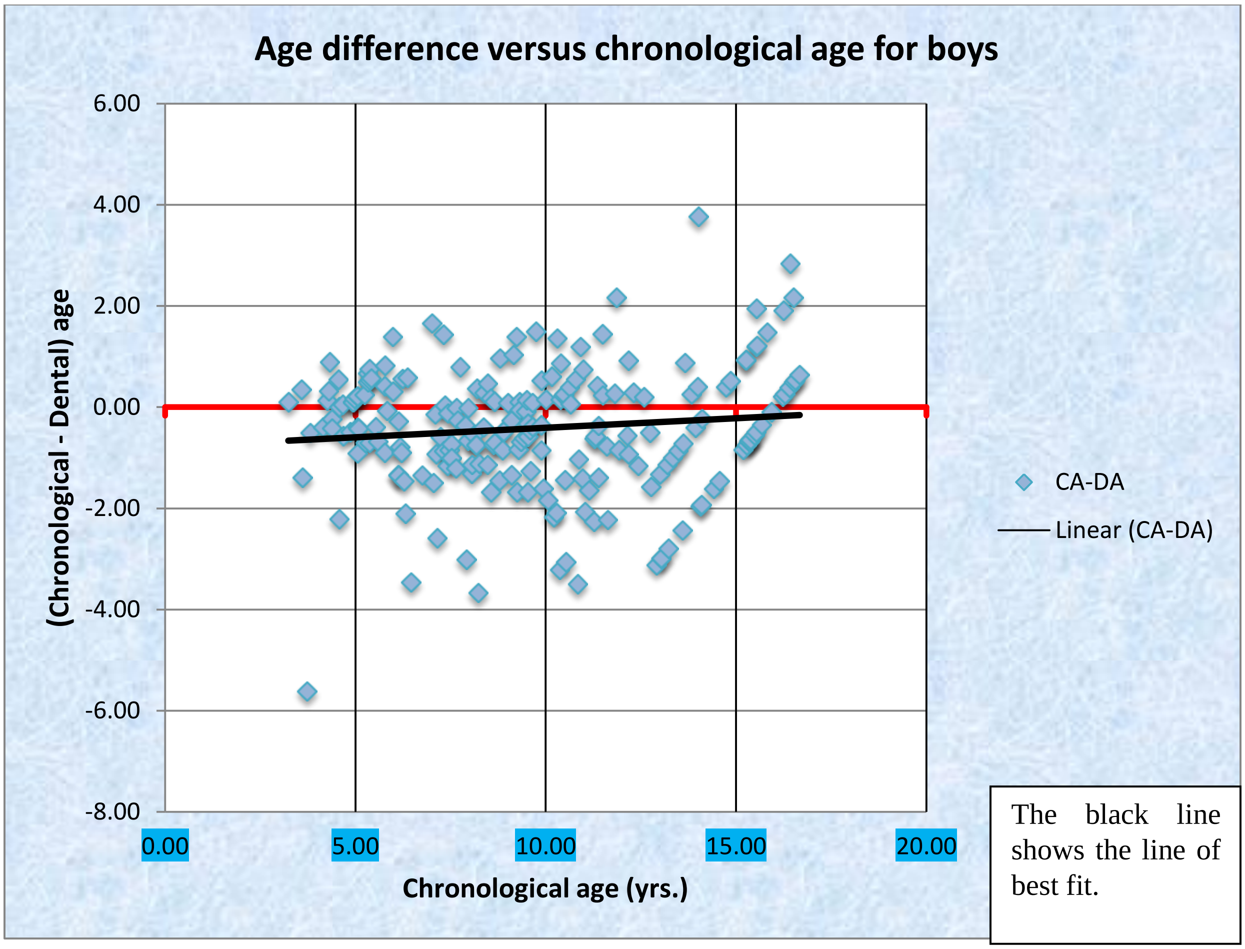


Figure 9. Scatter plot showing age differences versus the chronological age for boys.

4.3.3 EFFECT OF EXCLUDING OUTLIERS AND MATURE INDIVIDUALS

Removal of outliers did not result in gross change in the mean age difference i.e. only a reduction of 0.04 years. However, there was a great reduction of about 0.75 years in the MAD of the 3 years old. Following the exclusion of individuals with mature 7 mandibular teeth from the total sample, very few children remained in the 14 – 16 age cohorts. The difference between the estimated and chronological age reduced from 0.27 to 0.20 years. The MAD for girls and boys also reduced from 0.10 to 0.03 years and 0.42 to 0.35 years respectively. It was noted that the change was only 0.07 years which was less than a month, hence, it did not change the statistical significance of the overall MAD. Nonetheless, major changes were noted in the age group of 12 – 16 years old which had individuals at the final stage H of all the 7 mandibular teeth. There was significant overestimation of the 13 years old girls, underestimation of the 14 - 16 years old girls and 15 - 16 years old boys (table 8).

Table 8. Mean age difference after excluding mature individuals

Age Cohort (yrs.)	Girls (yrs.)					Boys (yrs.)					Combined boys and girls (yrs.)				
	n	Mean	95% CI for mean Lower Bound	Upper Bound	SD	n	Mean	95% CI for mean Lower Bound	Upper Bound	SD	n	Mean	95% CI Mean Lower Bound	Upper Bound	SD
12	11	-0.24	-0.88	0.40	0.96	8	-0.41	-1.11	0.28	0.83	19	-0.31	-0.74	0.11	0.89
13	11	-0.45	0.85	0.14	-0.83	9	-0.44	-1.03	0.16	0.77	20	-0.09	-0.52	0.35	0.92
14	6	1.90	0.53	3.26	1.30	4	1.12	-1.75	3.98	1.80	10	1.59	0.53	2.64	1.48
15	5	1.51	1.09	1.93	0.34	6	1.28	0.88	1.69	0.39	11	1.38	1.14	1.63	0.37
16	3	2.57	1.94	3.20	0.25	3	2.31	1.11	3.50	0.48	6	2.44	2.05	2.83	0.37
3-16 years	166	-0.03	-0.24	0.18	1.37	188	-0.35	-0.52	-0.17	1.21	354	-0.20	-0.33	-0.06	1.30

CI – confidence interval, SD – standard deviation.

4.4 DENTAL MATURITY IN CHILDREN ATTENDING THE UNDH

The Demirjian's (1973) maturity stages of all the seven mandibular teeth for each of the 401 radiographs were determined. In total 2807 teeth were examined and their dental maturity has been presented in tables 9 for the mandibular anterior teeth (incisors and canine) and table 10 for the posterior teeth (premolars and molars).

4.4.1 MEAN CHRONOLOGICAL AGE AT VARIOUS TOOTH MATURITY STAGES

Mean age of individuals at each tooth stage was calculated, for example, there were 7 children whose central incisors were at stage D, the mean of their chronological age was calculated resulting into a mean age of 4.14 years. This procedure was done for all the teeth. Some of the teeth especially the incisors and 1st molars had already passed their initial developmental stages i.e. stages A, B and C by the time the data was collected hence they are not presented in tables 9 and 10. It was noted that the earliest stage i.e. A could only be seen in the 2nd premolar and 2nd molar since they develop late.

Girls matured earlier than boys in two third of the stages. The differences ranged from 1-14 months but majority of the girls had reached the maturity stages not more than 6 months earlier than the boys. However, there was no statistically significant difference between the maturity for the girls and boys in the majority of the tooth stages. Statistically significant differences were only observed in 4 maturity stages namely, stage D of the lateral incisor, F of the first premolar, E and F of the canine. The highest difference was noted at stage E of the canine for girls which was 14 months earlier than for the boys p= 0.012 (Table 9).

Table 9. Mean chronological age at different maturity stages of the anterior mandibular teeth

Tooth	Stage	Girls				Boys				Combined girls and boys				P-value (girls vs boys)
		n	Mean	SE	SD	n	Mean	SE	SD	n	Mean	SE	SD	
I_1	D	7	4.14	0.24	0.63	12	4.53	0.18	0.62	19	4.38	0.15	0.64	**0.120**
	E	21	5.34	0.26	1.21	25	5.11	0.14	0.69	46	5.22	0.14	0.96	**0.903**
	F	10	5.82	0.31	0.98	9	6.01	0.26	0.78	19	5.91	0.2	0.87	**0.604**
	G	19	7.25	0.25	1.11	22	7.72	0.22	1.05	41	7.5	0.17	1.09	**0.990**
I_2	C	1				2	3.9	0.66	0.93	3	3.76	0.4	0.70	**1.000**
	D	10	4.36	0.17	0.55	23	4.95	0.17	0.79	33	4.77	0.13	0.77	**0.025***
	E	23	5.62	0.23	1.12	17	5.44	0.20	0.81	40	5.54	0.16	0.99	**0.859**
	F	10	6.65	0.57	1.8	8	6.68	0.44	1.24	18	6.66	0.36	1.53	**0.897**
	G	25	7.53	0.23	1.14	38	7.89	0.18	1.12	63	7.75	0.14	1.13	**0.177**
C	C	11	4.65	0.26	0.87	22	5.15	0.16	0.73	33	4.99	0.14	0.80	**0.069**
	D	28	5.85	0.29	1.54	33	5.99	0.24	1.39	61	5.92	0.19	1.45	**0.553**
	E	16	6.59	0.28	1.13	21	7.73	0.34	1.57	37	7.23	0.24	1.49	**0.005***
	F	45	8.57	0.19	1.25	57	9.27	0.19	1.45	102	8.96	0.14	1.40	**0.012***
	G	16	10.61	0.41	1.63	23	10.95	0.24	1.17	39	10.81	0.22	1.37	**0.329**

Key: I_1- central incisor, I_2 - lateral incisor, C - canine, SD-standard deviation, SE-standard error. *p<0.05 – significant

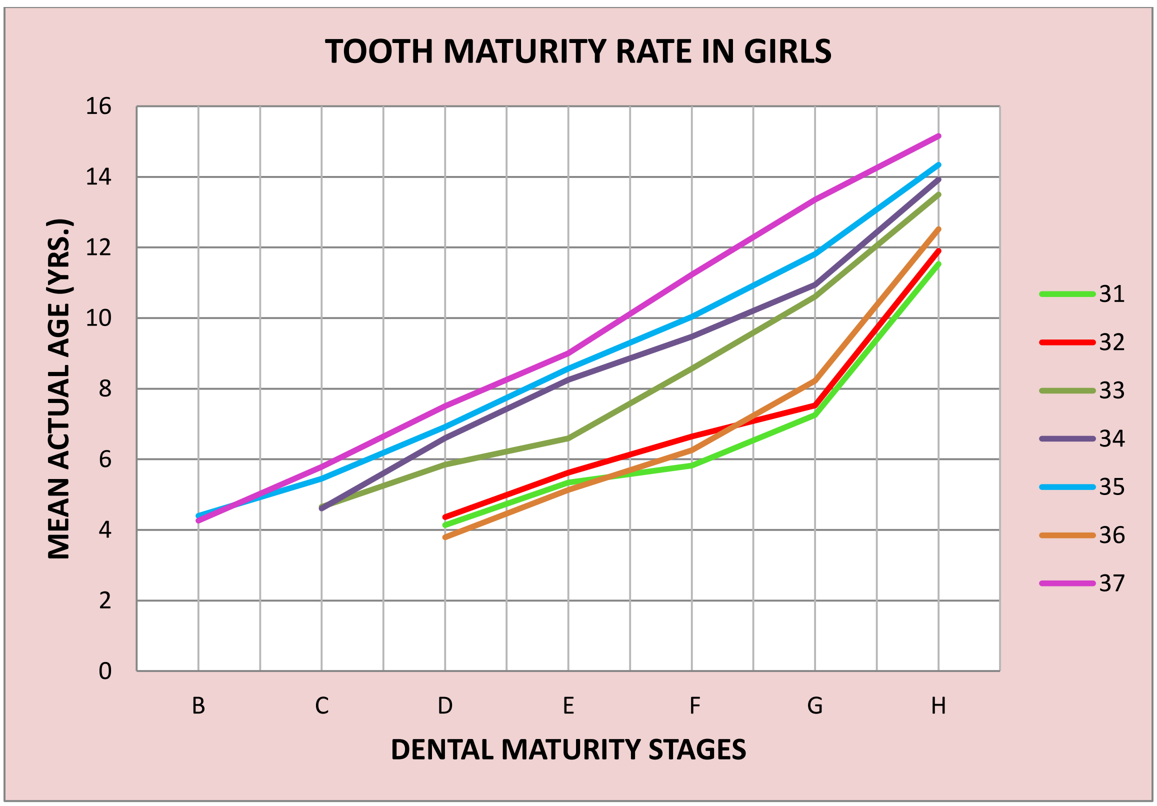
Table 10. Mean chronological age at different maturity stages of the posterior mandibular teeth

Tooth	Stage	Girls				Boys				Combined girls & boys				P-value (girls vs boys)
		n	Mean	SE	SD	n	Mean	SE	SD	n	Mean	SE	SD	
	B	1				2	3.95	0.36	0.50	3	3.99	0.21	0.36	**1.000**
	C	20	4.61	0.15	0.69	27	5.01	0.14	0.73	47	4.84	0.11	0.73	**0.074**
PM_1	D	34	6.60	0.23	1.35	30	6.49	0.24	1.33	64	6.55	0.17	1.33	**0.657**
	E	30	8.25	0.20	1.11	42	8.30	0.19	1.25	72	8.28	0.14	1.18	**0.882**
	F	20	9.47	0.37	1.66	32	9.94	0.23	1.32	52	9.75	0.20	1.46	**0.036***
	G	22	10.94	0.37	1.76	20	10.97	0.27	1.19	42	10.96	0.23	1.50	**0.980**
	A	2	4.78	0.69	0.98	2	3.42	0.18	0.25	4	4.1	0.49	0.98	**0.333**
	B	7	4.4	0.35	0.93	9	4.73	0.20	0.60	16	4.59	0.19	0.75	**0.351**
	C	20	5.45	0.32	1.41	26	5.30	0.16	0.83	46	5.37	0.16	1.11	**0.765**
PM_2	D	35	6.92	0.23	1.36	32	7.08	0.27	1.52	67	6.99	0.17	1.43	**0.649**
	E	26	8.57	0.22	1.11	39	8.46	0.15	0.92	65	8.51	0.12	0.99	**0.683**
	F	27	10.04	0.38	1.95	31	10.41	0.24	1.32	58	10.24	0.21	1.64	**0.275**
	G	22	11.81	0.34	1.62	28	11.71	0.33	1.76	50	11.75	0.24	1.68	**0.584**
	C								0.69	2	3.96	0.37	0.52	**1.000**
	D	2	3.79	0.30	0.42	3	4.02	0.40	0.75	5	3.93	0.25	0.55	**0.401**
M_1	E	22	5.13	0.31	1.44	28	5.09	0.14	1.25	50	5.11	0.15	1.09	**0.300**
	F	17	6.26	0.32	1.33	13	6.01	0.35	1.27	30	6.15	0.23	1.28	**0.606**
	G	51	8.22	0.23	1.67	64	8.30	0.16	2.6	115	8.26	0.14	1.46	**0.774**
	A	2	4.78	0.69	0.98	2	3.53	0.29	0.4	4	4.15	0.47	0.95	**0.333**
	B	11	4.26	0.14	0.47	11	4.65	0.20	0.67	22	4.46	0.13	0.60	**0.133**
	C	25	5.79	0.25	1.26	32	5.43	0.13	0.73	57	5.59	0.13	1.00	**0.174**
M_2	D	30	7.51	0.26	1.41	36	7.75	0.17	1.00	66	7.64	0.15	1.20	**0.231**
	E	40	9.00	0.19	1.20	53	9.57	0.21	1.53	93	9.33	0.15	1.42	**0.054**
	F	22	11.23	0.43	2.03	16	10.42	0.39	1.55	38	10.89	0.30	1.86	**0.162**
	G	36	13.35	0.31	1.83	37	13.25	0.32	1.93	73	13.30	0.22	1.87	**0.843**

Key: PM_1 - 1^{st} premolar, PM_2 – 2^{nd} premolar, M_1 – 1^{st} molar, M_2 – 2^{nd} molar, SD-standard deviation, SE-standard error, *p<0.05 – significant

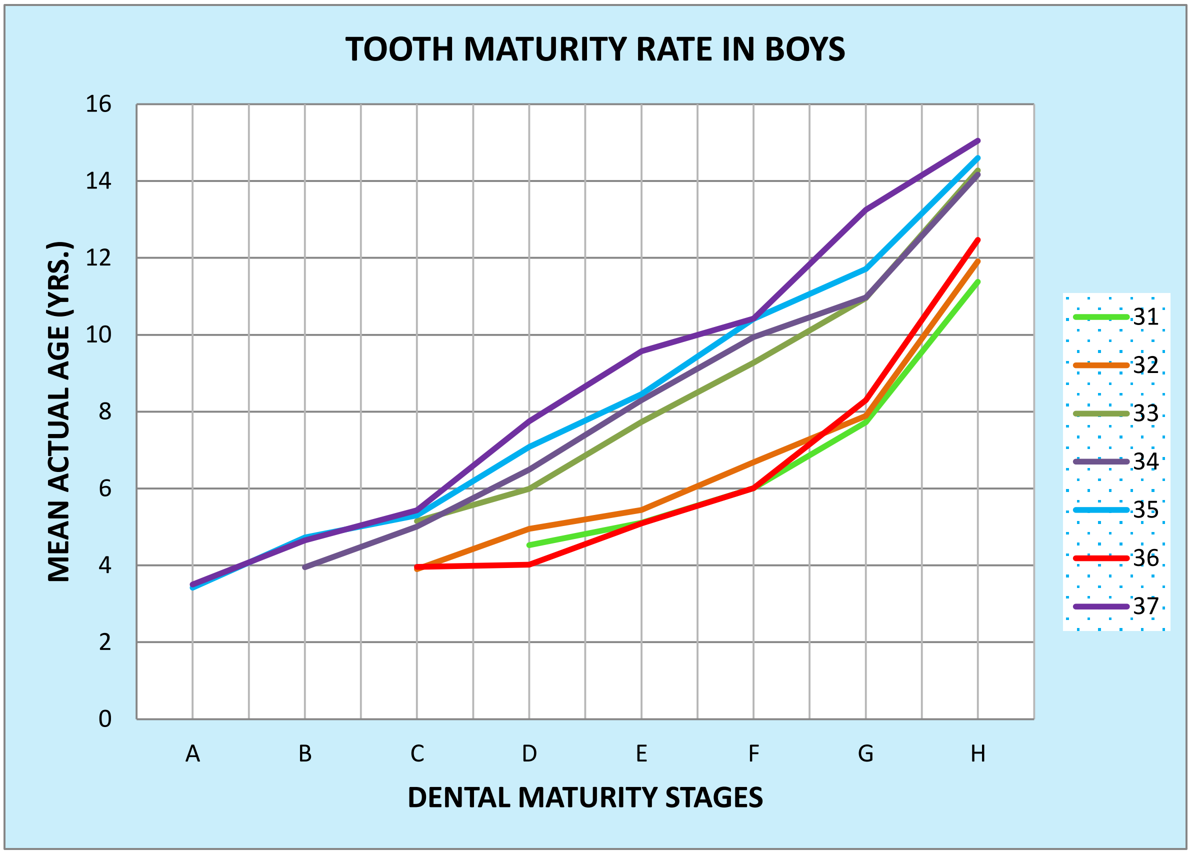
4.4.2 GROWTH RATE OF THE TEETH

Figure 10 and 11 shows the growth period of the teeth which ends on average shortly after 15 years for both boys and girls. The growth of the incisors and the 1st molars occurs early and they seem to grow at the same rate while the rest of the teeth develop later. From stage D to G of the two incisors and the 1st molar which represents the formation of the roots, it takes about 4 years but the rest of the teeth take a longer time to mature their roots. Root development of the 1st molar takes longer than the 2nd molar. In girls, the growth of the canine and first premolar shows a wider gap than in boys with the canine for the girls developing earlier than the premolar. The apices of the 1st premolar and canine close at around the same time in boys while in girls there is a difference of about 3 months.



31 – Central incisor, 32 – lateral incisors, 33 canine, 34 – 1st premolar, 35 – 2nd premolar, 36 – 1st molar, 37 – 2nd molar.

Figure 10. Rate of maturity of the mandibular teeth in girls



31 – Central incisor, 32 – lateral incisors, 33 canine, 34 – 1st premolar,

35 – 2nd premolar,   36 – 1st molar, 37 – 2nd molar.

Figure 11. Rate of the maturity of the mandibular teeth in boys

4.4.3 COMPARISON BETWEEN TOOTH MATURITY FOR BOYS AND GIRLS BASED ON MEAN CA

The mean chronological age at various maturity stages for the seven mandibular teeth is shown in figures 12 – 18. Comparison between boys and girls revealed minimal differences and the curves representing both genders were running close together except for the canine. Nevertheless, the girls were slightly ahead than the boys at stages D, F, G of central and lateral incisors, C,D,E,F,G,H of canine, C,E,F,G,H of 1st premolar B,D,F,H of 2nd premolar, D,G of 1st molar and B,D,E of 2nd molar.

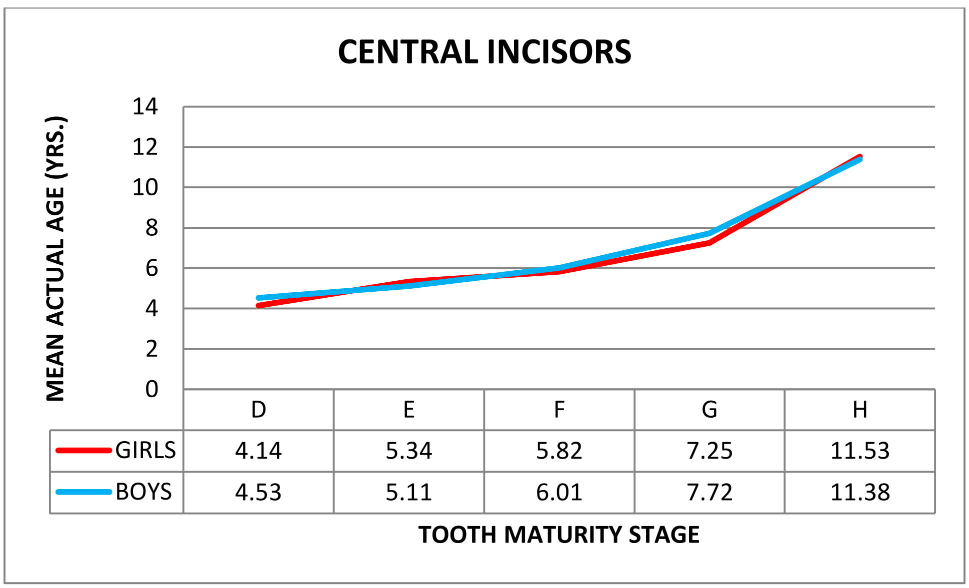


Figure 12. Comparison between the growth rate of central incisors in girls and boys.

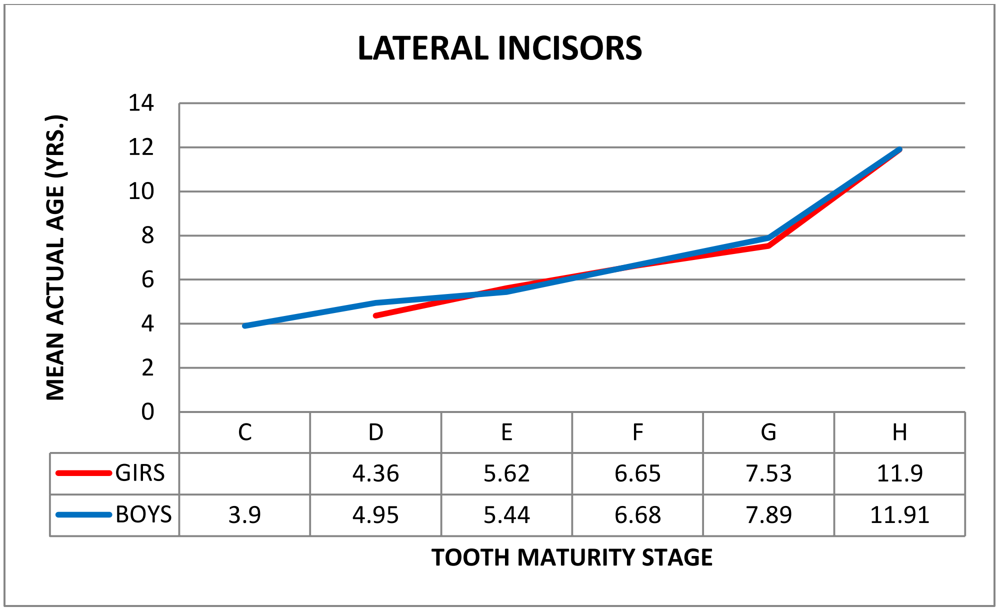


Figure 13. Comparison between the growth rate of lateral incisors in girls and boys.

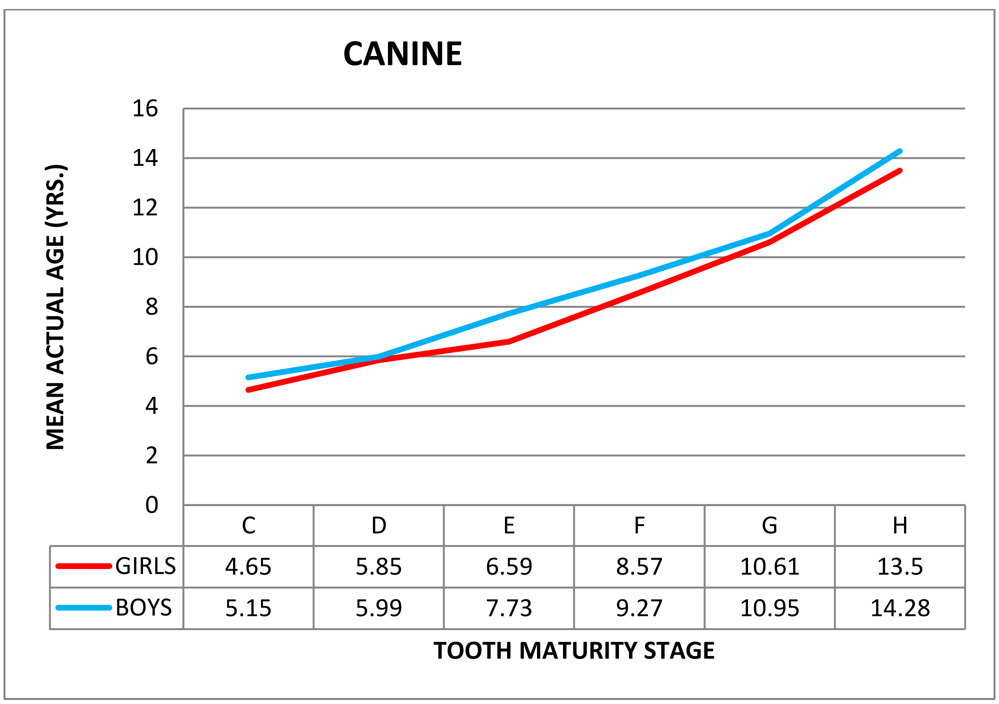


Figure 14. Comparison between the growth rate of canines in girls and boys.

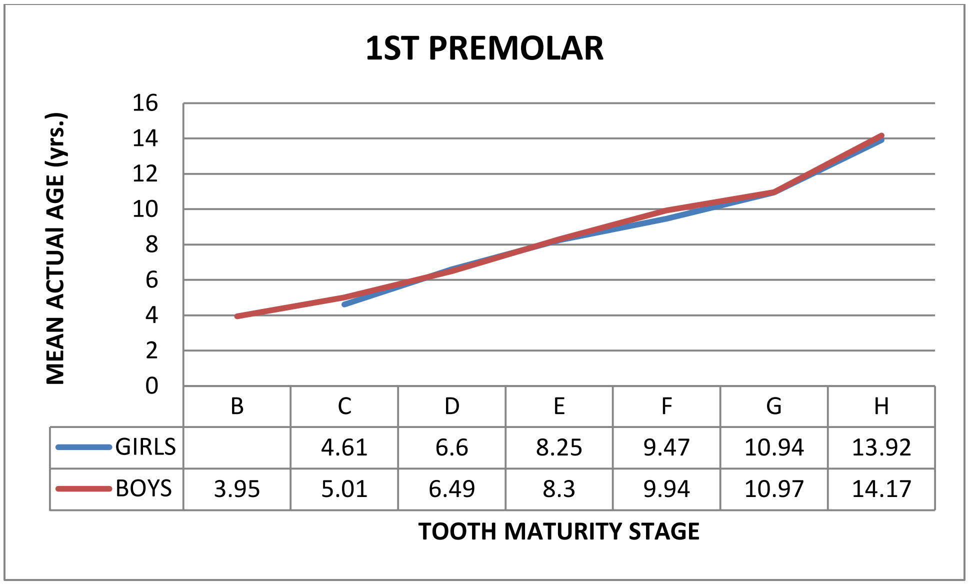


Figure 15. Comparison between the growth rate of 1st premolars in girls and boys.

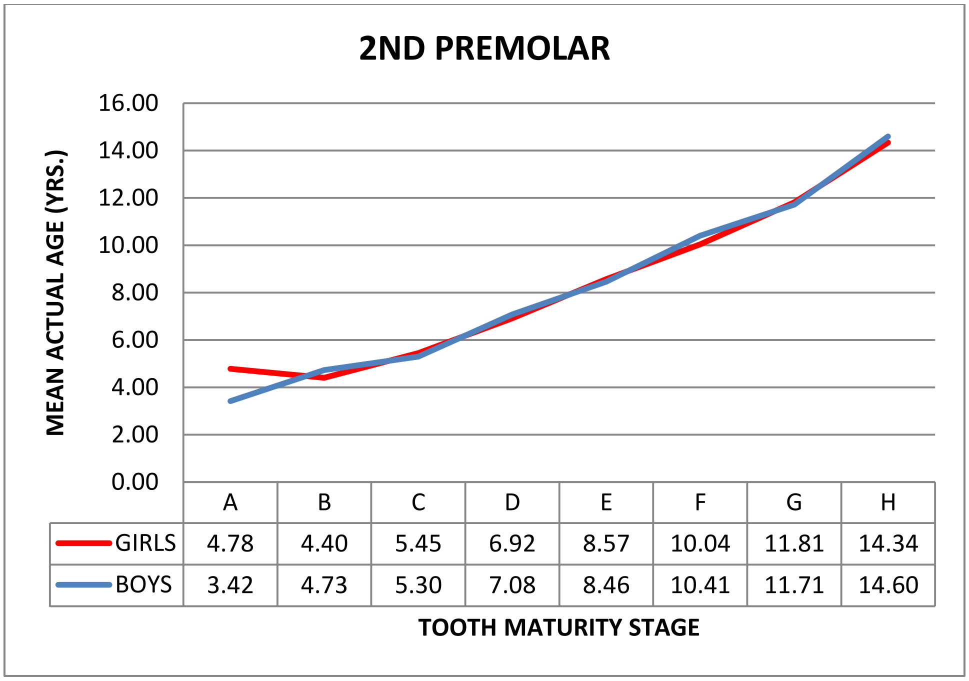


Figure 16. Comparison between the growth rate of 2nd premolars in girls and boys.

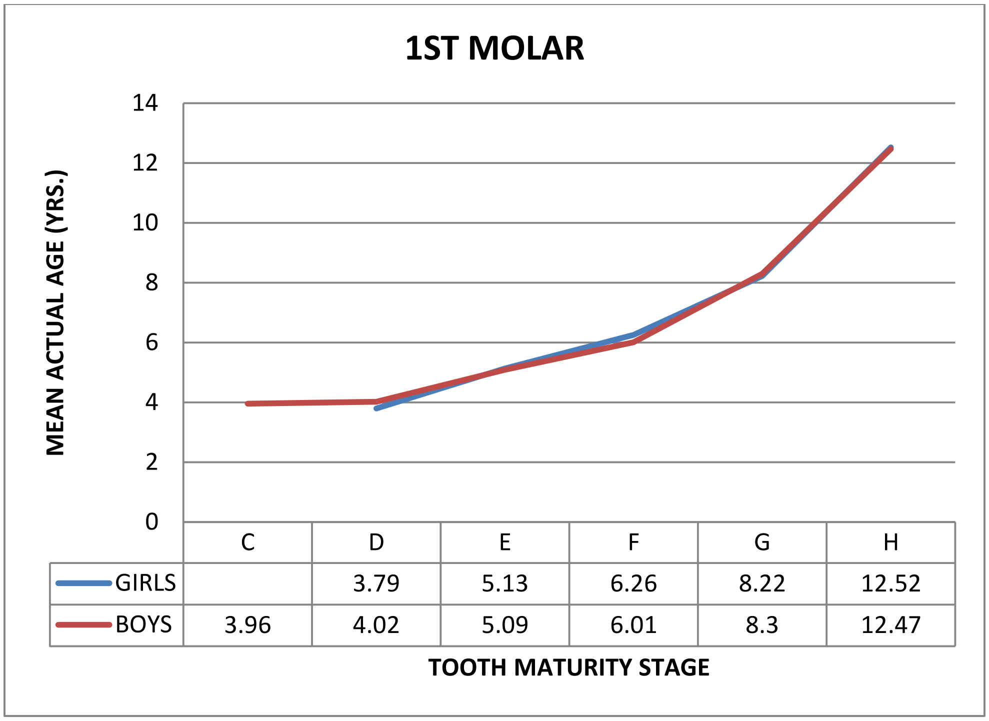


Figure 17. Comparison between the growth rate of 1st molars in girls and boys.

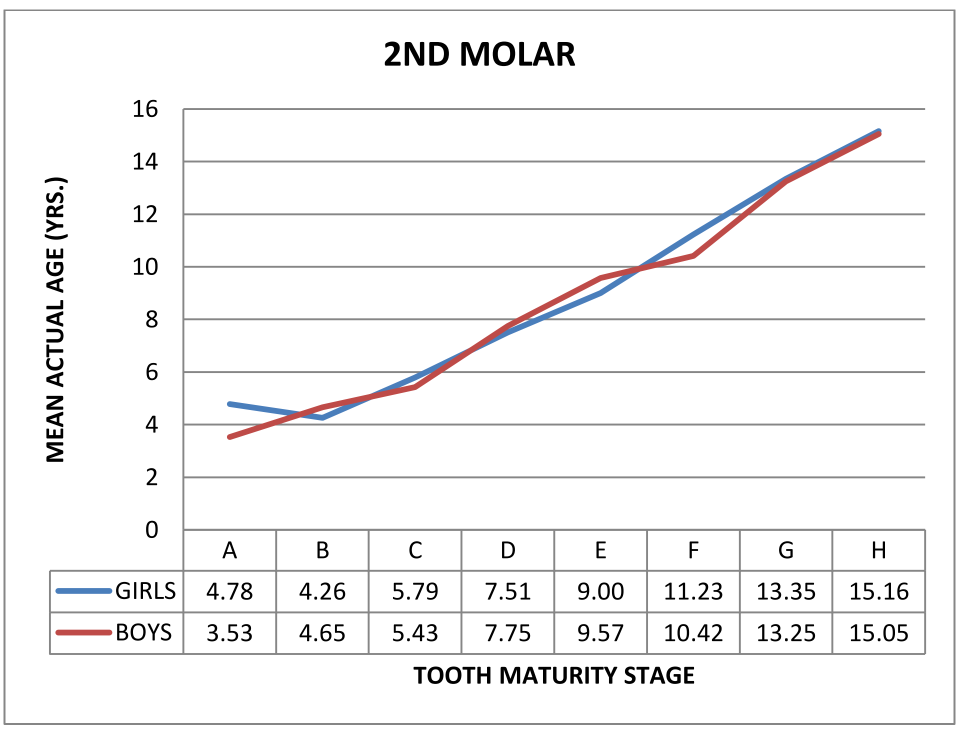


Figure 18. Comparison between the growth rate of the 2nd molars in girls and boys.

4.4.4 DISTRIBUTION OF CHILDREN AT VARIOUS TOOTH MATURITY STAGES

The analysis of the number of children at each maturity stage of the 7 mandibular teeth is presented in table 11 - 17. There was complete development of about 50% of the teeth which had already achieved the final stage H.

4.4.4.1 MATURITY STAGES FOR THE INCISORS

The majority (276, 69%) of the children had fully developed incisors. At ages 3 - 5 years the incisors were at stage D and E while nearly everyone aged 8 - 16 years old had completed root development (table 11 and 12). There were nearly equal proportions of boys and girls at each maturity stage. The earliest completion of development of the incisors was 3 – 4 years while a few 10 years old were yet to complete development.

Table. 11. Distribution of children at maturity stages of the central incisors

GENDER	STAGES	AGE GROUP														TOTAL (%)
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Girls	D	3	3	1	-	-	-	-	-	-	-	-	-	-	-	7(4)
	E	1	7	9	3	-	-	1	-	-	-	-	-	-	-	21(11)
	F	1	-	6	1	2	-	-	-	-	-	-	-	-	-	10(5)
	G	-	-	2	7	5	4	-	1	-	-	-	-	-	-	19(10)
	H	-	1	2	2	7	20	15	14	12	11	17	9	13	8	131(70)
	Total	5	11	20	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	D	2	7	3	-	-	-	-	-	-	-	-	-	-	-	12(6)
	E	2	7	14	2	-	-	-	-	-	-	-	-	-	-	25(12)
	F	-	1	4	2	2	-	-	-	-	-	-	-	-	-	9(4)
	G	-	-	-	5	8	6	3	-	-	-	-	-	-	-	22(10)
	H	1	-	-	2	13	16	22	21	15	9	13	8	16	9	145(68)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	D	5	10	4	-	-	-	-	-	-	-	-	-	-	-	19(5)
	E	3	14	23	5	-	-	1	-	-	-	-	-	-	-	46(11)
	F	1	1	10	3	4	-	-	-	-	-	-	-	-	-	19(5)
	G	-	-	2	12	13	10	3	1	-	-	-	-	-	-	41(10)
	H	1	1	2	4	20	36	37	35	27	20	30	17	29	17	276(69)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

Table 12. Distribution of children at various maturity stages of the mandibular lateral incisor

GENDER	STAGE	AGE GROUP														TOTAL (%)
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Girls	C	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1(1)
	D	2	6	2	-	-	-	-	-	-	-	-	-	-	-	10(5)
	E	1	4	13	3	1	-	1	-	-	-	-	-	-	-	23(12)
	F	1	-	2	4	1	1	-	1	-	-	-	-	-	-	10(5)
	G	0	1	1	6	9	5	3	-	-	-	-	-	-	-	25(13)
	H	0	-	2	-	3	18	12	14	12	11	17	9	13	8	119(63)
	Total	5	11	20	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	C	1	1	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	D	2	11	9	-	1	-	-	-	-	-	-	-	-	-	23(11)
	E	1	2	10	3	1	-	-	-	-	-	-	-	-	-	17(8)
	F	0	1	1	2	3	1	-	-	-	-	-	-	-	-	8(4)
	G	0	-	1	5	16	10	4	2	-	-	-	-	-	-	38(18)
	H	1	-	-	1	2	11	21	19	15	9	13	8	16	9	125(59)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	C	2	1	-	-	-	-	-	-	-	-	-	-	-	-	3(1)
	D	4	17	11	-	1	-	-	-	-	-	-	-	-	-	33(8)
	E	2	6	23	6	2	-	1	-	-	-	-	-	-	-	40(10)
	F	1	1	3	6	4	2	-	1	-	-	-	-	-	-	18(4)
	G	0	1	2	11	25	15	7	2	-	-	-	-	-	-	63(16)
	H	1	-	2	1	5	29	33	33	27	20	30	17	29	17	244(61)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

4.4.4.2 MATURITY STAGES FOR THE CANINE

Majority (128, 32%) of the examined canines were at stage H followed by F (102, 25%) then D (61, 15%) stage. Most of 3 – 6 years old were at stage C and D of crown development. Most of the 12 – 16 years old children had completely developed canines except canines from 2 girls and 2 boys whose apex had not closed. Earliest girl and boy to complete tooth development were aged 5 and 8 years old respectively while two 14 years old (boy and girl) were still at the root development stage (table 13).

Table 13. Distribution of children at different tooth maturity stages for the mandibular canines

		AGE GROUP														
GENDER	**STAGE**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**TOTAL (%)**
Girls	C	2	3	5	1	-	-	-	-	-	-	-	-	-	-	11(6)
	D	2	7	9	4	4	-	1	1	-	-	-	-	-	-	28(15)
	E	1	-	4	6	3	2	-	-	-	-	-	-	-	-	16(9)
	F	-	1	1	2	7	19	10	3	2	-	-	-	-	-	45(24)
	G	-	-	-	-	-	2	4	5	3	1	-	1	-	-	16(9)
	H	-	-	1	-	-	1	1	6	7	10	17	8	13	8	72(38)
	Total	5	11	20	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	B	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	C	2	6	12	2	-	-	-	-	-	-	-	-	-	-	22(10)
	D	1	8	9	4	9	1	1	-	-	-	-	-	-	-	33(15)
	E	1	1	-	2	7	6	3	1	-	-	-	-	-	-	21(10)
	F	-	-	-	3	7	14	17	11	4	-	-	1	-	-	57(27)
	G	-	-	-	-	-	1	4	6	9	2	1	-	-	-	23(11)
	H	-	-	-	-	-	-	-	3	2	7	12	7	16	9	56(26)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	B	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	C	4	9	17	3	-	-	-	-	-	-	-	-	-	-	33(8)
	D	3	15	18	8	13	1	2	1	-	-	-	-	-	-	61(15)
	E	2	1	4	8	10	8	3	1	-	-	-	-	-	-	37(9)
	F	-	1	1	5	14	33	27	14	6	-	-	1	-	-	102(25)
	G	-	-	-	-	-	3	8	11	12	3	1	1	-	-	39(10)
	H	-	-	1	-	-	1	1	9	9	17	29	15	29	17	128(32)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

4.4.4.3 MATURITY STAGES FOR THE 1st and 2nd PREMOLARS

Only 30% of the assessed 1st premolars had completed tooth development, majority of which were for 13 – 16 years old. Majority of the 5 – 6 years had just completed crown development while 7 – 11 years old were undergoing root development. Initial root formation was noted as early as 3 years while age 9 is the earliest age to complete root development (table 14).

Only 23% of the assessed 2nd premolars had completed tooth development, many of which were from 13 – 16 years old. Majority of 6 – 7 years old had just completed crown development. It is observed that the crown formation may be completed as early as three years and as late as 10 years though most of them had complete crown formation at 7 years. Majority of 8 – 12 years old were undergoing root development. Initial root formation was noted at 5 years while age 10 is the earliest age to complete root development (table 15).

Table 14. Number of children at different tooth maturity stages for the first premolars

GENDER	STAGE	AGE GROUP 3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL (%)
Girls	B	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1(1)
	C	4	9	7	-	-	-	-	-	-	-	-	-	-	-	20 (11)
	D	1	1	11	10	6	3	1	1	-	-	-	-	-	-	34 (18)
	E	-	-	1	3	7	12	5	2	-	-	-	-	-	-	30 (16)
	F	-	-	-	-	1	8	6	2	2	-	-	1	-	-	20 (11)
	G	-	-	1	-	-	1	3	6	5	4	1	1	-	-	22 (12)
	H	0	0	0	0	0	0	1	4	5	7	16	7	13	8	61 (32)
	Total	5	11	20	13	14	24	16	15	12	11	17	9	13	8	188 (100)
Boys		-	-	-	-	1	-	-	-	-	-	-	-	-	-	1(0)
	A	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	B	1	1	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	C	2	11	13	-	1	-	-	-	-	-	-	-	-	-	27(13)
	D	-	3	8	9	7	2	-	1	-	-	-	-	-	-	30 (14)
	E	1	-	-	1	13	15	11	-	1	-	-	-	-	-	42 (20)
	F	-	-	-	1	1	4	12	10	3	-	-	1	-	-	32 (15)
	G	-	-	-	-	-	1	2	7	5	5	-	-	-	-	20 (9)
	H	-	-	-	-	-	-	-	3	6	4	13	7	16	9	58 (27)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
	A	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1(0)
	B	1	2	-	-	-	-	-	-	-	-	-	-	-	-	3 (1)
	C	6	20	20	-	1	-	-	-	-	-	-	-	-	-	47(12)
	D	1	4	19	19	13	5	1	2	-	-	-	-	-	-	64(16)
Combined	E	1	-	1	4	20	27	16	2	1	-	-	-	-	-	72(18)
	F	-	-	-	1	2	12	18	12	5	-	-	2	-	-	52 (13)
	G	-	-	1	-	-	2	5	13	10	9	1	1	-	-	42(10)
	H	-	-	-	-	-	-	1	7	11	11	29	14	29	17	119 (30)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

Table 15.Number of children at different tooth maturity stages for second premolars

GENDER	STAGE	AGE GROUP 3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL (%)
Girls	A	-	1	1	-	-	-	-	-	-	-	-	-	-	-	2(1)
	B	3	1	3	-	-	-	-	-	-	-	-	-	-	-	7(4)
	C	1	8	8	1	-	1	1	-	-	-	-	-	-	-	20(11)
	D	1	1	6	11	9	4	2	1	-	-	-	-	-	-	35(19)
	E	-	-	1	1	4	12	5	3	-	-	-	-	-	-	26(14)
	F	-	-	1	-	1	6	6	5	5	1	-	2	-	-	27(14)
	G	-	-	-	-	-	1	2	5	3	5	5	1	-	-	22(12)
	H	-	-	-	-	-	-	-	1	4	5	12	6	13	8	49(26)
	Total	5	11	2-	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	A	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	B	-	7	2	-	-	-	-	-	-	-	-	-	-	-	9(4)
	C	2	7	13	2	2	-	-	-	-	-	-	-	-	-	26(12)
	D	1	-	6	7	11	3	2	2	-	-	-	-	-	-	32(15)
	E	-	-	-	2	9	15	13	-	-	-	-	-	-	-	39(18)
	F	-	-	-	-	1	3	9	10	5	2	-	1	-	-	31(15)
	G	-	-	-	-	-	1	1	8	8	5	3	-	1	1	28(13)
	H	-	-	-	-	-	-	-	1	2	2	10	7	15	8	45(21)
	NONE	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	A	2	1	1	-	-	-	-	-	-	-	-	-	-	-	4(1)
	B	3	8	5	-	-	-	-	-	-	-	-	-	-	-	16(4)
	C	3	15	21	3	2	1	1	-	-	-	-	-	-	-	46(11)
	D	2	1	12	18	20	7	4	3	-	-	-	-	-	-	67(17)
	E	-	-	1	3	13	27	18	3	-	-	-	-	-	-	65(16)
	F	-	-	1	-	2	9	15	15	10	3	-	3	-	-	58(14)
	G	-	-	-	-	-	2	3	13	11	10	8	1	1	1	50(12)
	H	-	-	-	-	-	-	-	2	6	7	22	13	28	16	94(23)
	NONE	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

4.4.4.4 MATURITY STAGES FOR THE MOLARS

Half of the assessed mandibular 1st molars had completed tooth development, majority of which were for 10 – 16 years old. Majority of 3 - 5 years old were at stage E of initial root formation. While 5 – 9 years old were at stages F and G of root formation (table 16). There were 47 (12%) individuals with completely developed 2nd molar which is the last tooth to complete development. The earliest completion of development was seen in a PR of a 12 years old boy while there was one 16 years old boy who still had open apices. Majority of the reviewed 2nd molars were in stage E when the root is about a third of the crown height (table 17).

In addition, 25(12%) boys already had complete development of the 7 mandibular teeth. They comprised of 1(11%), 4(31%) 4(50%), 10(63%) and 6(67%) of the 12, 13, 14, 15 and 16 years old boys respectively. It was also noted that, 22 (12%) of the girls also had mature teeth. They comprised of 6(35%), 3(33%), 8(62%) and 5(63%) of the 13, 14, 15 and 16 years old girls respectively. The earliest age with complete development of the 7 mandibular teeth was 13.02 and 12.91 years for girls and boys respectively.

Table 16. Distribution of children at tooth maturity stages for the first molars

GENDER	STAGE	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL (%)
		AGE GROUP														
Girls	D	1	1	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	E	3	9	7	1	-	1	1	-	-	-	-	-	-	-	22(12)
	F	-	-	10	5	1	-	-	1	-	-	-	-	-	-	17(9)
	G	1	1	1	7	10	16	9	4	1	-	1	-	-	-	51(27)
	H	-	-	2	-	3	7	6	10	11	11	16	9	13	8	96(51)
	Total	5	11	20	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	C	1	1	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	D	1	2	-	-	-	-	-	-	-	-	-	-	-	-	3(1)
	E	2	11	13	1	1	-	-	-	-	-	-	-	-	-	28(13)
	F	-	1	7	3	1	-	1	-	-	-	-	-	-	-	13(6)
	G	-	-	1	7	19	17	14	5	1	-	-	-	-	-	64(30)
	H	1	-	-	-	2	5	10	16	14	9	13	8	16	9	103(48)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	C	1	1	-	-	-	-	-	-	-	-	-	-	-	-	2(0)
	D	2	3	-	-	-	-	-	-	-	-	-	-	-	-	5(1)
	E	5	20	20	2	1	1	1	-	-	-	-	-	-	-	50(12)
	F	-	1	17	8	2	-	1	1	-	-	-	-	-	-	30(7)
	G	1	1	2	14	29	33	23	9	2	-	1	-	-	-	115(29)
	H	1	-	2	-	5	12	16	26	25	20	29	17	29	17	199(50)
	Total	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

Table 17. Distribution of children at different tooth maturity stages for 2nd molars

		AGE GROUP														
GENDER	**STAGE**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**TOTAL (%)**
Girls	A	-	1	1	-	-	-	-	-	-	-	-	-	-	-	2(1)
	B	3	8	-	-	-	-	-	-	-	-	-	-	-	-	11(6)
	C	2	1	15	4	1	1	1	-	-	-	-	-	-	-	25(13)
	D	-	1	2	9	8	5	3	1	1	-	-	-	-	-	30(16)
	E	-	-	1	-	5	16	10	5	3	-	-	-	-	-	40(21)
	F	-	-	1	-	-	2	1	7	3	4	3	1	-	-	22(12)
	G	-	-	-	-	-	-	1	2	5	7	8	5	5	3	36(19)
	H	-	-	-	-	-	-	-	-	-	-	6	3	8	5	22(12)
	Total	5	11	2-	13	14	24	16	15	12	11	17	9	13	8	188(100)
Boys	A	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2(1)
	B	1	7	3	-	-	-	-	-	-	-	-	-	-	-	11(5)
	C	1	7	18	4	2	-	-	-	-	-	-	-	-	-	32(15)
	D	-	-	-	6	18	8	3	1	-	-	-	-	-	-	36(17)
	E	1	-	-	1	1	13	20	11	3	2	-	1	-	-	53(25)
	F	-	-	-	-	2	1	2	3	6	2	-	-	-	-	16(8)
	G	-	-	-	-	-	-	-	6	6	4	9	3	6	3	37(17)
	H	-	-	-	-	-	-	-	-	-	1	4	4	10	6	25(12)
	NONE	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	Total	5	15	21	11	23	22	25	21	15	9	13	8	16	9	213(100)
Combined	A	2	1	1	-	-	-	-	-	-	-	-	-	-	-	4(1)
	B	4	15	3	-	-	-	-	-	-	-	-	-	-	-	22(5)
	C	3	8	33	8	3	1	1	-	-	-	-	-	-	-	57(14)
	D	-	1	2	15	26	13	6	2	1	-	-	-	-	-	66(16)
	E	1	-	1	1	6	29	30	16	6	2	-	1	-	-	93(23)
	F	-	-	1	-	2	3	3	10	9	6	3	1	-	-	37(9)
	G	-	-	-	-	-	-	1	8	11	11	17	8	11	6	73(18)
	H	-	-	-	-	-	-	-	-	-	1	10	7	18	11	47(12)
	NONE	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1(0)
	TOTAL	10	26	41	24	37	46	41	36	27	20	30	17	29	17	401(100)

5. DISCUSSION

An excellent degree of inter- and intraexaminer reliability was found in staging the teeth which has also been reported in other studies (Altalie et al., 2014; Franco et al., 2013; Yusof et al., 2013). Variability may be brought about by having teeth which are in between stages e.g. a canine at a maturity stage which is between stage D and E. To this end, Demirjian et al., (1973) recommends that such a tooth should be assigned the previously attained stage which in this example should be stage D.

For age estimation, stages of tooth maturity were assessed. Thus, the level of dental maturity of the studied population as well as determination of whether participants were either early or late in teeth development was documented. The dental age was determined using Willems' method for the first time in a Kenyan population. Remarkably, the estimated age was found to be highly and positively correlated to the chronological age. The performance of Willems' method in this select population has been compared with other studies as shown in table 18.

5.1 DEMOGRAPHIC CHARACTERISTICS OF THE STUDIED POPULATION

It was noted that the younger children were fewer than the older ones and this has also been observed by other authors. This could result from the fact that age estimation studies are usually done using previous radiographs taken from children attending pediatric and orthodontic clinics. This may partly influence the demographic characteristics of such studies. The youngest (0 – 4 years) children are usually fewer than the older ones while the majority are from the age groups of 5 to 9 years old (Ambarkova et al., 2014; Galic et al., 2011; Liversidge et al., 2010a, 2010b; Yusof et al., 2013). This may be because dental caries and malocclusion progress as the dentition develops hence older children may have a higher experience of such conditions than the younger ones (Tandon, 2008). A study by Masiga et al., (2005) which was done at the same study center revealed that 77% of the children visited the UNDH clinic due to pain (32%), caries (20%) and orthodontic treatment (25%). Additionally, there could be few young children undertaking PR since majority may not meet the selection criteria for panoramic imaging. Furthermore, the radiographic examination is technique sensitive and may not be easily carried out in children below 5 years (White and Pharoah, 2004).

The mean of the chronological age was 9.73±3.60 years which compares closely with the study conducted by Masiga et al., (2005) that found a mean age of 9 years. Furthermore, in our study, the 9 years old were the majority which was also noted in similar studies done in Australia and Sweden (Liversidge et al., 2006). This age group will definitely have a mixed dentition of deciduous and some permanent teeth (Ngassapa et al., 1996). In the current study, most of the 9 years old had complete development and eruption of the incisors while the canines and premolars were at stage E and F of root development. In addition, the first molar had already erupted but the apices were open while the second molar was merely at stage E with evidence of development of the bifurcation. At around this age the children may be more concerned about malalignment of the erupting teeth. Besides, the same age group is associated with the ugly duckling stage. It's a transient stage when the erupting canines impinge on the roots of the upper lateral incisors (figure 3) causing them to tip laterally resulting into temporal spacing of the upper incisors. (Kumar et al., 2014; Manne et al., 2012; Tandon, 2008). Hence, such an ugly appearance may prompt the children to seek further orthodontic intervention.

5.2 PERFORMANCE OF WILLEMS' METHOD IN ESTIMATING AGE IN DIFFERENT POPULATIONS

Since Willems et al., (2001a) modified the Demirjian's method of age estimation; several studies have been done which have revealed varying performance in different populations. Age estimation studies have found Willems et al., (2001a) method to either over- or underestimate the DA with an average of about 0.6 years (7.2 months) or less (Altalie et al., 2014; Liversidge et al., 2010a; Ramanan et al., 2012; Yusof et al., 2013). Similar to our study, a general overestimation of the age has been noted in previous studies done in United Arab Emirates (UAE), Malaysia and Japan (Altalie et al., 2014; Ramanan et al., 2012; Yusof et al., 2013). Willems' method over aged the select Kenyan population by 0.27 years which was slightly higher than the UAE (0.01 years), Japanese

(0.02 years) and British (0.14 years) populations (Altalie et al., 2014; Liversidge et al., 2010a; Yusof et al., 2013). In Malaysia and Macedonia there was an overestimation of 0.45 and 0.42 years respectively which was about 2 months more than in the present population (Ambarkova et al, 2014; Ramanan et al., 2012). Nevertheless, in South India, there was significant underestimation of 0.4 years (Mohammed et al, 2015). Though the current study had a low MAD of -0.27 years, it was found to be statistically significant. Nevertheless, the estimated age had a very strong positive correlation with the chronological age.

In the current study, Willems' method performed better in estimating the age of the girls than for the boys. This was also observed in studies done in Yugoslavia, Brazil, North India, South India and Malaysia, (Ambarkova et al., 2014; Franco et al., 2013; Grover et al., 2011; Mohammed et al., 2015; Ramanan et al., 2012). On the other hand, in Belgium and Japan the MAD for boys and girls were almost similar suggesting similarities in the dental development of the two populations (Willems et al., 2001a; Yusof et al., 2013).

In seven age studies, the MAD for girls ranged from 0.11 to -0.33 years which was comparable to the present study which had an MAD of -0.10 years (Altalie et al., 2014; Ambarkova et al., 2014; Franco et al., 2013; Grover et al., 2011; Mohammed et al., 2015; Ramanan et al., 2012; Yusof et al., 2013). The Willems' model performed better in girls from the select Kenyan population as compared to the Malaysian and Brazilian girls whose age was overestimated by 0.32 and 0.17 years respectively (Franco et al., 2013; Yusof et al., 2013). On the other hand, the method underestimated the age of UAE, Japanese, North and South Indian girls by 0.12, 0.08 0.24 and 0.33 years respectively (Altalie et al., 2014; Grover et al., 2011, Mohammed et al., 2015; Ramanan et al., 2012).

In most of the studies, the boys had a wider range of MAD of -0.58 to 0.7 years as compared to the girls (-0.33 – 0.12 years). It was also comparable to the current study whereby the boys had a mean error of -0.42 years (Altalie et al., 2014; Franco et al., 2013; Grover et al., 2011; Ramanan et al., 2012; Yusof et al., 2013). The Belgian and Japanese boys had a lower MAD of 0.00 and -0.06 years respectively compared to the select Kenyan population (Ramanan et al., 2012; Willems et al., 2001a). Similar to our study, there was an overestimation of 0.4 years of the Brazilian boys. There was greater overestimation of 0.52 and 0.58 years in the Macedonian and Malaysian boys respectively (Ambarkova et al., 2014; Ramanan et al., 2012). However, Willems' method underestimated the age of the South Indian boys by 0.7 years which was found to be highly significant.

It was noted that Willems' method performed the best in estimating the age of the 10 years old girls and 5 years old boys from the select Kenyan population. Additionally, in the overall sample there was best performance in the 9 years old age group which was likewise observed in the British population where the 9 years old had the lowest MAD of 0.02 years. It was closely followed by the 8 and 5 years old who had an MAD of only 0.04 years which was less than a month (Liversidge et al., 2010a). A similar observation was made by Ambarkova et al., (2014) whereby the lowest MAD (0.26 years) was recorded in the 9 years old age group. This observation may show minimal variations in the dental maturation of the 9 years old as compared to the other age groups. This observation could not be verified in other studies since the data was not provided.

In the current study, it was evident that Willems' model could only estimate the age of about a third of the children within 6 months of their chronological age. A higher percentage of 49% was found in an earlier study done by Liversidge et al., (2010a) which involved European children of Bangladesh and White ethnic origin. Willems' study was based on a European population which could be more or less similar to what Liversidge et al., (2010a) studied.

Table 18. The performance of Willems' method in different countries

	AUTHOR	YEAR	COUNTRY	AGE	OVERALL MAD(YRS.)	GIRLS MAD(YRS.)	BOYS MAD(YRS.)
1	Current study	2016	Kenya	3 -16.99	-0.27±1.30	-0.10±1.37	0.42±1.22
2	Altalie et al.	2014	UAE	4 -14.99	-0.01	0.12	-0.08
3	Ambarkova et al	2014	Yugoslavia	6 – 13.99	-0.42±0.86	-0.33±0.83	-0.52±0.87
4	El-Bakary	2010	Egypt	5 - 16	-0.15±0.62	-0.14±0.74	-0.29±0.48
5	Franco et al.	2013	Brazil	5 - 15.99	-0.14	-0.04±0.97	-0.24±0.97
6	Galic et al.	2011	Herzegovina	6 – 13	0.33	0.24	0.42
7	Grover et al.	2011	North India	6 – 15	0.30	-0.24	-0.36
8	Javadine et al.	2015	Iran	3.9 -14.5	0.36	0.31	0.43
9	Liversidge et al.	2010	Bangladesh /whites	3 – 16.99	-0.14±0.86		
10	Mohammed et al.	2015	South India	6 – 16.99	0.4	0.11	0.7
11	Ramanan et al.	2013	Japan	5 – 15.99	0.02	0.08±1.10	-0.06±0.97
12	Willems et al.	2001	Belgium	2 – 18.00	0.1	0.2±0.9	0.15±1.3
13	Yusof et al.	2013	Malaysia	4 – 14.99	-0.45±1.39	-0.32±1.43	-0.58±1.33

5.3 FACTORS CONTRIBUTING TO DIFFERENCES IN THE PERFORMANCE OF WILLEMS' METHOD IN VARIOUS POPULATIONS

The mean age differences that have been noted in previous studies could be due to normal variations in the growth characteristics of the studied populations. Besides, the timings and pattern of tooth development in different populations may vary as compared to the reference Belgium population which was used to derive Willems' model. In addition, Willems et al., (2001a) clearly indicated that their method was only validated with the Belgium population but may possibly not show the same results in other populations.

Different studies also had different sample sizes but a minimum of 10 children per age group has been found to be adequate in estimating the mean age. However, the larger the sample size the smaller the SD and the confidence intervals (Liversidge et al., 2010b). Another possible reason may perhaps be attributed to the age distribution in a given age cohort which may contribute to overall variations in demographic characteristics of different populations. Such population variations could be verified through the comparison of measures such as mode, median and the range of age distribution in a particular age cohort. Nevertheless, previous studies did not publish such useful information making it impossible to draw comparisons. Other contributing factors could be inherent within Willems' age estimation method. The method uses 46 weighted age scores for different stages of teeth development which may not necessarily reflect the growth rate/patterns in other populations (Willems et al., 2001a).

Variations were also noted where dissimilar age cohorts were studied as portrayed in table 18. Authors for instance, Altalie et al., (2014) studied 4 – 15.99 years old, 4 – 14.99 years old by Yusof et al., (2013), 3 – 16.99 years old by Liversidge et al., (2010a) and 5 – 15.99 years old by Franco et al., (2013). This could have influenced the overall mean age difference of the estimated age given that different age cohorts have unique growth characteristics since the teeth are at different stages of maturity. It was also observed that some study populations were classified into two years age intervals i.e. 6 - 7.99. This made it impossible to make comparisons with one year interval age cohorts (Cameriere et al., 2008; Liversidge et al., 2010a; Mohammed et al., 2015, Yusof et al., 2013).

5.4 TOOTH MATURITY

The study revealed that different patterns of tooth maturity existed in children from the same age groups. This may be due to individual differences in the rate of growth which could be attributed to factors such as ethnicity. The sampled population comprised of children from different ethnic backgrounds since the study was done in a cosmopolitan area. However, the ethnical origin of the participants was not studied since it was beyond the scope of the current study. The mean chronological age at different tooth stages for the Kenyan population was compared with a combined group comprising of children from Australia, Belgium, Canada, England, Finland, France, South Korea and Sweden (Appendix E). The Kenyan population had a lower mean age in most of the tooth stages than the combined group which may indicate early maturity. The noted differences ranged from 0 – 12 months. Most stages had a difference of less than 6 months indicating lack of gross variations in development in different populations. There was a notable difference for boys at root stage G of the canine and 2nd premolar whereby the mean age in the select Kenyan population was earlier than 1 year. The mean age at various stages of the first molar was nearly similar to the combined group. The differences were ≤4 months hence indicating some growth similarity with the largely white population (Liversidge, 2006).

In the Kenyan study, the girls were found to be slightly ahead of the boys in most of the tooth stages (0.03 - 1.14 years). A similar observation was noted in the results of the combined populations where girls were 0.08 - 1.17 years a head of boys in most tooth stages. The current study found that in most of the maturity stages there were no significant differences between boys and girls. This finding is similar to a recent study done in Sudan which involved both the Western and Northern population which revealed a lack of significant sexual dimorphism in teeth maturity (Elamin et al., 2016).

Remarkably, the girls in the Kenyan and the combined group from Australia, Europe Canada and South Korea were on average more than one year ahead of the boys in the root development of the canine. The maturity of the canine has been found to correlate strongly with the growth stages of the middle phalange of the third finger. It has been suggested that the maturity of the canine may be assessed in order to reflect the skeletal maturity (Hedge et al., 2014).

The comparison between mean age of the Belgium and Kenyan population at different tooth stages revealed that the Belgium girls and boys were on average ahead of the Kenyan population in most of the tooth stages. They were far more ahead in the maturity of the posterior teeth (1-20 months) than the anterior teeth (2 -11 months). The teeth of the Belgium girls matured more than one year earlier than the Kenyan girls in most tooth stages of the 1st premolar and both molars (Liversidge et al., 2006).

In the select Kenyan population, the youngest boy and girl to achieve the maturity of the seven mandibular teeth were aged 12.91 and 13.02 years old respectively. This was comparable to 13 years that was observed in a Bangladesh and White Caucasian population studied by Liversidge et al., (2010a). A different study involving 2 - 18 years old children of a European origin found one male who had completed development at a very early age of 10 years. The same population had a higher percentage (34%) of 10 – 16 years old with completely matured teeth as compared to 12% in the present study. Furthermore, majority (89%) of the 16 years old European children had a mature dentition as compared to 65% of the select Kenyan children Liversidge et al., (2010b). Among the seven mandibular teeth, the 2nd molar is the last tooth to achieve complete development. It was observed that in the Kenyan population, there was late (13.30 years) development of the apex of the 2nd molars as compared to other populations. Remarkably, children from other countries who were at the same stage were on average 0.92 – 1.73 years younger. Children from Quebec were the youngest (11.57 years), followed by France (11.60 years), Finland (11.83 years), Sweden (11.95 years), Belgium (12.04 years), Yugoslavia (12.36 years), Australia (12.39 years) and Koreans (12.84 years) (Ambarkova et al., 2014; Liversidge et al., 2006).

Further, the current study revealed that about a third of the 13 years old girls and boys had early completion of dental development of the first 7 mandibular teeth. Conversely, a third of 16 years old hadn’t achieved the same, thus, they were dentally delayed. This was also observed in other age groups. It indicates individual differences that exist in the timings of initiation of development. The knowledge about the dental maturity status of a child guides on the modality and timings for pedodontic and orthodontic procedures. Examples of procedures that depend on tooth maturity include but are not limited to serial extraction in interceptive orthodontics and placement of space maintainers when there is early loss of teeth. Early and late maturing children may have their orthodontic treatment started at an individualized times (AAPD, 2014; Almeida et al., 2012).

The information regarding age and stages of tooth development is useful in teaching oral biology and pediatric dentistry at the University of Nairobi. It can also be used in assessing and comparing dental growth and development in children attending the pediatric and orthodontic clinic at UNDH.

5.5 DRAWBACKS OF WILLEMS' METHOD OF AGE ESTIMATION

Willems' method has the possibility of estimating a maximum age of 15.79 and 16.03 years in girls and boys respectively. This is when all the first seven mandibular teeth are at stage H which represents complete tooth development. For that reason, the use of Willems' method should be limited to children who still have developing teeth (31 - 37) within their lower jaw. Although it was observed that 50% and 63% of the 14 and 15 years old boys respectively had already completed tooth development, they were all aged at 16.03 years. However, the overall age in both age cohorts was not significantly overestimated. This was masked by the wide range of the estimated age in the two age cohorts which was 10.24 – 16.03 years for the 14 years old and 13.59 - 16.03 years for the 15 years old. The wide range was as a result of having children with early and delayed maturity in the same age group. However, age estimation in the 16 years old age cohort was significantly affected through underestimation of their age since the maximum age estimated could not exceed 16.03 years.

The exclusion of the 12% individuals with mature 7 teeth did not affect the statistical significance of the overall MAD but individual age groups from 13 - 16 years old revealed gross changes in MAD. Notably, after the exclusion of mature individuals, very few remained in the 14 - 16 age cohorts. This was also noted by Liversidge et al., (2010b) who had to exclude 63% and 89% of the 15 and 16 years old respectively while using

Willems' method. This fact should be taken into account when researchers plan to carry out age estimation studies using Willems' method. Authors should exclude the mature individuals from the analysis since they can act as confounders leading to increased mean age differences. Furthermore, it is not possible to establish when the maturity was achieved since the teeth remain at stage H regardless of the number of years that have elapsed. It was noted that most of the age studies that have been published did not mention the exclusion of such mature individuals.

5.6 ESTIMATION OF AGE IN MATURE INDIVIDUALS

Mature individuals may require additional analysis of the development of the third molars whose development continues throughout the adolescent period. However, the development, morphology and eruption times of the third molars shows variability (Hassanali, 1985; Kohler et al., 1994; Senn and Weems, 2013; Thevissen, 2013). The other alternative is to utilise the skeletal development which is very valuable when the dentition has completed development (Senn and Weems, 2013).

In order to improve the accuracy in age estimation, dental and skeletal age assessment methods have also been utilized simultaneously in some countries. In Austria, unaccompanied minors of unknown age usually undergo the hand and wrist radiographic examination to determine whether one has attained a minimum age of 18 years. In the event the estimated age is above 18 years, further investigations ensue which include dental radiographs and computed tomography of the clavicle (Koppenberg, 2014). In Germany, age assessment is done through a physical exam, dental panoramic and hand and wrist radiographs. When the hand development is complete, a CT scan of the medial clavicular epiphyseal plate is undertaken (Schmeling, 2016).

5.7 STUDY LIMITATIONS

The information regarding the date of birth in relation to day, month and year was missing in some of the patients' files hence chronological age could not be determined.
Even though there was provision to register the patients' date of birth in the radiology

department, it was found that this important information was completely missing from the digital images of the patients. Therefore, one had to go through a tedious process of retrieving the manual patients' record in order to obtain this important data. This can significantly limit research studies that involve a large sample size. The study did not involve authentication of patients' DOB through a birth certificate. Therefore, the DOB indicated in the patients' file was used which was recorded as told by the parent or guardian. Any inaccurate recording of this important information may contribute to the mismatch between the PR and age cohorts resulting into inaccurate outliers.

Since the research study was retrospective, the patients were not examined and their general development and health status was unknown. However, the radiographs with jaws which exhibited developmental anomalies and lesions such as cyst, tumour or trauma were eliminated.

6. CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The research study was set out to estimate dental age using Willems' method in children attending the UNDH. It was observed that the method resulted in statistically significant overestimation of the age. However, the estimated dental age was highly and positively correlated to the chronological age. The method performed better in estimating the age for the girls as compared to boys who were significantly over aged. Majority of the children had their age estimated within one year of their actual age. There was a tendency to overestimate the age of the younger children as compared to the older ones. The dental maturity for children attending UNDH was also assessed. It was found out that there was no statistical difference between the tooth maturity for girls and boys in most of the maturity stages. However, girls were significantly a head of the boys in the root development of the canine. There existed different patterns of tooth maturity in children of the same age group. The youngest child with a mature dentition was found to be a boy aged 12.91 years old.

6.2 RECOMMENDATIONS

The current findings should be validated with a larger sample size that is representative of the Kenyan population. This will inform whether there is a need to modify Willems' method of age estimation. The date of birth should be recorded when carrying out a digital panoramic radiographic exam. This will make future radiographic age related data quick to collect.

Future research could be done prospectively whereby the general health status of the patient is assessed while ethnic background and date of birth can be verified through a birth certificate.

6.3 FURTHER STUDIES

Areas for further studies include,

1. Knowledge and use of age estimation methods in Kenya
2. Tooth maturation in Kenya
3. Estimation of the age of children with a mature dentition.
4. Assessment of the performance of other age estimation methods in Kenya
5. A review of the accuracy of verbally reported date of birth
6. An audit of the demographics of children attending the radiology division of UNDH.

7. REFERENCES

Agarwal, N., Ahuja, P., Sinha, A., Singh, A. (2012) Age estimation using maxillary central incisors: A radiographic study. *Journal of Forensic Dental Science.* 4. p.97-100.

Almeida, R. R., Almeida, M. R., Oltramari-Navarro, P. V., Conti, A. C., Navarro, L., Souza, K. R. (2012). Serial extraction: 20 years follow-up. *Journal of applied oral science*. 20(4). p.486-492.

AlQahtani, S. J., Hector, M. P., Liversidge, H. M. (2010) The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology*. 142. p.481–490.

Alshihri, A. M., Kruger, E., Tennant, M. (2015) Dental age assessment of 4–16 year old Western Saudi children and adolescents using Demirjian's method for forensic dentistry. *Egypt Journal of Forensic Sciences.* 6(2). p.152-156.

Altalie, S., Thevissen, P., Fieuws, S., Willems, G. (2014) Optimal Dental Age Estimation Practice in United Arab Emirates' Children. *Journal of Forensic Science*. 59. p.383-385.

Ambarkova V., Galic´ I., Vodanovic´ M., Bioc˘ina-Lukenda D., Brkic´ H. (2014) Dental age estimation using Demirjian and Willems methods: Cross sectional study on children from the Former Yugoslav, Republic of Macedonia. *Forensic Science International*. 234. p.187.e1–187.e7.

American Academy of Pediatric Dentistry (AAPD). (2014) Guideline on management of the developing dentition and occlusion in pediatric dentistry. *Clinical practice guidelines reference manual*. 37(6). p.253-265. Available at: http://www.aapd.org: [accessed 28th July 2016].

American Board of Forensic Odontology (ABFO). (2016) *Diplomates Reference manual.* Available at: http://www.abfo.org: [accessed 16th July 2016].

American Dental Association (ADA) Council on Scientific Affairs. (2006) The use of dental radiographs: Update and recommendations. *Journal of American Dental Association.* 137. p.1304-1312.

Amselem, S., Carel, J., De Roux, N., Issad, T., Maccari, S., Prevot, V., Susanne, C. (2007) Growth and Puberty Secular Trends, Environmental and Genetic Factors. *INSERM Collective Expert Report. Paris: Institut national de la santé et de la recherche médicale;* [Online] Available from: http://www.ncbi.nlm.nih.gov/books/NBK10786/. [Accessed: 24th June 2016]

Cameriere, R., Ferrante, L., Liversidge, H. M., Prieto, J. L., Brkic, H. (2008) Accuracy of age estimation in children using radiograph of developing teeth. *Forensic Science International.* 176. p.173-177.

Cameriere, R., Flores-Mir, C., Mauricio, F., Ferrante, L. (2007) Effects of nutrition on timing of mineralization in teeth in a Peruvian sample by the Cameriere and Demirjian methods. *Annals of Human Biology*. 34. p.547-556.

Cardoso, H. (2007) Differential sensitivity in growth and development of dental and skeletal tissue to environment quality. *Arquivos De Medicina*. 21(1). p.19-23

Carlson, B.M. (2014) *Human embryology & developmental biology*. 5th Ed. Philadelphia: Elservier Saunders.

CdeBaca, L. and Sigmon, J., N. (2014) Combating trafficking in persons: a call to action for global health professionals. *Global Health: Science and Practice.* 2 (3.). p.261-267.

Choi, Y., Kim, J., Yamaguchi, T., Maki, K., Ko C., Kim, Y. (2016) Cervical vertebral Body's volume as a new parameter for predicting the skeletal maturation stages. *Biomedical research International*. Article ID 8696735, 7 pages. Doi:10.1155/2016/8696735

Constitution of Kenya. (2010) [Online]. Available at: http://www.refworld.org/docid/4c8508822.html [accessed 16 October 2015].

Demirjian, A., Goldstein, H., Tanner, J. M. (1973) A new method for dental age estimation. *Human Biology*. 45. p.211-227.

Dvorak, J., George, J., Junge, A., Hodler, J. (2007). Application of MRI of the wrist for age determination in international U-17 soccer competitions. *British Journal of Sports Medicine*. 41(8). p.497–500. http://doi.org/10.1136/bjsm.2006.033431

Elamin, F. and Liversidge, H. M. (2013) Malnutrition has no effect on the timing of human tooth formation. *Plos one.* 8(8): e72274. [Online] Pubmed Database. Available from: http://doi.org/10.1371/journal.pone. [Accessed: 2nd July 2016].

Elamin, F., Hector, M. P., Liversidge, H. M. (2016) The timing of mandibular tooth formation in two African groups. *Annals of Human Biology* (in press).

El-Bakary, A. A., Hammad, S. M., Mohammed, F. (2010) Dental age estimation in Egyptian children, comparison between two methods. *Journal of Forensic and Legal Medicine.* 17. p.363-367.

Farman A., G. (1993) Developmental dental abnormalities. In: Farman A., G., Nortjé C. J., Wood R., E. eds. *Oral and maxillofacial diagnostic imaging*. Missouri: Mosby.

Franco, A., Thevissen, P., Fieuws, S., Souza, P. H. C., Willems, G. (2013) Applicability of Willems model for dental age estimations in Brazilian children. *Forensic Science International.* 231. p.401.e1–401.e4.

Galic, I., Vodanovic, M., Cameriere, R., Nakas, E., Galic, E., Selimovic, E., et al. (2011) Accuracy of Cameriere, Haaviko, and Willems radiographic methods on age estimation on Bosnian-Herzegovian children age cohorts 6-13. *International Journal of Legal Medicine.* 125. p.315-321.

Gilbert, C., Scott, I., Fairgrieve, S. I., Keenan, S. C. (2014) A Test of the Demirjian method of dental ageing using a mixed population sample from Northern Ontario, *Canadian Society of Forensic Science Journal*, 47. p.1-19. DOI:10.1080/00085030.2014.885698

Gilsanz, V., Ratib, O. (2005) *Hand Bone Age. A Digital Atlas of Skeletal Maturity*. [Online] Berlin Heidelberg: Springer-Verlag. Available from: http://www.springeronline.com [Accessed: 5th July 2016].

Giri, J., Shrestha, B. K., Yadav, R., Ghimire, T. R. (2016) Assessment of skeletal maturation with permanent mandibular second molar calcification stages among a group of Nepalese orthodontic patients. Clinical, Cosmetic and Investigational Dentistry. 8. p.57–62. *http://doi.org/10.2147/CCIDE.S93561*

Gleiser, I. and Hunt, E. E. (1955) The permanent mandibular first molar: Its calcification, eruption, and decay. *American Journal of Physical Anthropology*. 113. p.253-283.

Graber TM. (2001) *Orthodontics: Principles and Techniques*. 3rd Ed, India: Laxman Chad Arya.

Grover, S., Marya, C.M., Avinash, J., Pruthi, N. (2011) "Dental Age estimation of 6-15 year old North Indian children using Willems Method. *Revista Latinoamericana de Ortodonciay Odontopediatria.* Depósito Legal Nº: pp200102CS997 - ISSN: 1317-5823. [Online] Available from: http//www.ortodoncia.ws/publicaciones/2011/art17.asp. [Accessed: 12th may 2016].

Gungor, O. E., Kale, B., Celikoglu, M., Gungor, A. Y., Sari, Z. (2015) Validity of the Demirjian method for dental age estimation for Southern Turkish children. *Nigerian Journal of Clinical Practice* 18.p.616-619.

Hassanali, J. (1985) The third permanent molar eruption in Kenyan Africans and Asians. *Annals of human biology.* 12(6). p.517-523.

Hassanali, J. and Odhiambo, J. W. (1982) Estimation of calendar age from eruption times of permanent teeth in Kenyan Africans and Asians. Annals of human biology. 9. p.175-177.

Hedge, G., Hedge, N., Kumar, A., Keshavaraj. (2014) A new system for assessment of growth using mandibular canine calcification stages and its correlation with modified MP3 stages. *Journal of Pharmacy and Bioallied Science*. 6(1). p.S58-S63

Hedge, R. J., Khare, S. S., Saraf, T. A., Trivedi, S., Naidu, S. (2015) Evaluation of the accuracy of Demirjian method for estimation of dental age among 6-12 years of children in Navi Mumbai: A radiographic study. *Journal of Indian Society of Pedodontics and Preventive Dentistry.* 33(4). p.319-323.

Javadinejad, S., Sekhavati, H., Ghafari, R. (2015) A comparison of the accuracy of four age estimation methods based on panoramic radiography of developing teeth. *Journal of Dental Research, Dental Clinics, Dental Prospects*. 9(2). p.72-78.

Jheon, A. H., Seide, K., Biehs, B., Klein, O. D. (2013) From molecules to mastication: the development and evolution of teeth. *Wiley Interdisciplinary Reviews Developmental Biology*. 2(2). p.165–183. doi:10.1002/wdev.63.

Johnson D. (2008) Pectoral girdle and upper limb. In: Standring S. (ed.). *Gray's Anatomy. The anatomical basis of clinical practice.* 40th Ed. China: Churchill Livingstone, Elsevier.

Karami, M., Moshirfatemi, A., Daneshvar, P. (2014) Age determination using ultrasonography in young football players. *Advanced Biomedical Research*. 3:174 [Online] Medline database. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/pmc4166061 [Accessed: 8th August 2016 http://doi.org/10.4103/2277-9175.139192

Kihara, E. N., Opondo, F., Ocholla, T. J., Chindia, M. L., Wagaiyu, E. G. (2012) 5-year audit of the range and volume of diagnostic radiographic services at the University of Nairobi Dental Hospital. *Open Journal of Stomatology.* 2. p.234-236.

Kohler, S., Schmelzle, R., Loitz, C., Puschel, K. (1994) Development of wisdom teeth as a criterion of age determination. *Annals of Anatomy*. 176. p.339-345.

Koppenberg, S. (2014) Unaccompanied minors in Austria –legislation, practices and statistics. [Online] Austria: *International Organisation for migration*. Available from: http://www.iomvienna.at. [Accessed: 17th June 2016].

Kothari, C. R. and Garg, G. (2014) *Research methodology Methods and techniques*. 3rd Ed. New Delhi: New age international (P) limited.

Kumar, M., Benerjee, P., Gondhalekar, R., Lall, R., Parwani, R. (2014) Dental occlusion among school going children of Maharashtra. *Journal of International Oral Health.* 6(4). p.53-55

Kvaal, S. and Solheim, T. (1994) A non-destructive dental method for age estimation. *Journal of Forensic Odontostomatology*. 12. p.6-11.

Lan, Y., Jia, S., Jiang, R. (2014) Molecular patterning of the mammalian dentition. *Seminars in Cell Developmental Biology*. 25-26. p.61-70.doi:10.1016/j.semcdb.2013.12.003.

Larsen, S. T., Arge, S., Lynnerup, N. (2015) The Danish approach to forensic age estimation in the living: how, how many and what's new? A review of cases performed in 2012. *Annals of Human Biology*. 42(4). p.340-345

Liversidge, H. M, Smith B. H., Maber, M. (2010a) Bias and Accuracy of Age Estimation Using Developing Teeth in 946 Children. *American Journal of Physical Anthropology*. 143. p.545–554.

Liversidge, H. M. (2010b) Interpreting group differences using Demirjian's dental maturity method. *Forensic Science International*. 201. p.95–101.

Liversidge, H. M., Chaillet, N., Mornstad, H., Nystrom, M., Rowlings, K., Taylor, J., Willems, G. (2006) Timing of Demirjian's tooth formation stages. *Annals of Human Biology*. 33(4). p.454–470.

Liversidge, H. M., Speechly, T., Hector, M. P. (1999) Dental maturation in British children: are Demirjian standards applicable? *International journal of Paediatric Dentistry*. 9. p.263-269.

Logan WHG, Kronfeld R. (1933) Development of the human jaws and surrounding structures from birth to the age of fifteen years. *Journal of America Dental Association*. 20(3). p.379-427.

MacDonald, R. E., Avery, D. R., Jeffrey, A. D. (2004) *Dentistry for the child and adolescence*. Missouri: Mosby/Elsevier;

Manne, R., Gandikota, C., Juvvadi, S. R., Rama, H. R. M., Anche, S. (2012) Impacted Canines: Etiology, diagnosis and orthodontic management. *Journal of Pharmacy and Bioallied Sciences*. 4(2). p.234-238.

Márquez-Grant, N. (2015) An overview of age estimation in forensic anthropology: perspectives and practical considerations, *Annals of Human Biology,* 42:4. p.306-320.

Masiga, M. A. (2005) Presenting chief complaints and clinical characteristics among patients attending the department of paediatric dentistry clinic at the University of Nairobi dental hospital. *East African Medical Journal*. 82(12). p.652-655.

Mohammed, R. B., Sanghvi, P., Perumalla, K. K., Srinivasaraju, D., Srinivas, J., Kalyan, U. S., Rasool S. M. I. (2015) Accuracy of Four Dental Age Estimation Methods in Southern Indian Children. *Journal of Clinical and Diagnostic Research.* 9(1). p.1-8.

Moore, K. L., Persaud, T. V. N., Torchia, M. G. (2013) *The developing human: Clinically oriented embryology*. 9th Ed. Canada: Elservier Saunders.

Moorrees, C. F. A., Fanning, E. A., Hunt, E. E. (1963) Age variation of formation stages for ten permanent teeth. *Journal of Dental Research*. 42. p.1490–1502.

Mughal, A. M., Hassan, N., Ahmed, A. (2014) Bone age assessment methods: A critical review. *Pakistan Journal of Medical Science*. 30. p. 211 – 215.

Ngassapa, D., Hassanali, J., Amwayi, P., Guthua, S. (1996) *Essentials of orofacial anatomy*. Tanzania: Dar es salaam University press.

Nolla, C. M. (1960) The development of the permanent teeth. *Journal of Dentistry for children*. 27. p.254-266

Panchbhai, A. S. (2011) Dental radiographic indicators, a key to age estimation. *Dentomaxillofacial Radiology*. 40. p.199-212.

Pelowski, M., Wamai, R. G., Wangombe, J., Nyakundi, H., Oduwo, G. O., Ngugi, B. K., Ogembo, J. G. (2016) How would you children register their own births? Insights from a survey of students regarding birth registration knowledge and policy suggestions in Kenya. *Plos one*. [Online] Pubmed Database. 11(3). Available from: http://doi.org/10.1371/journal.pone.0149925. [Accessed: 27th July 2016].

Phillips, V. M. and Van Wyk Kotze, T. J. (2009) Testing standard methods of dental age estimation by Moorrees, Fanning and Hunt and Demirjian, Goldstein and Tanner on three South African children samples. *Journal of Forensic Odontostomatology*, 27(2). p.20-28.

Polit D. F., Beck, C. T. (2012) *Nursing Research: Generating and assessing evidence for nursing practice.* 9th Ed. Philadelphia: Lippincott Williams and Wilkins.

Ramanan, N., Thevissen, P., Fleuws, S., Willems, G. (2012) Dental age estimation in Japanese individuals combining permanent teeth and third molars. *Journal of Forensic Odontostomatology*. 30. p.34-39.

Ritz-Timme, S., Cattaneo, D., Collins, M. J., Waite, E. R., Schutz, H. W., Kaatsch, H. J., Borrman, H. I. (2000) Age estimation: the state of the art in relation to the specific demands of forensic practice. *International Journal of Legal Medicine*. 113. p.129–136.

Satoh, M. (2015) Bone age: assessment methods and clinical applications. *Clinical Pediatric Endocrinology*. *24*(4). p.143–152. http://doi.org/10.1297/cpe.24.143

Schmeling, A., Dettmeyer, R., Rudolf, E., Vieth, V., Geserick, G. (2016) Forensic age estimation—methods, certainty, and the law. *Deutsches Arzteblatt International.* 113. p.44–50. DOI: 10.3238/arztebl.2016.0044

Senn, D. R. and Weems R. A. (2013) *Manual of forensic odontology*. 5th Ed. United States: CRC Press, Taylor and Francis Group.

Separated Children in Europe Programme (SCEP). (2012) *Position Paper on Age Assessment in the Context of Separated Children in Europe*. Available at: http://www.refworld.org/docid/4ff535f52.html [accessed 11th July 2016]

Simmer, J. P., Hu, J. C. (2001) Dental enamel formation and its impact on clinical dentistry. *Journal of dental education.* 65(9). p.896 - 905

Slootweg, P. J. (2007) *Dental Pathology*: Alteration acquired after tooth eruption. 1st Ed. Berlin Heidelberg: Springer-Verlag.

Suryadeva, S. and Khan, M. B. (2015) Role of Homeobox Genes in Tooth Morphogenesis: *A Review Journal of Clinical and Diagnostic Research*. 9(2). p.9-12

Tandon, S. (2008) *Text book of pedodontics*. 2nd Ed. New Delhi: Hyderabad.

Thevissen, P. (2013) *Dental age estimation in sub-adults: striving for an optimal approach*. Belgium: Leuven University press.

Tomas, L. F., Mónico, L. S. M., Tomás, I., Varela-Patiño, P., Martin-Biedma, B. (2014) The accuracy of estimating chronological age from Demirjian and Nolla methods in a Portuguese and Spanish sample. *BioMed Central Oral Health*. 14. p.160-172.

United Nations Children's Fund (UNICEF). (2013) *Age Assessment: A Technical Note.* [Online] Available from: *http://www.refworld.org/docid/5130659f2.html*. [Accessed: 11th July 2016]

United State. Department of State. (2013) *Trafficking in persons report 2013*. Washington (DC): U.S. Department of state. [Online] Available from: http://www.state.gov/j/tip/rls/tiprpt/2013. [Accessed: 27th July 2016].

Wang, Y., Li, L., Zheng, Y., Yuan, G., Yang, G., He, F., Chen, Y. (2012) BMP activity is required for tooth development from the lamina to bud stage. *Journal of Dental Research.* 91(7). p.690-695.

Wehkalampi, K., Silventoinen, K., Kaprio, J., Dick, D. M., Rose, R. J., Pulkkinen, L., Dunkel, L., (2008) Genetic and environmental influences on pubertal timing assessed by height growth. *American Journal of Human Biology*. 20(4). p.417-423. doi: 10.1002/ajhb.20748.

Whaites E. Radiography. In: (1996) *Essentials of dental radiography and radiology*. 3rd Ed. London: Churchill Livingstone.

White, S. C. and Pharoah, M. J. (2004) *Oral Radiology: Principles and interpretation*. 5th Ed. St Louis: Mosby Company.

Willems, G., Van Olmen, A., Spiessens, B., Carels, C. (2001a) Dental age estimation in Belgian children: Demirjian's technique revisited. *Journal of Forensic Science.* 46. p.125-127.

Willems, G. (2001b) A review of the most commonly used dental age estimation techniques. *Journal of Forensic Odontostomatology*. 19. p.9-17.

Yan, J., Lou, X., Xie, L., Yu, D., Shen, G., et al. (2013) Assessment of dental age of children aged 3.5 to 16.9 years using Demirjian's method: A Meta-Analysis Based on 26 Studies. *Plos one.* 8(12): e84672. doi:10.1371/journal.pone.0084672

Yang, F., Jacobs, R., Willems, G. (2006) Dental estimation through volume matching of teeth imaged by cone-beam CT. *Forensic Science International* 159. p.78-83.

Young, L., Orosco, R., Milner, S. (2010) Double Fire Tragedy of Kenya. *Open access* *journal of plastic surgery*. [Online] Pubmed Database. 10(e3). Available from: www.eplasty.com [Accessed: 27th July 2016]

Yuan, G., Yang, G., Zheng, Y., Zhu, X., Chen, Z., Zhang, Z., Chen, Y. (2015) The non-canonical BMP and Wnt/β-catenin signaling pathways orchestrate early tooth development. *Development*. 142. p.128-139 doi:10.1242/dev.117887

Yusof, M. Y., Thevissen, P. W., Fieuws, S., Willems, G. (2013) Dental age estimation in Malay children based on all permanent teeth types. *International journal of legal medicine.* 128(2). p.329-333.

8. APPENDICES

APPENDIX A. DATA COLLECTION FORM

DENTAL AGE ESTIMATION IN CHILDREN ATTENDING A UNIVERSITY DENTAL HOSPITAL

Enter the required information or mark appropriately.

SERIAL NUMBER

Form completion date

				2	0	1	
d	d	m	m	year			

A. Bio Data

Date of Birth

d	d	m	m	year			

Gender – Tick appropriately.

F			M	

B. Panoramic image

1. Is the panoramic radiograph available?

Yes	No

2. If 'Yes', is it diagnostically acceptable?

Yes	No

3. If 'Yes', proceed to Question 4, if No exclude the participant.

4. Are there associated features of syndromes, gross pathology, cleft lip and palate?

Yes	No

5. If ‘NO’, proceed to Question 6, if ‘Yes’ exclude the participant.

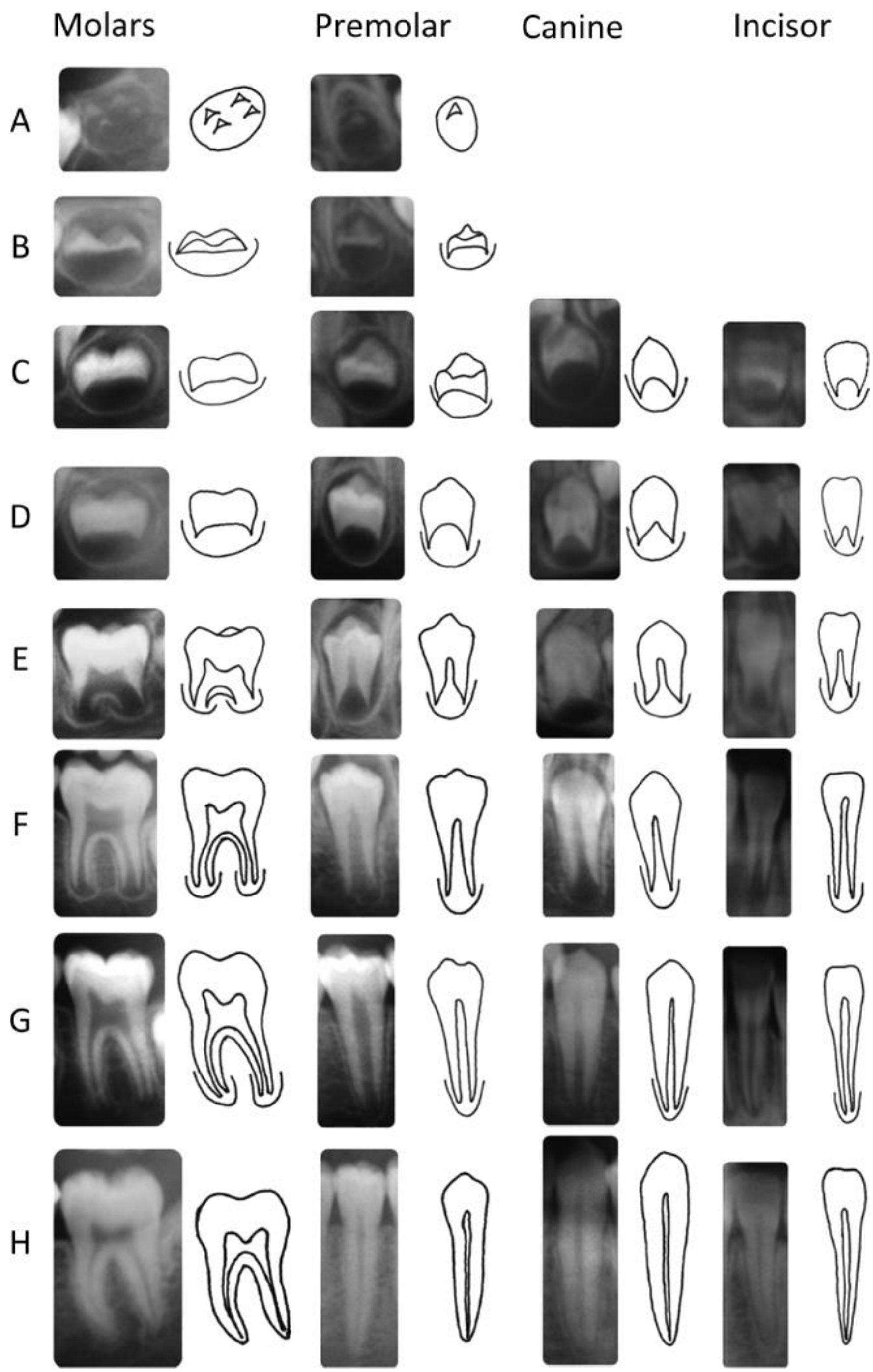
6. When was the panoramic examination done?

d	d	m	m	year			

7. Staging according to Demirjian et al., (1973) method and corresponding age score according to Willems tables.

LEFT MANDIBULAR TEETH	MATURATION STAGE (A-H)	SCORE	AGE
CENTRAL INCISOR			
LATERAL INCISOR			
CANINE			
1stPREMOLAR			
2nd PREMOLAR			
1ST MOLAR			
2ND MOLAR			

APPENDIX B. DEMIRJIANS' TOOTH MATURITY CHART



Adapted from Liversidge, H. M. (2012).

APPENDIX C. DEMIRJIAN'S TOOTH STAGES DESCRIPTION

Table I. Tooth stage descriptions.

Stage	Descriptions
A	In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.
B	Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface.
C	a. Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen. b. The beginning of a dentinal deposit is seen. c. The outline of the pulp chamber has a curved shape at the occlusal border.
D	a. The crown formation is complete down to the cemento–enamel junction. b. The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave towards the cervical region. The projection of the pulp horns, if present, gives an outline shaped like an umbrella top. In molars the pulp chamber has a trapezoidal form. c. Beginning of root formation is seen in the form of a spicule.
E	*Uniradicular teeth:* a. The walls of the pulp chamber now form straight lines, whose continuity it broken by the presence of the pulp horn, which is larger than in the previous stage. b. is less than the crown height. *Molars:* a. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape. b. is still less than the crown height.
F	*Uniradicular teeth:* a. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape. b. The root length is equal to or greater than the crown height. *Molars:* a. The calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings. b. The root length is equal to or greater than the crown height.
G	The walls of the root canal are now parallel and its apical end is still partially open (Distal root in molars).
H	a. The apical end of the root canal is completely closed (Distal root in molars). b. The periodontal membrane has a uniform width around the root and the apex.

Reprinted from Appendix in 'A New System of Dental Age Assessment' by Demirjian, A., Goldstein, H., Tanner, J. M. (1973) *Human Biology: The International Journal of Population Genetics and Anthropology*, 45 (2). Copyright© 1973 Wayne State University Press, with the permission of Wayne State University Press. Stage E point b updated as The root lenght reaches at least 1/3 of crown height for both uniradical teeth and molars (Levesque and Demirjian 1980).

Adapted from Liversidge, H. M. (2012)

TABLE 1—*Developmental tooth stages according to Demirjian's technique (1) with corresponding age scores expressed directly in years for each of the seven left mandibular teeth in boys.*

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 2—*Developmental tooth stages according to Demirjian's technique (1) with corresponding age scores expressed directly in years for each of the seven left mandibular teeth in girls.*

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	0.11	0.21	0.32	0.66	1.28	2.09	4.04

Adapted from Willems et al., (2001a)

APPENDIX E. COMBINED MEAN AGE OF TEETH MATURITY STAGES FROM DIFFERENT COUNTRIES

Table X. Mean ages of children 'in a tooth formation stage' (combined groups).

		Girls				Boys				Girls and boys		
Tooth	Stage	Mean	SE	SD	*n*	Mean	SE	SD	*n*	Mean	SE	SD
I_1	D	4.06	0.08	1.01	163	4.21	0.08	1.19	225	4.15	0.06	1.12
	E	5.14	0.04	0.74	298	5.38	0.05	1.00	427	5.28	0.04	0.91
	F	6.36	0.05	0.87	270	6.61	0.05	0.82	309	6.49	0.04	0.85
	G	7.66	0.04	0.89	462	8.00	0.05	1.06	562	7.85	0.03	1.00
I_2	C	3.38	0.13	0.70	29	3.82	0.11	0.73	42	3.64	0.09	0.75
	D	4.42	0.06	0.96	254	4.68	0.06	1.08	389	4.58	0.04	1.04
	E	5.71	0.05	0.87	337	6.03	0.05	1.05	437	5.89	0.04	0.99
	F	7.06	0.04	0.80	353	7.49	0.05	0.95	432	7.30	0.03	0.91
	G	8.31	0.04	0.98	645	8.83	0.04	1.10	688	8.58	0.03	1.08
C	C	4.15	0.08	1.02	174	4.54	0.07	1.19	330	4.40	0.05	1.15
	D	5.35	0.05	1.03	372	5.82	0.05	1.14	514	5.63	0.04	1.12
	E	7.08	0.04	0.97	544	7.74	0.04	1.07	749	7.46	0.03	1.08
	F	8.81	0.03	1.08	996	9.78	0.04	1.22	1069	9.31	0.03	1.25
	G	10.85	0.04	1.28	821	12.02	0.05	1.33	819	11.43	0.04	1.43
P_1	B	3.57	0.18	1.31	56	3.78	0.08	0.69	69	3.68	0.09	1.02
	C	4.73	0.04	0.78	308	4.99	0.05	1.10	436	4.88	0.04	0.99
	D	6.26	0.05	0.96	408	6.64	0.04	1.04	559	6.48	0.03	1.03
	E	7.92	0.03	0.93	798	8.35	0.04	1.05	808	8.14	0.03	1.02
	F	9.77	0.04	1.14	893	10.29	0.04	1.24	930	10.04	0.03	1.22
	G	11.46	0.05	1.18	659	12.14	0.05	1.23	591	11.78	0.04	1.25
P_2	A	4.14	0.16	1.43	78	4.32	0.14	1.37	90	4.24	0.11	1.39
	B	4.79	0.07	0.88	160	4.86	0.07	1.07	223	4.83	0.05	1.00
	C	5.90	0.07	1.24	340	6.02	0.06	1.22	448	5.97	0.04	1.23
	D	7.29	0.05	1.09	496	7.46	0.05	1.16	577	7.38	0.03	1.13
	E	8.54	0.04	1.14	745	9.06	0.04	1.23	777	8.81	0.03	1.21
	F	10.51	0.04	1.29	975	10.98	0.05	1.43	958	10.74	0.03	1.38
	G	12.33	0.05	1.32	701	12.94	0.06	1.42	633	12.62	0.04	1.40
M_1	D	3.74	0.08	0.77	101	4.02	0.12	1.40	138	3.90	0.08	1.18
	E	4.87	0.06	0.97	249	5.06	0.05	1.04	362	4.98	0.04	1.02
	F	6.04	0.05	0.92	314	6.42	0.06	1.17	437	6.25	0.04	1.09
	G	8.22	0.04	1.28	1194	8.66	0.04	1.40	1302	8.45	0.03	1.36
M_2	A	4.05	0.11	0.67	41	4.07	0.07	0.55	66	4.06	0.06	0.60
	B	4.63	0.06	0.84	175	4.83	0.06	0.86	216	4.74	0.04	0.85
	C	6.01	0.05	1.04	402	6.13	0.05	1.15	564	6.08	0.04	1.10
	D	7.67	0.04	1.05	793	7.96	0.04	1.13	800	7.81	0.03	1.10
	E	9.35	0.04	1.11	735	9.71	0.04	1.14	797	9.54	0.03	1.14
	F	10.84	0.04	1.06	629	11.34	0.05	1.18	575	11.08	0.03	1.15
	G	12.92	0.04	1.41	1098	13.42	0.05	1.43	998	13.16	0.03	1.44

Adapted from Liversidge et al., (2006)