AGE ESTIMATION USING ORTHOPANTOMOGRAMS WITH DEMIRJIAN AND WILLEMS METHODS AMONG CHILDREN ATTENDING DENTAL CLINICS IN WESTERN KENYA

BY

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DECLARATION

This research thesis is my original work and has not been presented for an award of degree in any university.

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DEDICATION

This work is dedicated to Mr. &Mrs. Peter Ode whose immense sacrifice, encouragement, moral and spiritual support has gone a long way in making this dream a reality. God bless them.

ABSTRACT

Background: An individual's age forms an important part of their biodata and is not only necessary for the living but for the deceased. In addition, it is a vital requirement in identifying children who are victims of child abuse, trafficking and murder. Verification of an individual's age can be done through authentic documents such as certificate of birth, national identity cards or passports. Nevertheless, there are situations where the age of an individual cannot be confirmed due to entrenched documents, hence the actual age has to be estimated. Therefore, various methods have been used to estimate age in different population among them being Demirjian and Willems methods that have widely been utilized. This has been achieved majorly through assessment of morphological changes of teeth as displayed by individual orthopantomograms. However, in Kenya, there is hardly any approved method that can be used to achieve this purpose, hence the need to determine the available methods in estimating the age of children in Western Kenya. **Objective:** To estimate age using orthopantomograms with Demirjian and Willems methods among children attending dental clinics in Western Kenya. **Materials and methods**: A cross-sectional study was conducted at Dental and Maxillofacial Imaging Centre in Kisumu County, Western Kenya. A total of 171 panoramic radiographs of children aged between 5-17 years were examined in order to determine the tooth maturity stages(A-H) for the first seven mandibular teeth on the left side. Each maturity stage was then assigned a corresponding maturity score as per Demirjian and Willems conversion tables, summed up and converted into dental age. The age difference was then obtained by subtracting dental age from chronological age. Descriptive and inferential statistics were used and data analyzed through SPSS version 26.0 and presented in tables and figures. **Results:** A sample of 171 panoramic radiographs of children aged 5-17 years were assessed, 91(54%) males and 80(46%) females. The study samples were divided into 6 age cohorts and comparison between sexes were tested. The mean chronological age for the entire age cohort was 9.11 years with a median age of 9.13 years. The overall mean dental age using Demirjian was 8.16±2.7. Among the females the deviation from the chronological age was ±2.22 years while in males it was ±1.68 at 95% CI. This depicted a wider margin of error in females than in males. There was an overall underestimation of the entire age cohort using Willems method with mean dental age of 8.94±2.264 with a standard error of 0.173 years. Among the females the deviation from the chronological age was ±2.062 years while in males it was ±1.95 at 95% CI. This depicted a wider margin of error in females than in males and a significant delay in dental maturity in both females and males. The comparison between dental age and chronological age was found not to be significant using both methods at P=<0.05. Pearson's correlation test revealed a strong positive association between the dental and chronological age in both methods (r= 0.767). Demirjian had a strong association in only two age cohorts (7-8.99 & 9.-10.99 years) while Willems had a stronger association in four age cohorts (5-6.99, 7-8.99. 9-10.99, 11-12.99 years). **Conclusion:** Use of both Demirjian and Willems method resulted in statistically significant underestimation of age. In terms of accuracy, both methods had a strong positive correlation, however, Willems method was found to be more accurate in estimating age among children in Western Kenya because it had a strong association in majority of the age cohorts as compared to Demirjian.

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LIST OF ABBREVIATIONS& ACRONYMS

CA	Chronological Age
CI	Confidence Interval
DAMIC	Dental and Maxillofacial Imaging Centre
DA	Dental Age
FGFS	Fibroblast growth factors
OPG	Orthopantomogram
PR	Panoramic radiographs
Shh	Sonic hedge hog
SPSS	Statistical Package for Social Sciences
UNICEF	United nations children Emergency fund
Wnt3	Wingless.

DEFINITION OF OPERATIONAL TERMS

Accuracy of age estimation method: The degree to which the results of age estimation method conforms to the actual age.

Age Estimation: A process of determining a person's age based on physical or biological characteristics such as dental features or skeletal development.

Child: any human being under the age of eighteen (18) years (Kenyan Constitution,2010).

Chronological age: Also known as actual age is obtained from birth registration documents such as birth certificates, Identity cards or passports.

Dental age: Also known as estimated age, is obtained when looking at the growth and development of individuals teeth.

Orthopantomogram: A dental radiograph used to identify the hard tissues of oral cavity and surrounding skeletal structures. It is also known as panoramic radiograph.

Underestimation: Indicates a positive difference between Chronological and Dental age

Overestimation: Indicates a negative difference between Chronological and Dental age

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CHAPTER ONE

INTRODUCTION

1.1 Introduction/background information

The biodata of an individual entails their age that is not only necessary for the living but for the dead. Authentic documents such as certificate of birth, national identity cards or passports can be used to verify an individual's age. Nevertheless, in some circumstances where an individual's age can't be established, age estimation must be authenticated (UNICEF, 2013).

In this regard, it is important to understand that Chronological age (CA), also known as actual age, is obtained from birth registration documents while Dental age (DA) or estimated age is obtained by looking at the growth and development of an individual's teeth (Flores *et al.*,2016). Age estimation is normally applied in diverse fields as such forensic medicine, odontology, anthropology and archeological studies (Send and Weem, 2013; Ritz-Timme *et al.*, 2000; Marquez-Grant, 2015).

In the field of dentistry, the age of a patient and maturity status of their tooth enables the dentists to plan for orthodontic and pedodontics management of various tooth conditions (Panchbhai, 2011; Grabber, 2001; Tandon, 2008). Dentists often rely on observation of eruption patterns and the use of chronological tables which have been developed using foreign population which may not have maturity rates similar to the local population (Hassanali 1985; Hassanali & Odhiambo, 1982; Ngassapa *et al.,* 1996).

Within the dental clinic, tooth maturity stage and estimated age can be ascertained when assessing growth and development among paediatric patients. This is important in planning for treatment.

Teeth maturity plays a major role in decision making of when to extract teeth or commence orthodontic treatment. In addition, some maturity indicators like bone and sexual growth can be integrated with age for detecting paediatric hormonal problems and maturity anomalies (Demirjian *et al.,*2001*;* Tandon, 2008).

In most cases, actual age is a vital requirement whenever one gets employed, during admission of school children, in child adoption and marriage (Constitution of Kenya, 2010; Senn and Weems, 2013; Willems *et al.,* 2001). Moreover, unaccompanied minors seeking asylum require age determination to qualify them for citizenship rights such as education and free health care (Panchbai, 2011; Larsen *et al.,*2012; Senn and Weems, 2013). Globally, sports participants require age determination to group them into different sports for games such as soccer.

At times imaging techniques have to be utilized to confirm the age of an individual. (Dvorak *et al.*, 2007). According to UNICEF, (2013), individual's age enables lawyers to handle civil cases amicably by assessing whether the victim has obtained the appropriate age for adult or juvenile imprisonment.

A child's biological age is majorly ascertained by assessing skeletal, physical and dental development (World Health Organization, 2021). Age estimation is realized by considering individuals state of health, physical appearance, psychosocial behavior (Schmeling, 2016; Senn and Weems, 2013; UNICEF, 2013).

Studies done within Europe have utilized non -medical and medical methods to ascertain an individual's age. Some of the non-medical methods include interviews, documentary evidence and psychosocial assessments. On the other hand, medical methods include, imaging techniques & physical examination. Imaging modalities include use of x-rays such as digital OPGs to obtain radiographs of dentition. Magnetic Resonance Imaging has also gained popularity because it prevents exposure of ionizing radiations to patients (Separated Children in Europe Programme, 2012).

The choice of age estimation methods depends on an individual's status whether alive or dead, a child or an adult, human tissue availability and techniques of age determination (Senn & Weems, 2013). Various methods that have been utilized for age estimation include; Nolla's method, Haavikko's method, Demirjian and modified Demirjian's by Willems (Demirjian *et al.,* 1973; Willems *et al.*, 2001). Demirjian's method was tested in Caucasian population and resulted in age overestimation hence Willems method has proved to be more accurate in recent studies (Willems *et al.*, 2001).

In Kenya therefore, the study seeks to test the performance of various methods in age estimation of children attending dental clinics in Western Kenya due to few established national standards for age estimation, few publications on dental maturity and utilization of scoring radiographic age estimation methods in this region.

1.2 Problem Statement

Legally accepted documents such as certificates of birth, national identity cards and passports are normally used in identification of individual's age. Whenever such authentic documents are misplaced or invalid, it deprives one from enjoying their citizen rights and freedom (Constitution of Kenya, 2010).

A multiple cluster survey of 2011/2014 report in Kakamega and Kisumu County indicated that 50% and 47% of children respectively had no birth registration documents especially in the rural areas due to socio-economic factors. Moreover, in Kenya, a study conducted in Kwale county revealed that more than half of the children did not possess birth certificates and therefore were not qualified for national identification card at the appropriate age (Pelowski *et al.*,2016). These data therefore, invites the need for age estimation among the Kenyan population.

1.3Justification of study

In situations where legally accepted identification documents are missing, there is need to determine the age of a child. Juvenile cases may prompt one to establish the assailant's and victim's age. They include child abuse, defilement, and trafficking. A child's age is also significant in knowing whether an individual has attained the appropriate age for criminality (Cdebacca & Sigmnon, 2014; United States department, 2013; UNICEF, 2013).

Age is relevant whenever one applies for national identification card or a visa to enable them enjoy constitutional rights. In cases where we have unaccompanied minors like refugees or asylum seekers and immigrants with no birth registration certificates, age will have to be determined for them to enjoy full citizen rights. In Kenya, therefore, the performance of available methods of age estimation should be explored to realize the most appropriate one for its population.

1.4 Significance of study

The applicability of different methods in this study will improve treatment planning in Pediatrics and Dental departments in Kenyan Hospitals to help manage tooth conditions associated with age in children. This study model will help develop baseline data for Kenyan model of age estimation in children so as to establish national policy guidelines for age estimation.

Knowledge of this study will enable lawmakers to identify the age of children who are victims of child abuse, trafficking and murder and to determine whether the perpetrators have attained the age of criminal responsibility so as to solve juvenile civil cases.

It will also enable the immigration department to settle immigrants, refugees and Kenyan asylum seekers who have no birth certificates or legally accepted documents. The sports department in Kenya as well will apply this knowledge to group children of approximated ages into different games such as soccer when legal documents are missing or invalid.

1.5 STUDY OBJECTIVES

1.5.1 Broad objective

To estimate age using orthopantomograms with Demirjian and Willems methods among Kenyan children attending dental clinics in Western Kenya.

1.5.2 Specific objectives:

1. To estimate age using orthopantomograms and Demirjian method among Kenyan children attending dental clinics in Western Kenya.
2. To estimate age using orthopantomograms and Willems method among Kenyan children attending dental clinics in Western Kenya.
3. To compare the accuracy of age estimated by Willems and Demirjian methods with the chronological age of children attending dental clinics in Western Kenya.

1.6 Research questions

1. How is age estimated using orthopantomograms and Demirjian method among Kenyan children attending dental clinics in Western Kenya?
2. How is age estimated using orthopantomograms and Willems methods among Kenyan children attending dental clinics in Western Kenya?
3. What is the comparison of accuracy of estimated age using Willems method and Demirjian method to the chronological age of children attending dental clinics in Western Kenya?

1.7. Possible limitations and delimitations

1.7.1 Limitations

There is likely to be a possibility of lack of cooperation from the dental clinic staff to provide access to patients' records, owing to the sensitivity of information sought.

Variability in radiological interpretation: Radiological interpretation may vary among Radiologists, which could affect the accuracy of the study results.

Majority of the diagnostic imaging and referral forms lacked date of births hence slowing data collection process.

1.7.2 Delimitations

Lack of cooperation from the facility staff was solved by obtaining relevant permits and authorization to access this data, and obtaining supportive communication in time.

Variability in radiological interpretation was fixed by of use of a standardized radiological interpretation protocol to enhance the accuracy of the results.

When carrying out digital panoramic radiographic exams, the parents of the children were called to produce the date of births of children and therefore such should be recorded to enhance quicker data collection in future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Developmental and morphological features of human teeth have been used to determine maturity of teeth and chronological age. Various methods have been used to achieve this purpose with Demirjian's method being the most extensively utilized (Demirjian *et al.*,1973). However, Willems *et al.* (2001) has been established to be more accurate than other methods. In addition, techniques of imaging have also been utilized to estimate age including use of panoramic radiographs of the jaws.

2.2Development of teeth

The human teeth develop from the 1st pharyngeal arch on the alveolar segment of the jaw. The arch then subdivides into maxillary and mandibular process which further forms the lower and upper jaw respectively. This process of development commences when neural crest cells migrate to the maxillary then to the mandibular process and settle below the ectoderm of the oral cavity (Moore *et al.,* 2013). Ectodermal-mesenchymal cell interaction has a major contribution to growth and development of teeth.

Bone morphogenic proteins (BMP), Fibroblast growth Factors (FGF), Sonic hedgehog (Shh) and Wingless mediate several signal pathways. The ectodermal dental field is outlined by the expression of transcription factorpitx-1 while teeth formation is done by Homeobox genes (Dlx-1, Dlx-2). Buccal lingual gradient of molecules enhances the arrangement of human teeth in one row.

Expression of BMP-4 activates Msx-1 and Msx-2 genes which initiates growth of incisors while expression of Dlx-1 and Barx-1 is restricted by FGF8 to form molars posteriorly. In addition, normal tooth morphogenesis and tooth number is regulated by Ectodysplasin (Eda) gene (Jheon *et al.*,2013; Carlson, 2014; Suryadera *et al.*, 2015; Wang *et al.*, 2012; Tuan *et al.*, 2015). Tooth maturity normally starts from the crown above to the root below. These three stages include; Bud, Cup and Bell stage. (Fig.1) followed by upward growth, petrification and eruption. Within the jaw bone, dental crypts enclose the growing teeth and can easily be visible on radiographs and become initially radiolucent and later become radiopaque (Suryadera *et al.,* 2015; Carlson, 2014; Demirjian *et al.,* 1973).

During bud stage, there is formation of dental lamina from proliferation of oral epithelial cells in the basal layer. Formation of a tooth bud is then realized when the lamina of teeth develops towards the underlying mesenchyme below, enlarging and encompassing it. On the apex of the tooth bud, an enamel knot, which is a modulating Centre, appears expressing Bone Morphogenic Proteins, Sonic hedgehog, Wingless genes and fibroblast growth factors. They regulate the morphological changes of the tooth crown. Transcription level factor influences gene expression at the enamel knot leading to downward growth of cells into cup stage. Normally teeth on the anterior segment is associated with one primary center with the posterior segment having secondary centers because of the many cusps (Fig 1) (Suryadeva *et al.*, 2015; Lan *et al.*,2014). Once development of tooth crown is complete, formation of enamel ceases and the cementum begins together with dentine marking the beginning of development of tooth crown.

Eruption of teeth commences before tooth development is complete and continues within the sequence of a specific time for each tooth. The deciduous (primary) and permanent (secondary) teeth result from continuous growth and development from prenatal to early adult life. In relation to this, age assessment can continue up to early adult life (Tandon, 2008; Carlson, 2014). In Bell stage, morphological differentiation begins. The enamel organ and the dental papilla develops from the underlying neural crest and ectodermal cells. Enamel is secreted by ameloblasts which differentiate from the enamel while dentine is secreted by odontoblasts from dental papilla cells. Molecular interaction causes change in morphology of teeth.

Initial tooth petrification commences at the apex of other cusps and on visible radiographs (Demirjian *et al*., 1973; Simmer and Hu, 2001; Carlson, 2014). More importantly, birth defects can distinctively form neonatal incremental line which can be used to verify the life status of a child at birth (Senn & Weems, 2013). In spite of geographical zone differences, studies have shown that tooth development occurs at the same time for the European and other populations. A study metanalysis of 9002 children (2-16.99 years) of European origin (England, Belgium, Sweden, Finland, France, Southern, Quebec and Australia) realized insignificant difference in dental growth. Majority of the teeth were observed to grow at similar time especially dental maturity (Kaval&Solheim,1994; Slootweg, 2007; Liversidge *et al*., 2006; Tandon,2008).

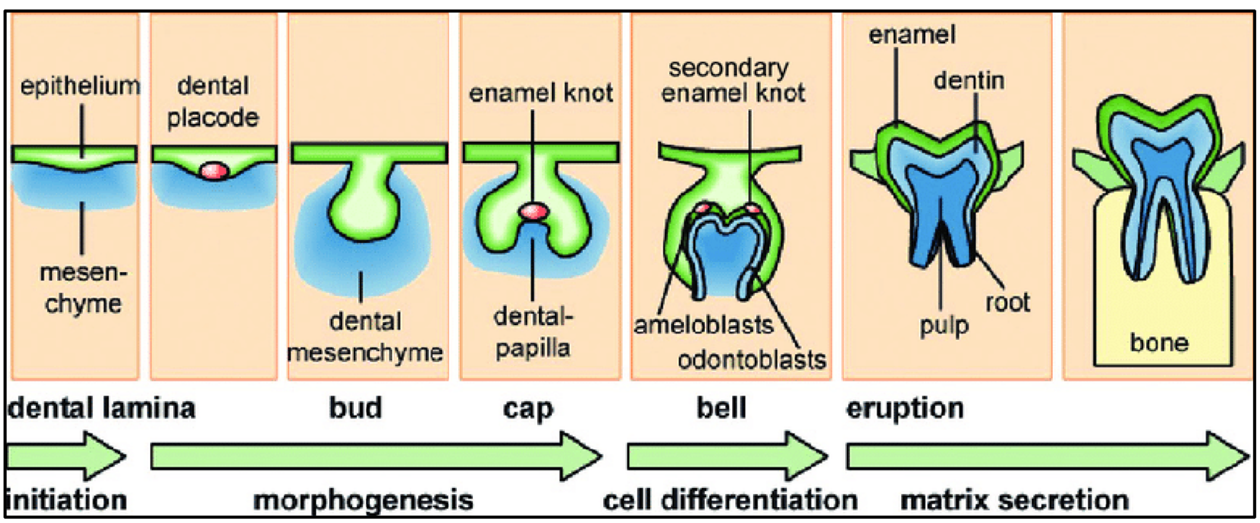

Figure 1:*Images of stages of tooth development in children*

Note. Adapted from Elina Jarvinen, University of Helsinki, Finland.

2.3Tooth Development Anomalies

Disease anomalies can affect the development of human teeth resulting in change of position, size, shape, number and structure. These changes can affect age estimation in children. The number of teeth can be affected by anomalies such as missing hypodontia or extra teeth. Dentinogenesis and amelogenesis imperfecta can result from defective formation of dentine and enamel, odontodysplasia (ghost teeth) and dentine dysplasia may manifest with grossly enlarged pulp chambers and abnormally short roots. The teeth may also appear abnormally smaller or longer than normal. Rickets typically present at the age of 6-24 months (Prentice *et al.,* 2013). Being a critical age for tooth development, the dental manifestations include; enamel hypoplasia, delayed formation of teeth and increased incidence of dental caries (David B'eal *et al.*,2014).

The normal shape of teeth can also be affected with abnormalities that bring changes to the whole teeth, crown, or root. The commonly seen abnormalities include; concrescence, fusion of teeth, dilaceration, dens invaginators, taurodontism and extra roots (Whaites, 1996; Farman *et al.,* 1993). Some studies have shown that birth outcomes affect ameloblasts during secretory or maturation phase of tooth development causing both hypoplastic and hypo mineralized enamel. Prematurity and Low Birth Weight (LBW) have been found to only affect the enamel structure of primary teeth since permanent teeth mineralize only after birth (Sabel *et al.,* 2008).

Most of the teeth anomalies can be distinctively recognized on dental radiographs. The distinctive features can help in inclusion or exclusion criteria. The modified Willems method is subject to changes in morphology of tooth crown and roots and therefore any alteration in morphology should be excluded to prevent result misinterpretation (Willems *et al*., 2001).

2.4 Age Estimation methods in children

Most methods for estimating dental age in children rely on tooth developmental stages. These methods can be adopted both prenatally and postnatally since tooth development commences at week 6 of gestation while petrification of first incisors and first molar commences at week 13-15 of gestation (Tandon, 2008; Macdonald *et al.*, 2004). Teeth developmental then continues up to about 16-25 years (Ngassapa,1996; AL Qahtani *et al.,* 2010)

The methods of age estimation rely on growth characteristics such as histological appearance through microscopic observation of incremental line as well as observation of mineral content of teeth. Some of the available techniques used involve radiographic and visual examination of developing teeth. When assessing age in children and adolescence, the last two methods are used (Willems, 2001; Tandon, 2008). Tooth eruption is often targeted by both endogenous and exogenous factors (Tandon, 2008; Seen and Weems, 2013).

2.5 Demirjian's method

Demirjian's method evolved from a large Canadian, French population as postulated by Demirjian *et al.,* (1973). This method relies on radiographic assessment of seven permanent teeth localized at the left side of mandibular segment. The teeth on the lower jaw segment appeared clearer than the ones on the maxillary segment as viewed on panoramic radiographs. Most of the teeth on the maxillary segment are normally underlying the bones of the maxilla and the face (White & Pharoah, 2004).

This method relies on 8 developmental stages of tooth (Table 1), noted with letters from A-H (lowest to highest maturation point). Numerical values are then attached to the stages based on Demirjian tables of conversion for male and female children. The values are then summed up once the corresponding values of the 7 permanent teeth on the lower jaw are achieved and the final results of maturity scores turned into estimated age by the use of Demirjian conversion table (Table 1).Studies done by Kihara Eunice, (2016) in selected Kenyan children at the University of Nairobi Dental hospital showed an overestimation of 0.53 years in the actual age. The accuracy and applicability of this method is therefore pegged on the overestimation of 1 year and below (Cheillet *et al.,* 2004).

The method relies on the morphological appearance of teeth which can be damaged by geometrically distorted orthopantomogram images (Whaites, 1996). This method's application has proven to be greatly reliable (Yusuf *et al*., 2013; Altalie *et al.,*2014; Jaradinejad *et al*., 2015). In Belgian Caucasian population, Willems *et al.* (2001) used Demirjian's method to estimate age. The study gave out a mean chronological and dental age difference of 0.5 & 0.9 years for male and female children respectively showing an overestimation (Kihara, 2016).

Table 1:*Developmental stages of teeth as given by Demirjian*

A.	Calcified cusp tips are not fused.
B.	Calcified cusp tips are fused with well-defined occlusal surface outline.
C.	Complete formation of enamel at the occlusal surface. Deposition of dentine also commences at this stage.
D.	Complete formation of the crown up to the cement-enamel junction. Formation of the roots is visible with the pulp horns beginning to differentiate.
E.	Root length is less than crown length, the pulp horns and chambers differentiate further. There is also visible radical bifurcation on the molars.
F.	Crown length is equal and greater than root length. Funnel shaped apex is visible.
G.	The walls of the root canal are parallel and the apical ends are still open.
H.	The apical ends are closed and uniform periodontal ligament space is seen around the tooth

Note: Adapted by Demirjian *et al. (*1973).

2.6 Willem's model of age estimation

The method was based on Belgian Caucasian reference population. Willems applied part of Demirjian (1973) method by using the same A-H tooth staging technique relying on the left seven mandibular teeth. Once the stages of development for the seven permanent teeth have been identified, each tooth stage is then accorded new maturity scores and summed up to obtain dental age using the conversion tables (Table 2 &3)

Apart from Belgian Caucasian population, Willems model has performed better than Demirjian method in other population. In order to ascertain the most appropriate method of age estimation, eleven methods were tested by Liversidge *et al.* (2010). The methods include: 3 Liversidge, 2 Nystrom methods, olla, Demirjian, Willems, Chaillet, Moorasses, and Haaviko and Anderson. A study population of nine hundred and forty-six children aged between three and sixteen years of White and Bangladesh ethnic origin were tested by these methods.

As opposed to other methods, Willems method was confirmed to be more accurate with the smallest mean and standard deviation in age estimation. In Macedonian children, Willem's method evidently performed better than Demirjian (Ambar kora *et al.*, 2014). Among the Egyptian population, it performed better as opposed to Cameriere method with a difference of -0.15 years & -0.29 years respectively in terms of mean (El-Bakery *et al.*, 2010).

Table 2 :*Conversion table for boys as given by Willems*

TOOTH	A	B	C	D	E	F	G	H
Central incisor	_	_	1.68	1.49	1.5	1.86	2.07	2.19
Lateral incisors	_	_	0.55	0.63	0.74	1.08	1.32	1.64
Canine	_	_	_	0.04	0.31	0.47	1.09	1.9
First premolar	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
Second premolar	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 3:Conversion table for girls as given by Willems

TOOTH	A	B	C	D	E	F	G	H
Central incisors	_	_	1.83	2.19	2.34	2.82	3.19	3.14
Lateral incisors	_	_	_	0.29	0.32	0.49	0.79	0.7
Canine	_	_	0.6	0.54	0.62	1.08	1.72	2
First premolar	-0.95	-0.15	0.16	0.41	0.6	1.27	1.58	2.19
Second premolar	-0.19	001	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

Note.* Adapted by Willems *et al. (*2001*)

2.7 Significance of imaging in dental age estimation

Age determination has been achieved through several techniques of imaging such as, intraoral periapical, panoramic imaging (PR), cone beam and lateral oblique of the mandible. (Demirjian *et al.*, 1973; Willems *et al.*,2001; Yang *et al.*,2006; Pachachi, 2011; Agarwal *et al.,* 2012). Panoramic radiographs have been utilized to estimate age. It singles out scanned images of structures of the face including both mandibular and maxillary dental arches.

These images taken are initially used to provide general outlook of the upper and lower jaw segments. In addition, it plays a major role in planning for projection of radiographs (White and Pharoah, 2004). Panoramic images (Figure 2) have majorly been used to study deciduous tooth resorption and permanent teeth development.

These techniques of imaging are also applied to rule out anomalies in tooth development such as impacted and ankylosed teeth. Moreover, PRs is also useful in diagnosis of traumatic injuries and oral pathology (Graber, 2001; Tandon, 2008; White and Pharoah, 2004).

Panoramic imaging is recommended where there is proof of eruption of first permanent teeth in children aged between five to seven years (Ngassapa *et al*., 1996; AL Qahtani *et al.,* 2010). American Dental Association Council (2006) further recommends periapical or panoramic examination for assessing developing third molars in adolescents. However, in view of these recommendations and other technical aspects associated with PR, clinicians may not routinely request for PR of children below 5 years as such was evidenced by previous studies where such examinations were not commonly available (Alshihri *et al.,* 2015; Galic *et al.,* 2011; Liversidge *et al.,* 2006).

Figure 2: Initial image of orthopantomogram showing overall late developing dentition

Note. **Adapted from Ferring Dental Practice Hospital, London.**

CHAPTER THREE

MATERILAS AND METHODS

3.1 Study Area

This research study was conducted at Dental and maxillofacial Imaging Centre(DAMIC), a private imaging facility located in United Mall at the former Tuskys supermarket (opposite Kisumu Girls Secondary School) along Jomo Kenyatta Highway of Kisumu City. It is a state-of-the-art Dental imaging Centre that offers a variety of clear digital dental radiographs such as orthopantomograms (OPGs) to help manage dental and maxillofacial conditions. It receives many dental imaging referrals from both private and public facilities in the region because of its quality diagnostic images. Moreover, the other facilities lack storage records of previous orthopantomograms done as opposed to Dental and Maxillofacial Imaging Centre.

3.2 The study Design

A cross-sectional analytical design was used to compare the outcome of the variables for analysis.

3.3 Study population

The study targeted digital orthopantomograms of Kenyan children between the ages of five to seventeen (5-17 years) from DAMIC records. This age bracket is a recommendation of the American Dental Association Council on Scientific Affairs (2006) where PRs are considered for children with an evidence of permanent tooth eruption which likely occurs at 5-7 years. In addition, From the ages of 5 years, children are able to cooperate and sit still for capture of quality digital images unlike those below 5 years who are likely to be unsettled and cause commotion during the procedure and in adolescent children for assessing the developing third molar.

The maximum age limit for this study was 17 years as this is the average age where adolescents attain full teeth maturity as evidenced by the third molar growth (James, 2008). This helped the researcher to target a larger sample size for quality data collection. The digital orthopantomograms was a product of GENDEX ORTHORALIX 9200 with all the standard protocols in place.

3.4 Sample Size determination

In this study, the sample size was calculated using Yamane Taro formula (1967) because it provides a simplified formula that determines and calculates a reliable sample size from a given population that is less than 10,000. It also has a high level of precision.

$$n = \frac{N}{1 + Ne^2}$$

Where: n=sample size

N = study population

e =maximum acceptable margin of error/ allowable error 5 %

The study population consisted of 300 panoramic radiographs of children recorded and stored from the year 2017-2022.

Where:

$$n = \frac{300}{1+300(0.05)^2}$$

= 171

Therefore, the minimum target sample size was 171 radiographs.

3.5 Sampling technique/method

In this study, purposive sampling method was used to select panoramic radiographs.

3.6. Inclusion criteria and exclusion criteria

3.6.1 Inclusion criteria

Radiographs with diagnostic quality images.

Radiographs with available information on date of birth and date of panoramic imaging.

Radiographs with no missing permanent teeth on the mandibular segment.

3.6.2 Exclusion criteria

Radiographs with distorted images.

Radiographs with missing biodata.

Radiographs with pathologies and cysts on teeth dentition.

3.7. Study variables

Variables are any characteristics that can take on different values which keep on changing (Thomas, 2020)

Social demographic variable -Age and gender.

3.7.1 Independent variables

1. Tooth morphology
2. Tooth type

3.7.2 Dependent variables

1. Tooth Maturity stage
2. Tooth Maturity score
3. Child's Estimated dental age

3.8 Data collection and tools

3.8.1 Data collection form

In this study the data collection form was divided into the following sections on the appendices;

Appendix I A.

Questions on Panoramic images

Table containing type of tooth, tooth stages(A-H), maturity score, estimated dental age (Demirjian & Willems) and chronological age.

Appendix I B.

Figure 3 & table 4-Tooth developmental stages as given by Demirjian.

Appendix I C & D

Table 5 & 6- Conversion tables for teeth maturity scores in boys and girls as given by Demirjian.

Appendix I E & G

Table 7 & 8- conversion tables from maturity scores to dental age for boys and girls as given by Demirjian.

Appendix I G & H

Table 9 & 10- conversion tables for teeth maturity scores in boys and girls as given by Willems.

3.8.2 Data collection procedure.

PREPARATION AND TRAINING

The Principal Investigator(myself) was calibrated and the research assistants from Dental and Maxillofacial Imaging Centre trained by a specialist in Dentistry before data collection. Preparation involved random examination of 10 panoramic radiographs and identification of eight stages of tooth development as outlined by Demirjian *et al.,* (1973). This examination was done and verified by the dental specialist to avoid biasness. In addition, there was training on how to apply Demirjian and Willems methods maturity scores to calculate dental age.

PRE-TESTING OF DATA FORM

Data collection form was pre-tested and checked for completeness to minimize errors. Any omitted data was rechecked and entered. This was to ensure validity.

RETRIEVAL OF PANORAMIC RADIOGRAPHS

The radiographs in soft copy were retrieved from a computer data base connected to the digital panoramic x-ray machine by the research assistants from Dental and Maxillofacial Imaging Centre. The date of panoramic imaging (DOP) was noted for each radiograph and every image coded and assigned Arabic numerals (1 M, 2M for males…and 1F ,2 F for females) in order to conceal any identity of the patients and avoid biasness. The date of birth (DOB) and gender was extracted from the diagnostic imaging and referral forms available in the records.

CHRONOLOGICAL AGE DETERMINATION

Chronological age was calculated by subtracting the Date of birth (DOB) from Date of panoramic imaging (DOP) i.e. (DOB-DOP) and expressed in two decimal points. The ages of children were then grouped into six age cohorts.

DETERMINATION OF TOOTH MATURITY

DEMIRJIAN

The panoramic radiographs were then examined by the Principal Investigator by looking at the morphological appearance of the teeth on the PRs and staged (A-H) according to Demirjian's (1973) maturity chart and table [Appendix I B. Figure 3 & Table 4]. The A-H staging of Demirjian was applied on the seven mandibular left permanent teeth and each stage accorded maturity scores for boys and girls (Appendix I C, TABLE 5 & 6). The scores were then entered on the data form.

WILLEMS

The previously identified tooth stages were then assigned corresponding age scores using Willems age score tables for boys and girls [Appendix I G, H, Table 9 and 10].

DENTAL AGE DETERMINATION

DEMIRJIAN

The maturity scores by Demirjian were then summed up and the total sum converted to corresponding dental age as given by the conversion table for boys and girls (Appendix E, F Table 7 & 8).

WILLEMS

The maturity scores as given by Willems, were then summed up to give estimated dental age. The obtained data was then merged together into a Microsoft Excel sheet.

3.8.3 Instruments of Reliability and Validity

Reliability was tested using Fleiss's kappa and revealed a substantial (Kappa= 0.61-0.81) to almost perfect agreement (Kappa= 0.81-1.00).10% of the images were selected randomly to measure intraexaminer reliability. Content Validity was verified by an expert from the paediatric dental department.

3.8.4 Data Analysis

The data obtained was consolidated and transferred from Microsoft Excel and subjected to statistical analysis through statistical package for social sciences (SPSS) version 26.0. Statistical data was then analyzed descriptively using measures of central tendency (mean and median) and measures of dispersion such as standard deviation, minimum and maximum. This was used to find frequency distribution of maturity age scores as given by Demirjian and Willems. It also helped to describe the spread of age scores by calculating the standard deviation.

Inferential statistics included confidence interval (CI), standard error and paired sample t-test was presented as point and interval estimate. For objective 1 & 2, a confidence interval of 95% was used to measure the interval estimate for the mean difference between chronological and estimated age by Demirjian and Willems model. The paired sample t-test was used to measure the statistical significance between chronological and estimated ages. Linear regression test was used to measure the probability and relationship between chronological and estimated age of females and males.

Independent sample t-test was utilized to test significance difference between the mean age for males (boys) and females (girls) age. In objective 3, Pearson's correlation (Pearson's r) was used to test for association between chronological age and dental age as given by Demirjian and Willems methods.

Tables and figures such as box plots were used to present results according to different age cohorts (Kothari and Garg ,2014). The data for boys and girls were presented as a combination of both. P-values deduced from Paired sample t-test represented significance level and any value less than 0.05 indicated a statistical significance. The CI that did not include 0 in its range indicated that the mean age difference was statistically significant (Polit & Beck, 2012). A positive or negative age difference (CA-DA) indicated an underestimation or over-estimation of a child's age, respectively.

3.9. Ethical considerations

The research proposal was presented to the school of graduate studies for review and further approval was done by Maseno University Scientific and Ethical Review Committee (MUSERC) under approval No. MUSERC/01149/22. Thereafter, a research study permit was obtained from National Commission for Science and Technology (NACOSTI)-License No: NACOSTI/P/22/22401, to authorize data collection. The researcher then made a pre-visit to Dental and Maxillofacial Imaging Centre to seek consent from the director and make arrangements to collect data.

3.10. Dissemination of findings

Copies of the dissertation will be presented to the school of postgraduate and research, Maseno University. Copies will also be sent to the library, data collection centers and the findings presented in conferences and published in a referred journal of biomedical science.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

The main aim of the current study was to estimate age through a radiological assessment of orthopantomograms (Figure 2 Chapter 2) in children aged between 5 and 17 years in the Kenyan population. This age bracket is a recommendation of the American Dental Association Council on Scientific Affairs (2006) where panoramic radiographs are considered for children with an evidence of permanent tooth eruption which likely occurs between 5 to7 years. In addition, children aged 5 years are able to cooperate and sit still for capture of quality digital images unlike those below 5 years who are likely to be unsettled and cause commotion during the procedure thus, leading to inaccurate dental age. The maximum age limit for this study was 17 years as this is the average age where adolescents attain full teeth maturity as evidenced by the third molar growth (James, 2008).

The study samples were divided into 6 age cohorts and comparison between sexes were tested. In this chapter, results of the analysis are presented in three main sets viz: the total sample population, Demirjian method and Willems method. Each set presents findings and correlation of variables starting from the staging intervals, tests of significance, asymmetry and sex dimorphism within the sample groups. The last subset presents correlations between the two sample groups.

4.2 DEMOGRAPHIC CHARACTERISTICS

A total of 171 panoramic radiographs were assessed, made up of 91(54%) males and 80(46%) females. (Figure 4.1)

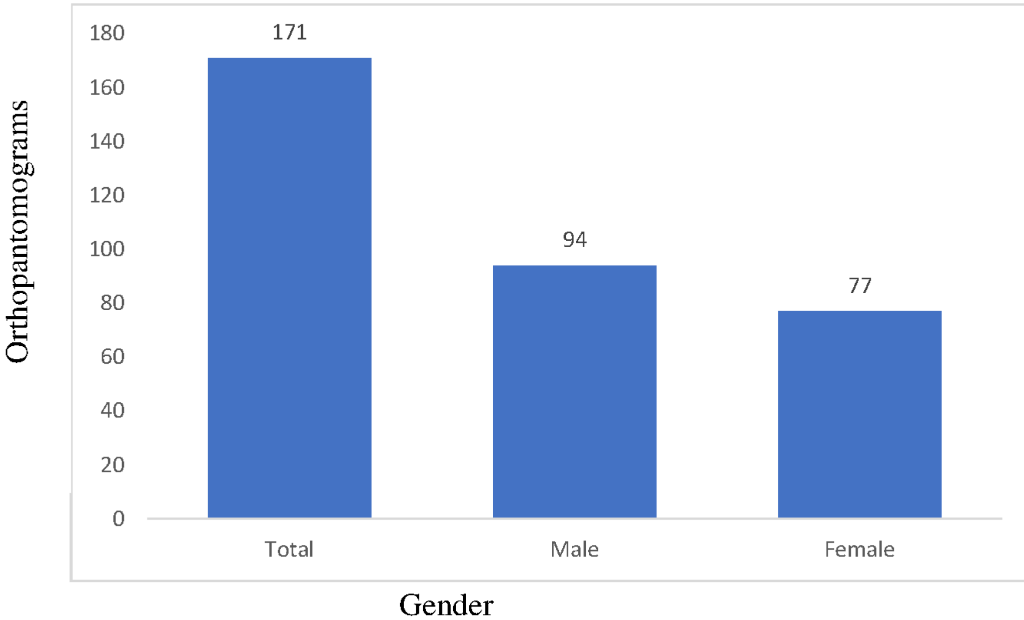

Figure 4.1: ***Sex distribution of the respondents***

The radiographs were collected for children aged between 5 and 17 years. Most of the children were aged 9 years (15%). The mean chronological age was 9.11 years with a median age of 9.13 respectively (Table 4.1).

Table 4.1: ***Age distribution in the total sample population***

CA	Male	Female	Total	Percentage
5 years	5	5	10	5.8%
6 years	7	8	15	8.8%
7 years	11	11	22	12.9%
8 years	15	10	25	14.6%
9 years	17	10	27	15.8%
10 years	9	13	22	12.9%
11 years	10	8	18	10.5%
12 years	6	5	11	6.4%
13 years	7	0	7	4.1%
14 years	2	3	5	2.9%
15 years	2	2	4	2.3%
16 years	1	1	2	1.2%
17 years	2	1	3	1.8%
Total	94	77	171	100%

Intra-Observer test

The correlation between the results of the intra-observer and the primary researcher was tested through a linear regression and Fleiss' Kappa analysis. (Table 4.2). There were no significant differences between observations of the independent observer and the primary researcher.

All the parameters examined had a substantial (Kappa= 0.61-0.81) to almost perfect agreement (Kappa = 0.81-1.00) given that the same methodology applies in all population groups (Demirjian and Willems).

Table 4.2: ***Linear regression analysis showing no significant difference between the two sets of results***

Attributes	Laterality	κ	SE	95%CI	P-value	R
Demirjian	Male	0.69	0.02	0.22	0.75	0.12
	Female	0.72	0.05	0.53	0.91	0.11
Willems	Male	0.77	0.07	0.84	0.78	0.18
	Female	0.81	0.05	0.73	0.18	0.12

Key: κ **=** *Fleiss' Kappa analysis, SE=Standard Error, CI= Confidence Interval, R= Regression coefficient*

4.2 ESTIMATED DENTAL AGE USING DEMIRJIAN METHOD

Table 4.3: ***Mean Dental age of the total respondents using Demirjian method***

Dental Age Demirjian							
Age cohort	N	Mean	Std. D	SEM	Min	Max	Variance
5-6.99	25	5.56	1.960	.392	2	9	3.840
7-8.99	47	6.85	1.853	.270	2	11	3.434
9-10.99	49	8.04	1.755	.251	6	14	3.082
11-12.99	29	9.21	1.114	.207	9	13	1.241
13-14.99	12	12.33	2.309	.667	10	17	5.333
15-17.99	9	13.89	1.364	.455	12	16	1.861
Total	171	**8.16**	**2.758**	**.211**	2	17	7.604

Using Demirjian method, the mean dental age was 8.16± 2.7 with a standard error of mean of 0.211 in the total respondents (Table 4.3).

Estimated dental age using Demirjian method in males and females

Table 4.4: ***Difference in age estimation using Demirjian method among sexes***

	Female Demirjian				Male Demirjian			
Age cohort	N	Mean	SD	SEM	N	Mean	SD	SEM
5- 6.99	13	4.08	1.441	.400	12	7.17	.835	.241
7- 8.99	21	5.90	2.189	.478	26	7.62	1.061	.208
9 -10.99	23	7.04	1.745	.364	26	8.92	1.230	.241
11-12.99	13	8.46	1.127	.312	16	9.81	.655	.164
13 -14.99	3	13.33	3.786	2.186	9	12.00	1.803	.601
15 -17.99	4	14.25	.957	.479	5	13.60	1.673	.748
Total	77	**7.09**	**3.096**	**.353**	94	**9.03**	**2.087**	**.215**

In females, the mean dental age was 7.09± 3.096 with a standard error of mean of 0.353. Among the males; the mean estimated age using Demirjian method was 9.03±2.087 with a standard error of 0.215.

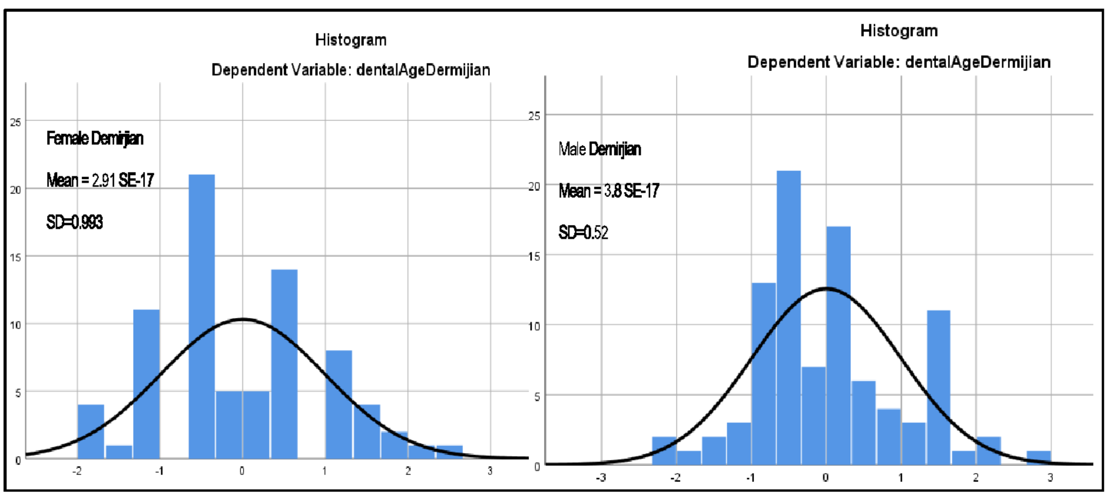

Figure 4.2: ***Histogram illustrating error in Dental age estimation in boys and girls using Demirjian method***

The distribution of frequency of dental age estimation errors is illustrated in figure 4.2 using Demirjian method. The chronological age of 61% of females were underestimated while 53% of the males were underestimated using Demirjian method of age estimation. The probability of underestimation of CA was therefore high using Demirjian method. However, the cumulative error for age estimation for both sexes was less than ± 1.683 years.

Table 4.5: ***Linear regression test for relationship between chronological age and Dental age in males and females***

	FEMALES			MALES		
Predicted models	Minimum	Maximum	Std. Deviation	Minimum	Maximum	Std. Deviation
Predicted Value	.76	11.53	**2.223**	6.30	13.68	**1.683**
Residual	-3.346	3.499	**1.535**	-2.831	3.628	**1.233**
Std. Predicted Value	-1.968	2.878	**1.000**	-1.624	2.759	**1.000**
Std. Residual	-2.166	2.265	**.993**	-2.284	2.927	**.995**

Using the regression analysis test for linearity, the mean difference between CA and DA was plotted against the age frequency distribution to determine how wide the deviation is from the chronological age (standard error of mean). Among females, the deviation from CA was ±2.22 years at 95% confidence interval (CI). while in males, the deviation from CA was ±1.68. This means that the females had a wider margin of error during age estimation than males (Table 4.5).

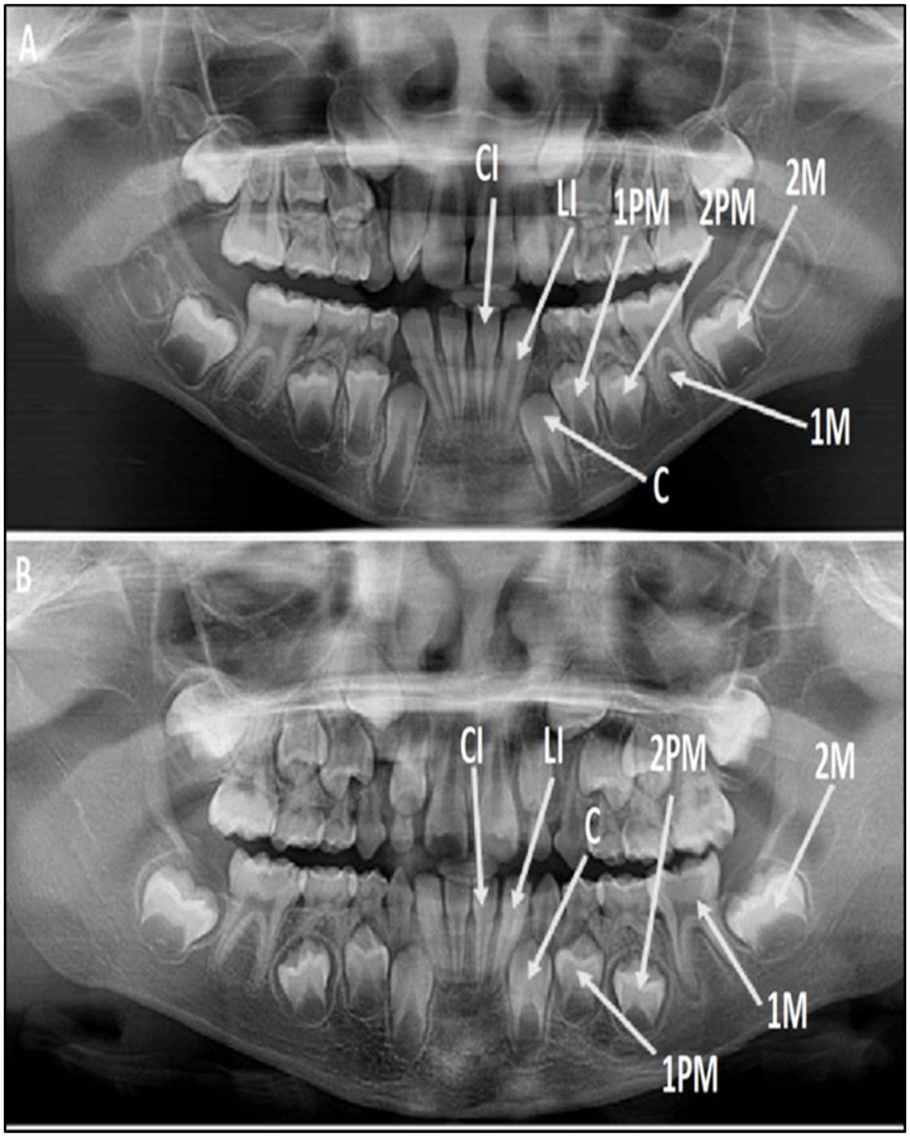

Figure 4.3: A & B -Digital Orthopantomogram images of a 10 year -old male and female child whose Dental ages were estimated at 9 and 8 years respectively using Demirjian method.

Key: CI-Central incisor, **LI -**Lateral incisors**, C-** Canines, **1PM**- First Premolar, **2PM**- Second Premolar, **1M** -First Molar, **2PM**- Second Molar.

Dental Age estimation using Demirjian method

The seven mandibular left permanent teeth were assessed and staged(A-H) according to their development from the digital orthopantomograms (Figure 4.3 & 4.4) Maturity score was then given for each tooth according to the Demirjian conversion tables for boys and girls (Table 1 chapter 2) The scores were then summed up and converted to dental age.

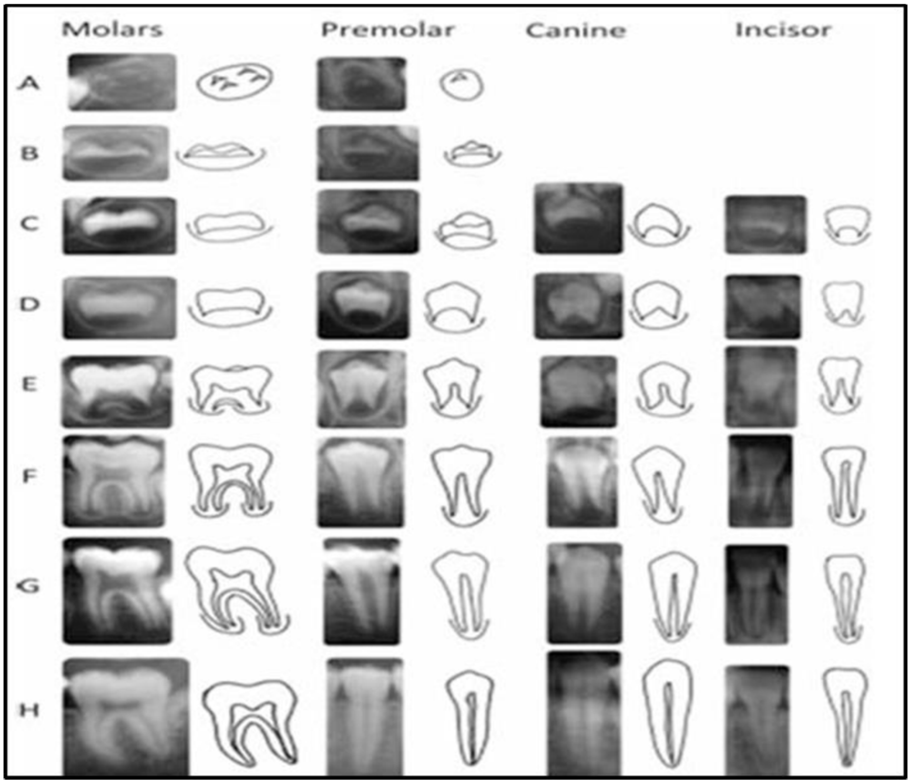

Figure 4.4: *Image of A-H tooth staging according to Demirjian*

4.3 ESTIMATED DENTAL AGE USING WILLEM'S METHOD

Table 4.6: ***Dental age using Willems method in the total sample population***

Dental Age, Willems							
Age cohort	N	Mean	Std. Deviation	Std. Error of Mean	Minimum	Maximum	Variance
5-6.99	25	6.12	1.130	.226	5	9	1.277
7-8.99	47	7.62	1.171	.171	7	11	1.372
9-10.99	49	9.08	1.152	.165	9	14	1.327
11-12.99	29	10.52	1.153	.214	10	15	1.330
13-14.99	12	12.33	.492	.142	13	14	.242
15-17.99	9	13.33	1.000	.333	13	16	1.000
Total	171	**8.94**	**2.264**	**.173**	5	16	5.126

Using Willems method, the mean estimated age of all the respondents was 8.94± 2.264 with a standard error of 0.173 years (Table 4.6).

Table 4.7: ***Estimated dental age using Willem's method in males and females***

Age cohort	Female Willem's N	Mean	SD	SEM	Male Willems N	Mean	SD	SEM
5- 6.99	13	5.77	1.092	.303	12	6.50	1.087	.314
7- 8.99	21	7.86	.910	.199	26	7.42	1.332	.261
9 -10.99	23	8.87	.815	.170	26	9.27	1.373	.269
11-12.99	13	10.62	1.557	.432	16	10.44	.727	.182
13 -14.99	3	12.00	.000	.000	9	12.44	.527	.176
15 -17.99	4	14.00	1.155	.577	5	12.80	.447	.200
Total	77	**8.75**	**2.289**	**.261**	94	**9.10**	**2.244**	**.231**

In females, the mean estimated age using Willems method was 8.75± 2.289 with a standard error of mean of 0.261. Among the males, the mean estimated age was 9.10±2.244 with a standard error of 0.231 (Table 4.7).

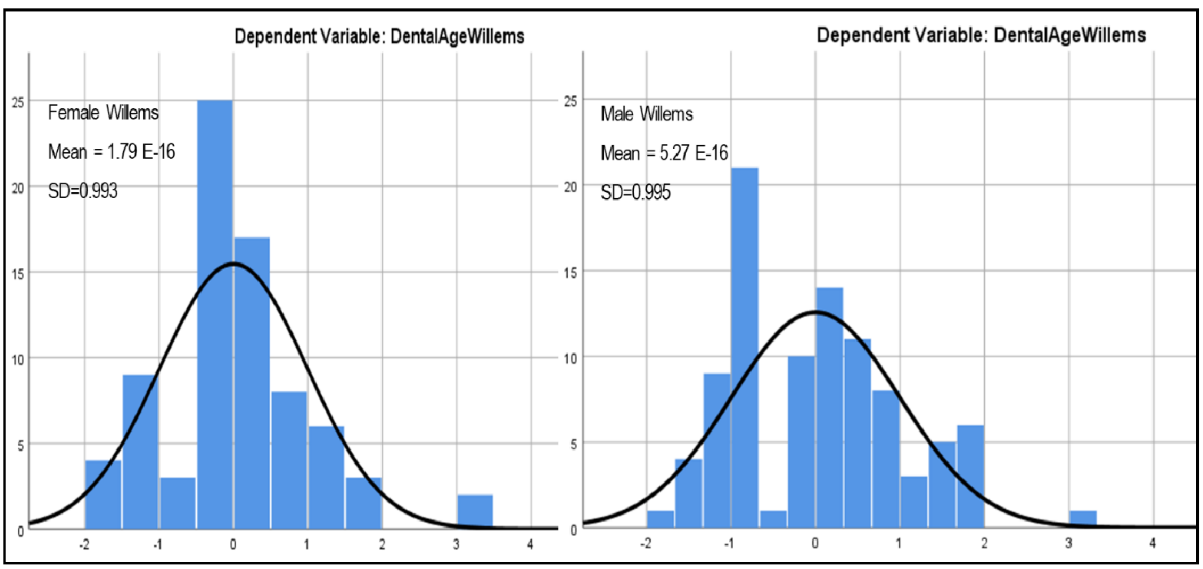

Figure 4.5: ***Histogram illustrating error in Dental age estimation in boys and girls using Willems method***

The distribution of frequency of dental age estimation errors is illustrated in figure 4.5 using Willems method. The chronological age of 57% of females were underestimated while 56% of the males were underestimated using Willems method of age estimation.

Table 4.8: ***Linear regression test for relationship between chronological age and Dental age in males and females***

Predicted models	FEMALES Minimum	Maximum	Std. Deviation	MALES Minimum	Maximum	Std. Deviation
Predicted Value	5.60	14.76	**2.062**	5.93	14.48	**1.952**
Residual	-1.944	3.056	**.994**	-2.064	3.510	**1.107**
Std. Predicted Value	-1.529	2.913	**1.000**	-1.624	2.759	**1.000**
Std. Residual	-1.944	3.055	**.993**	-1.855	3.155	**.995**

Among females, the deviation from CA was ±2.062 years at 95% confidence interval (CI), while in males, the deviation from CA was ±1.952. The probability of underestimation of CA was therefore high in females using Willems method. However, the cumulative error for age estimation for both sexes was less than ± 1.95 years (Figure 4.5 & Table 4.8).

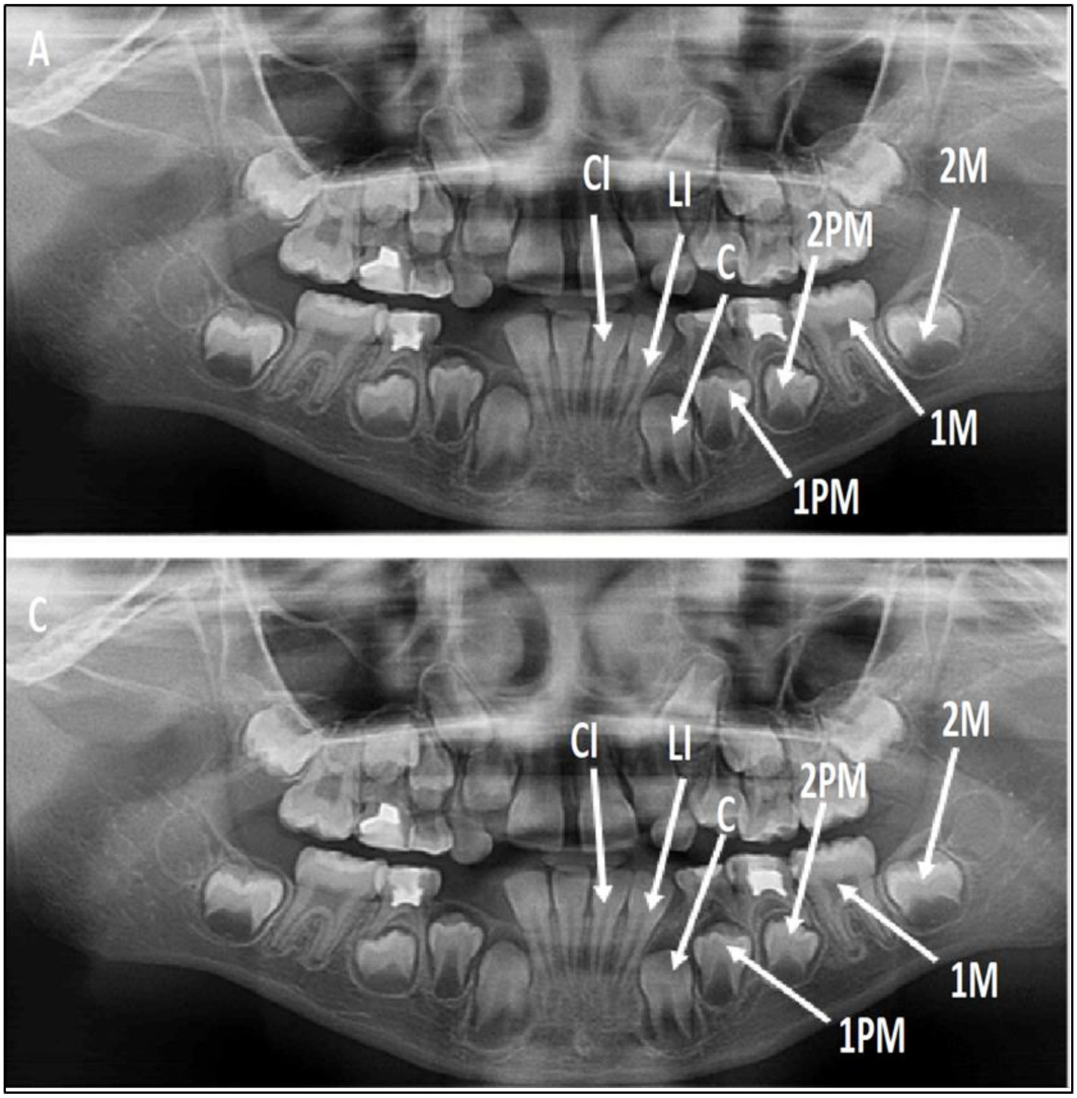

Figure 4.6: A & C- Digital orthopantomogram images of 12 years -old male and female child whose Dental ages were estimated at 10 and 9 years respectively using Willems method.

Key: CI-Central incisor, **LI -**Lateral incisors**, C-** Canines, **1PM**- First Premolar, **2PM**- Second Premolar, **1M** –First Molar, **2PM**- Second Molar.

Dental Age estimation using Willems method

The seven left mandibular teeth were assessed, staged(A-H) and assigned maturity scores according to Willems conversion tables (Tables 2 & 3 chapter 2). The scores were then summed up to obtain dental age.

4.4. ACCURACY OF DEMIRJIAN AND WILLEMS METHOD IN AGE ESTIMATION

The mean difference between chronological age and estimated age using Demirjian and Willem's method from the total sample population was applied and the results were subjected to Pearson correlation tests to check for the strength of association between the estimated age (Dental age) and the chronological age.

Table 4.9: ***Difference between mean chronological age and mean dental age by Demirjian method***

Age cohort	Mean CA	Mean Dermirjian	Mean difference	P Value
5- 6.99	5.99	5.56	0.43	.125
7- 8.99	7.99	6.85	1.14	**.004**
9 -10.99	9.99	8.04	1.94	**.047**
11-12.99	11.99	9.21	2.08	.563
13 -14.99	13.99	12.33	1.68	.378
15 -17.99	16.49	13.89	2.64	.978
Total	**11.07**	**8.16**	**2.91**	**.000**

Pearson's test revealed a significant correlation between dental and chronological age in age group 7- 8.99, 9 -10.99 years (p=<0.05) using Dermijian method of age assessment (Table 4.9).

Table 4.10: ***Difference between mean chronological age and mean dental age by Willems method***

Age cohort	Mean CA	Mean Willems	Mean difference	P Value
5- 6.99	5.99	6.12	0.13	.038
7- 8.99	7.99	7.62	0.37	.015
9 -10.99	9.99	9.08	0.91	.009
11-12.99	11.99	10.52	1.47	.018
13 -14.99	13.99	12.33	1.68	.711
15 -17.99	16.49	13.33	2.13	.410
Total	**11.07**	**8.94**	**2.01**	**.000**

Pearson's correlation revealed a significant correlation between dental and chronological age in age group 5-6.99, 7- 8.99, 9 -10.99 and 11-12.99 years (p=<0.05) using Willems method of age assessment (Table 4.10).

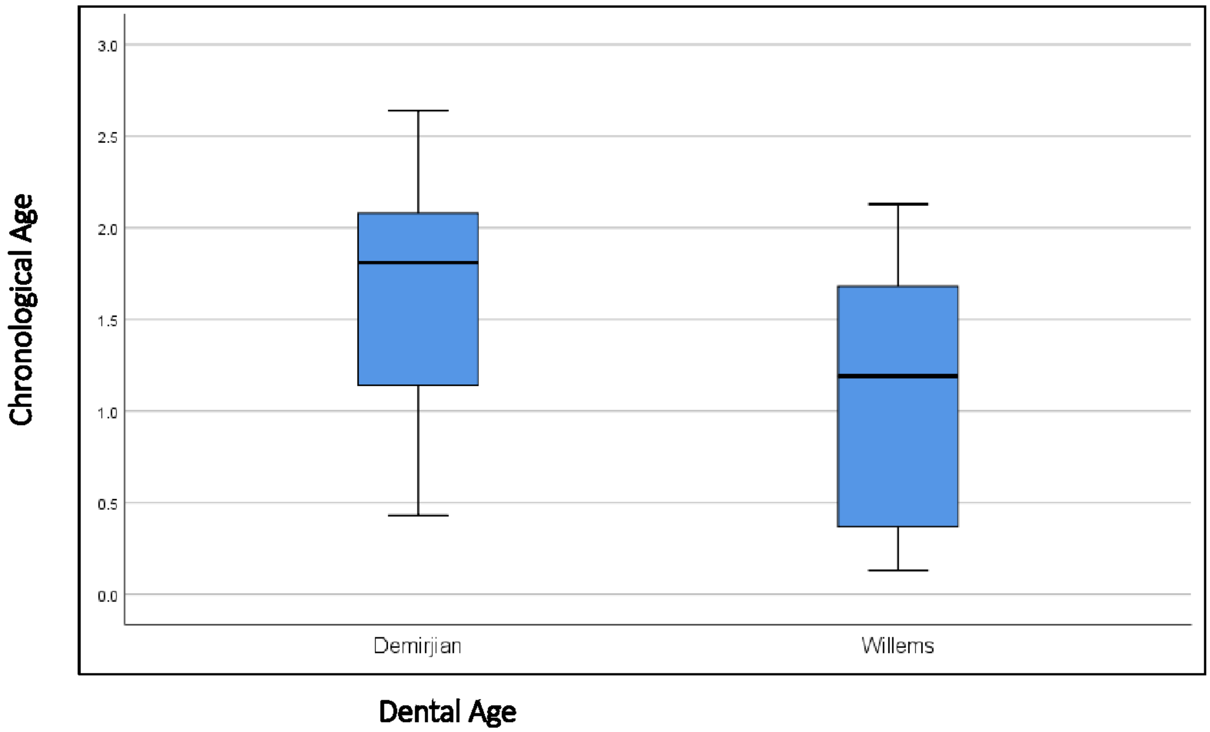

Figure 4.4: Plot box illustrating relationship between Willems and Demirjian method of age assessment

Using box plots for easy visualization of the difference between dental age attained by Demirjian and Willems method. The mean age difference for Willems method was closer to the chronological age (at 0.0 mark) this is more accurate than the Demirjian method.

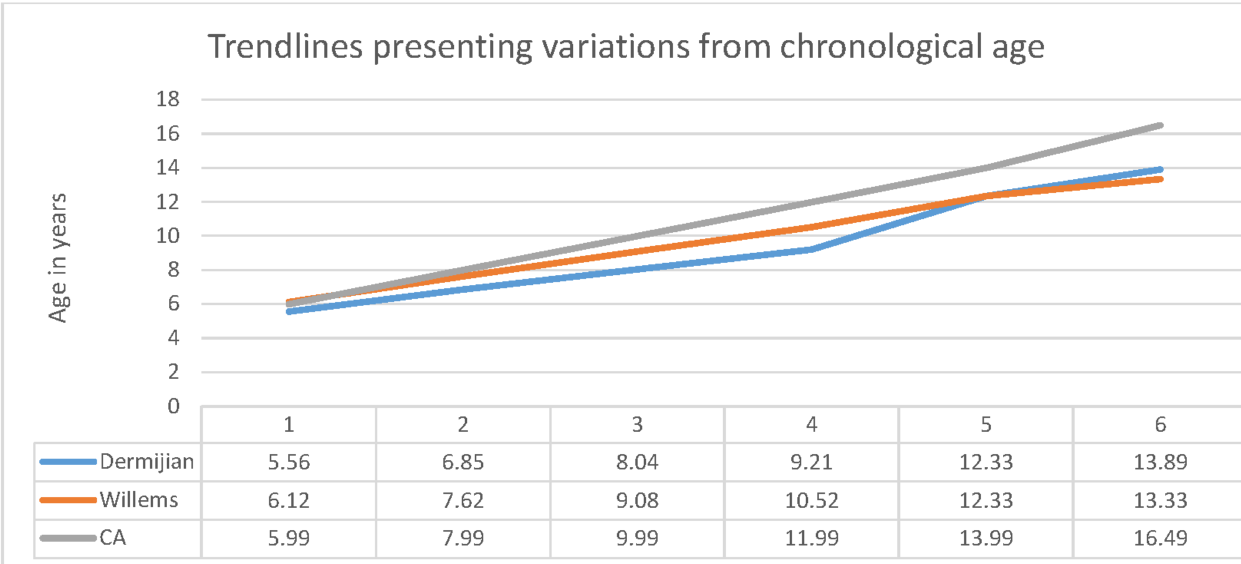

Figure 4.8: Trend lines presenting variations from chronological age

Trend lines depicting the relationship between chronological age and estimated age using Demirjian and Willems method. The results of the paired linear model indicated a wide gap between CA and EA using Demirjian method as compared to using Willems method. In addition, the trend lines also indicate the two methods are more accurate in estimating age in younger children below 10 years as compared to those above 10 years (Figure 4.8)

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Introduction

Dental age estimation has been found to correlate with chronological age more than other maturity standards in the development of children. (Liversidge *et al.*,2014; Panchbhai *et al.,* 2012). Panoramic radiographs are commonly used for dental age estimation because it is convenient and noninvasive. Among the radiographic methods of age estimation, Demirjian and Willems methods has been used widely.

5.2 Socio-demographic characteristics

In the current study, a total of 171 panoramic radiographs of children aged 5 to 17 years were assessed. This age bracket is a recommendation of the American Dental Association Council on Scientific Affairs (2006) where panoramic radiographs are considered for children with an evidence of permanent tooth eruption which likely occurs between 5 to7 years. In addition, children aged 5 years are able to cooperate and sit still for capture of quality digital images unlike those below 5 years who are likely to be unsettled and cause commotion during the procedure thus, leading to inaccurate dental age. The maximum age limit for this study was 17 years as this is the average age where adolescents attain full teeth maturity as evidenced by growth of the third molar (James, 2008).

Of the total radiographs, (54%) were males while (46%) were females (Figure 4.1). The mean chronological age (CA) was 9.11 years which compares closely with studies conducted by Masiga *et al.* (2005) at the University of Nairobi dental Hospital that found a mean age of 9 years. This age group is associated with ugly duckling stage where erupting canines infringe on the roots of the upper lateral incisors causing them to tip laterally resulting into temporal spacing of the upper incisors (Kumar *et al.,* 2014; Manne *et al*., 2012; Tandon, 2008). Therefore, most of the children in this age group are prone to seek further orthodontic intervention.

5.3. Dental age estimation using Demirjian method

The scoring system using Demirjian method of age estimation has a wide application in ascertaining maturity scores of teeth. The maturity scores are obtained by first staging(A-H) the seven left mandibular teeth and then according them values according to the Demirjian conversion tables for boys and girls. The scores are then summed up and converted into dental age. Therefore, to determine the precise age, population specific standards need to be developed (Esan *et al.*, 2017).

In the present study, the dental age was underestimated using Demirjian method for this age cohort. The overall mean age difference between the estimated dental age and the chronological age was 8.16 ±2.7 with a standard error of mean as 0.211 years (Table 4.3). There was an overall underestimation in all the age cohorts with a mean difference of 7.09±3.096 in females and 9.03±2.087 in males (Table 4.4). In the entire sample population, the difference in the estimated dental age varied from 0.957-3.78 in females and 0.655-1.803 in males. The greatest underestimation of dental age in females and males was found both in the 13-14.99-year-old age group (Table 4.4) This revealed that there was advanced dental maturity in the older age groups at puberty stage as opposed to the younger age group). Similarly, varying degrees of underestimation was reported by Mani *et al. (*2008) in children of pubertal age group (13-15 year -old females) and (14-15-year-old males). Mani *et al.* (2008) attributed this to para-pubertal speed fluctuation leading to faster dental maturation. Among females, the deviation from chronological age was ±2.22 years at 95% CI while in males the deviation was ±1.68(Table 4.5). This depicted that the females had a wider margin of error during age estimation as opposed to males. Various literature has also reported that females are generally ahead in tooth formation and emergence as compared to males (Demirjian *et al.,* 1980; Upadhyay *et al.,*2016). Contrary to these results, Rai (2008) reported that the Demirjian method showed high accuracy when applied to Indian children aged 7.5-16 years.

In accordance with the results of the present study, Tunc and Koyuturk (2008) concluded that the Northern Turkish children aged 4-12 years were more advanced in dental maturity since the mean difference between dental and chronological ages of boys and girls varied from 0.36 to 1.43 years and 0.50 to 1.44 years. Similarly, the study of Ivan Galic *et al. (*2010) on Bosnia-Herzegovina showed that children in this study are more advanced in the dental maturity scores when compared to the Demirjian sample. Applicability of the Demirjian method in Kuwait concluded that children had a delay in dental maturity when compared to the present study (Qudeiman and Behbehani, 2009). Similar findings were reported in the study done by Cruz-Landeira and Linares-Argote (2010). In that study, the Demirjian method was tested on Spanish and Venezuelan children and there was an inaccurate estimation for the age of the studied children where there was also delayed dental maturity compared to the French-Canadian population.

These observed differences in the chronological and estimated dental age in the present and previous studies, could be attributed to numerous factors such as; the method of execution, the sample structure (age, sex, ethnicity, nationality and social status), examiners subjectivity and the statistic approach used in obtaining the results (Bagic, 2008). Moreover, there could be a difference in the present day comparisons due to positive secular trends. In summary therefore, the study results revealed an underestimation of age in both females and males using Demirjian method.

5.4. Dental age estimation using Willems method

Willems (2001) method is a modified Demirjian (1973) where scoring was done using same A-H staging technique relying on the left seven mandibular teeth. Once the stages of development for the seven permanent teeth were identified then each tooth stage was accorded new maturity scores according to the Willems conversion tables (Table 2 & 3) and summed up to obtain dental age (Willems *et al.*,2001). Different studies done in various populations have found Willems method to either Under or overestimate the dental age (DA) with an average of 0.6 years (7.2 months or less) (Altalie *et al.,* 2014; Liversidge *et al.*, 2010; Ramanan *et al.*, 2013).

In the present study, the chronological age was underestimated by Willems method for this age cohort (5-17 years). The overall mean difference between dental age and chronological age was 8.94 ±2.264 with a standard error of mean at 0.173 years (Table 4.6). Similar observations were made in 946 children aged 3-16.99 years from Bangladesh and British Caucasian ethnic origin which revealed an overall underestimation of 8.02±0.93 (Maber *et al.,* 2006). In the present study therefore, the overall mean difference between dental age and chronological age was 8.75±2.289 in females and 9.10±2.24 in males using Willems method (Table 4.7).

In the entire sample, the difference in dental age varied from 0.000-1.557 in females and 0.447-1.373 in males. The greatest underestimation in females was found among the cohort aged 11-12.99 years followed by 15-17.99 years and 5-6.99-years. In the males, the greatest underestimation was found in the 9-10.99 followed by 7-8.99- and 5-6.99-year-old age groups (Table 4.6). These findings were also similar to those observed in south Indian children aged 3-15 years where the greatest underestimation in females was found in 8-9.99 years followed by 14-15.99 years and 12-13.99-year-old age groups while in males, the greatest underestimation was found in 14-15.99 years followed by 12-13.99- and 8-9.99-year-old age groups. In the contrary, this population (South Indian children) had an overestimation in the 10-11.99-year-old age group. In addition, before the age of 10 years, the males were more advanced in their dental age compared to the females who took the lead after 10 years (Table 4.7). This gender differences could be attributed to differences in the sample size, method of age calculation, age groups, age and sex distribution of the original study population and statistical methodologies.

In the present study, it was noted that Willems showed a high probability of underestimation in females at 57% than in males at 56 % (Figure 4.5) which is in agreement with studies conducted in North Indian children aged 6-15 years where Willems method underestimated chronological age of 58% females and 56% males (Grover *et al.,* 2011). This is in contrast to studies done among 330 Turkish children aged 5-15 years where Willems performed better in males than females (Rai *et al.,* 2006; Apaydin *et al.*,2018). Among females, the deviation from the chronological age was ±2.062 at 95% confidence while in males the deviation was ±1.95(Figur4.5). This depicted that females had a wider margin of error as opposed to males. Moreover, it was observed that there was a significant delay in the dental maturation of females and males similar to observations seen in South Indian children aged 6-14 years who had a delayed dental maturation of 0.08 years and 0.69 years in females and males respectively. The delay in dental maturity maybe partly explained by population differences, genetic variations, nutritional factors, socio-economic status, dietary habits and lifestyle. Therefore, Willems method was found to perform better in females than in males in age estimation.

5.5. Accuracy of Demirjian and Willems methods in age estimation

Correlation between chronological and dental age is relevant to orthodontics, paediatric dentistry and forensic medicine. These correlations are important addition to patient records (radiographic study models) since they provide basic knowledge on dental development and can be used for further therapeutic decisions.

The mean chronological age for the whole age cohort was 9.11 years while the mean dental age by Demirjian method was 8.16±2.7(Table 4.3) and on comparison, there was no statistical difference. Similarly, the comparison of these parameters was not significant for females and males. However, Nour El Deen *et al.* (2016) found a significant difference between chronological age and Demirjian dental age in the study of Saudi children aged 6-13 years. Among females, the deviation from chronological age was ±2.22 years at 95% CI while in males the deviation was ±1.68(Table 4.5). This depicted that the females had a wider margin of error during age estimation as opposed to males. Various literature has also reported that females are generally ahead in tooth formation and emergence as compared to males (Demirjian *et al.,* 1980; Upadhyay *et al.*,2016). Contrary to these results, Rai, (2008) reported that the Demirjian method showed high accuracy when applied to Indian children aged 7.5-16 years.

The comparison of mean chronological age with Willem's dental age (8.94±2.26) was found not to be significant (Table 4.6). The chronological age was higher as compared to the dental age in Willem's method. Among different age groups, the difference between the dental age and chronological age was found to be increasing as the age group advanced from smaller age group. This suggests that dental age by Willems method is much closer to chronological age in younger children and therefore more accurate for this age cohort. Nevertheless, Van *et al. (*2001) observed an overestimation over the chronological age. Among females, the deviation from the chronological age was ±2.062 at 95% confidence while in males the deviation was ±1.95(Figur4.5). This depicted that females had a wider margin of error as opposed to males. Moreover, it was observed that there was a significant delay in the dental maturation of females and males similar to observations seen in South Indian children aged 6-14 years who had a delayed dental maturation of 0.08 years and 0.69 years in females and males respectively.

The delay in dental maturity maybe partly explained by population differences, genetic variations, nutritional factors, socio-economic status, dietary habits and lifestyle. Therefore, Willems method was found to perform better in females than in males in age estimation. In the present study, there was an underestimation of dental age by both methods over chronological age among females and males. These findings are not in line with Baghdadi who observed overestimation of age among Saudi children especially in the age group of 5-7 years (Baghdadi *et al.,*2014).

In the present study, Pearson's correlation test was used and revealed a strong positive association between the dental age and the chronological age in both methods (r= 0.767) (Table 4.9, 4.10 and appendix II). The findings of this study were similar to those observed in South Indian children aged 3-15 years which showed a significant correlation between dental age and chronological age in both males(r=0.71) and females(r=0.88) and in the entire sample(r=0.78).

It was also noted that Demirjian method had a strong positive association in only two age cohorts (7-8.99 and 9-10.99 years) -(Table 4.9) Alshihri *et al.* (2016) found no strong association between chronological and dental age among these age cohorts using Demirjian method in both genders. On the contrary, Al-Dharrab *et al.* (2017) found an overestimation in boys and underestimation in dental age by Demirjian method in certain age cohorts yet the group of 5-7 years range exhibited underestimation of dental age. Willems had a strong association in four age cohorts (5-6.99, 7-8.99, 9-10.99 and 11-12.99 years). (Table 4.10) This suggests that there could be relative delay in dental maturity related to slow growth pattern during childhood as compared to postnatal growth and pubertal growth. Dental mineralization patterns have shown that early stages of tooth development are almost the same in both genders. However, sexual dimorphism in developmental pace takes place around the completion of tooth crown and prolongs to increase during the stage of root formation. These findings suggest that tooth formation follows the pattern of general growth and may be affected by hormonal changes (Alshihri *et al.*, 2015).

When the difference between the two dental ages was calculated, it was observed that the age by Willems method was underestimated than the age by Demirjian method. Furthermore, their correlations among all parameters were statistically significant(P=<0.05) (Table 4.9, 4.10 & Appendix II). Although both the dental ages in the present study were underestimated, a meta-analysis by Esan *et al.* (2017) suggests that there is overestimation of dental age over chronological age in both the methods. They further observed that Willems method provides more accurate chronological age estimation in various population-based studies, whereas Demirjian method provides insight into maturity scores. Therefore, from the present study, Willems method was found to be more accurate in estimating age among children in western Kenya as compared to Demirjian method.

5.6. Conclusion

There was an overall underestimation using Demirjian method in both females and males.

There was also an overall underestimation of age using Willems method in both gender, however, Willems method performed better in females than males.

There was a significant correlation using both methods, however, Willems method was more accurate than Demirjian method in estimating age among children in western Kenya.

5.7 Recommendation

1. Demirjian method should be combined with other age estimation methods to enhance accuracy.

2. Willems method should be combined with other age estimation methods to enhance its accuracy.

3. There is need to develop specific age estimation methods and scoring guidelines for the Kenyan population to increase accuracy. The current scoring guidelines were developed using Caucasian populace.

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APPENDICES

APPENDIX I:DATA COLLECTION FORM

A. PANORAMIC IMAGES

1. Are the panoramic radiographs present?

TRUE……. Or FALSE………….

2. If 'TRUE 'are they clear and of accepted diagnostic quality? TRUE…. Or FALSE…….

3. If 'TRUE' continue to the next question (4), if 'FALSE 'exclude the radiographs.

4. Do the radiographs have missing permanent teeth on the left mandibular segment? TRUE………. or FALSE…………

5. Do the radiographs have incomplete records with actual ages above 17 years or below 5 years? TRUE …………or FALSE……………………

Type of tooth	Tooth stages (A-H)	Maturity score Demirjian	Estimated age (DA) Demirjian	chronological age	Maturity stage(A-H) Willems	Maturity score Willems	Estimated age Willems	chronological age
Central incisors								
Lateral incisors								
canines								
1st premolar								
2nd premolar								
1st molar								
2nd molar								
TOTALS								

B. ***Figure 3:*** *Tooth development stages as given by Demirjian*

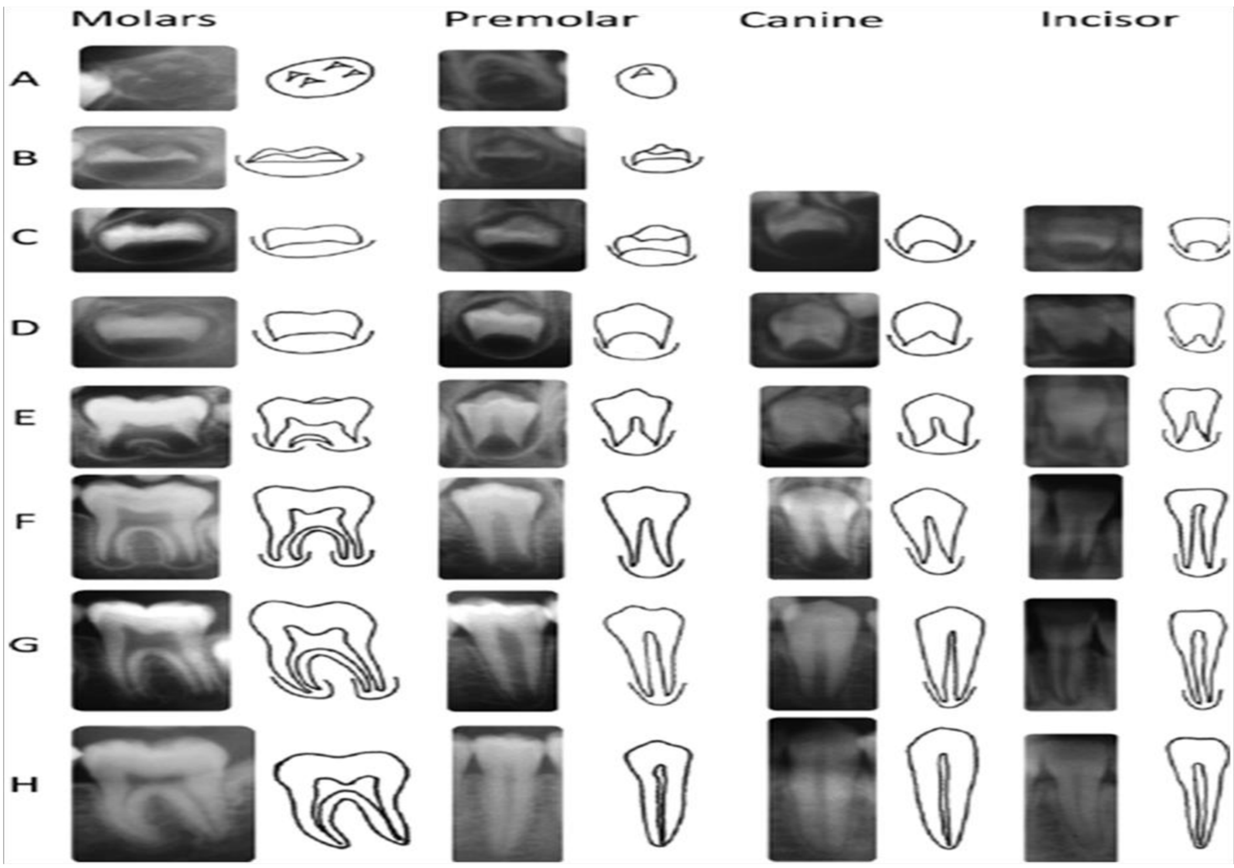

Table 4: *Developmental stages of teeth as given by Demirjian*

A	Calcified cusp tips are not fused.
B	Calcified cusp tips are fused with well-defined occlusal surface outline.
C	Complete formation of enamel at the occlusal surface. Deposition of dentine also commences at this stage.
D	Complete formation of the crown up to the cement-enamel junction. Formation of the roots is visible with the pulp horns beginning to differentiate.
E	Root length is less than crown length, the pulp horns and chambers differentiate further. There is also visible radical bifurcation on the molars.
F	Crown length is equal and greater than root length. Funnel shaped apex is visible.
G	The walls of the root canal are parallel and the apical ends are still open.
H	The apical ends are closed and uniform periodontal ligament space is seen around the tooth

Table 5: *Conversion table for teeth maturity scores in boys as given by Demirjian*

TOOTH	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Central incisor	_	**–**	_	0.0	1.9	4.1	8.2	11.8
Lateral incisors	_	_	0.0	3.2	5.2	7.8	11.7	13.7
Canine	_	_	0.0	3.5	7.9	10.0	11.0	11.9
First premolar	_	0.0	3.4	7.0	11.0	12.3	12.7	13.5
Second premolar	1.7	3.1	5.4	9.7	12.0	12.8	13.2	14.4
First molar	_	_	0.0	8.0	9.6	12.3	17.0	19.3
second molar	2.1	3.5	5.9	10.1	12.5	13.2	13.6	15.4

SECTION D

Table 6: *Conversion table for maturity scores in girls as given by Demirjian*

TOOTH	A	B	C	D	E	F	G	H
Central incisor	_	_	_	0.0	2.4	5.1	9.3	12.9
Lateral incisors	_	_	0.0	3.2	5.6	8.0	12.2	14.2
Canine	_	_	0.0	3.8	7.3	10.3	11.6	12.4
First premolar	_	0.0	3.7	7.5	11.8	13.1	13.4	14.1
Second premolar	1.8	3.4	6.5	10.6	12.7	13.5	13.8	14.6
First molar	_	_	0.0	4.5	6.2	9.0	14.0	16.2
second molar	2.7	3.9	6.9	11.1	13.5	14.2	14.5	15.6

SECTION E.

Table 7: *Conversion from maturity score to dental age for boys as given by Demirjian*

AGE	SCORE	AGE	SCORE	AGE	SCORE	AGE	SCORE	AGE	SCORE
3.1	**12.9**	**6.1**	**34.7**	**9.1**	**84.3**	**12.1**	**94.2**	**15.1**	**97.7**
3.2	**13.5**	**6.2**	**35.8**	**9.2**	**85**	**12.2**	**94.4**	**15.2**	**97.8**
3.3	**14**	**6.3**	**36.9**	**9.3**	**85.6**	**12.3**	**94.5**	**15.3**	**97.8**
3.4	**14.5**	**6.4**	**38**	**9.4**	**86.2**	**12.4**	**94.6**	**15.4**	**97.9**
3.5	**15**	**6.5**	**39.2**	**9.5**	**86.7**	**12.5**	**94.8**	**15.5**	**98**
3.6	**15.6**	**6.6**	**40.6**	**9.6**	**87.2**	**12.6**	**95**	**15.6**	**98.1**

3.7	**16.2**	**6.7**	**42**	**9.7**	**87.7**	**12.7**	**95.1**	**15.7**	**98.2**
3.8	**17**	**6.8**	**43.6**	**9.8**	**88.2**	**12.8**	**95.2**	**15.8**	**98.2**
3.9	**17.6**	**6.9**	**45.1**	**9.9**	**88.6**	**12.9**	**95.4**	**15.9**	**98.3**
4	**18.2**	**7**	**46.7**	**10**	**89**	**13**	**95.6**	**16**	**98.4**
4.1	**18.9**	**7.1**	**48.3**	**10.1**	**89.3**	**13.1**	**95.7**		
4.2	**19.7**	**7.2**	**50**	**10.2**	**89.7**	**13.2**	**95.8**		
4.3	**20.4**	**7.3**	**52**	**10.3**	**90**	**13.3**	**95.9**		
4.4	**21**	**7.4**	**54.3**	**10.4**	**90.3**	**13.4**	**96**		
4.5	**21.7**	**7.5**	**56.8**	**10.5**	**90.6**	**13.5**	**96.1**		
4.6	**22.4**	**7.6**	**59.6**	**10.6**	**91**	**13.6**	**96.2**		
4.7	**23.1**	**7.7**	**62.5**	**10.7**	**91.3**	**13.7**	**96.3**		
4.8	**23.8**	**7.8**	**66**	**10.8**	**91.6**	**13.8**	**96.4**		
4.9	**24.6**	**7.9**	**69**	**10.9**	**91.8**	**13.9**	**96.5**		
5	**25.4**	**8**	**71.6**	**11**	**92**	**14**	**96.6**		
5.1	**26.2**	**8.1**	**73.5**	**11.1**	**92.2**	**14.1**	**96.7**		
5.2	**27**	**8.2**	**75.1**	**11.2**	**92.5**	**14.2**	**96.8**		
5.3	**27.8**	**8.3**	**76.4**	**11.3**	**92.7**	**14.3**	**96.9**		
5.4	**28.6**	**8.4**	**77.7**	**11.4**	**92.9**	**14.4**	**97**		
5.5	**29.5**	**8.5**	**79**	**11.5**	**93.1**	**14.5**	**97.1**		
5.6	**30.3**	**8.6**	**80.2**	**11.6**	**93.3**	**14.6**	**97.2**		
5.7	**31.1**	**8.7**	**81.2**	**11.7**	**93.5**	**14.7**	**97.3**		
5.8	**31.8**	**8.8**	**82**	**11.8**	**93.7**	**14.8**	**97.4**		
5.9	**32.6**	**8.9**	**82.8**	**11.9**	**93.9**	**14.9**	**97.5**		
6	**33.6**	**9**	**83.6**	**12**	**94**	**15**	**97.6**		

SECTION F

Table 8: *Conversion from maturity score to dental age for girls as given by Demirjian*

AGE	SCORE	AGE	SCORE	AGE	SCORE	AGE	SCORE
3.0	13.7	7.0	51.0	11.0	94.5	15.0	99.2
.1	14.4	.1	52.9	.1	94.7	.1	99.3
.2	15.1	.2	55.5	.2	94.9	.2	99.4
.3	15.8	.3	57.8	.3	95.1	.3	99.4
.4	16.6	.4	61.0	.4	95.3	.4	99.5
.5	17.3	.5	65.0	.5	95.4	.5	99.6
.6	18.0	.6	68.0	.6	95.6	.6	99.6
.7	18.8	.7	71.0	.7	95.8	.7	99.7
.8	19.5	.8	75.0	.8	96.0	.8	99.8
.9	20.3	.9	77.0	.9	96.2	.9	99.9
4.0	21.0	8.0	78.8	12.0	96.3	16.0	100.0
.1	21.8	.1	80.2	.1	96.4		
.2	22.8	.2	81.2	.2	96.5		
.3	22.5	.3	82.2	.3	96.6		
.4	23.2	.4	83.1	.4	96.7		
.5	24.0	.5	84.8	.5	96.8		
.6	24.8	.6	84.8	.6	96.9		
.7	25.6	.7	85.3	.7	97.0		

.8	26.4		86.1	.8	97.1		
.9	27.2	.9	86.7	.9	97.2		
5.0	28.0	9.0	87.2	13.0	97.3		
.1	28.9	.1	87.8	.1	97.4		
.2	29.7	.2	88.3	.2	97.5		
.3	30.5	.3	88.8	.3	97.6		
.4	31.3	.4	89.3	.4	97.7		
.5	32.1	.5	89.8	.5	97.8		
.6	33.0	.6	90.2	.6	98.0		
.7	34.0	.7	90.7	.7	98.1		
.8	35.1	.8	91.1	.8	98.2		
.9	36.8	.9	91.4	.9	98.3		
6.0	37.0	10.0	91.8	14.0	98.3		
.1	38.0	.1	92.1	.1	98.4		
.2	39.1	.2	92.3	.2	98.5		
.3	40.2	.3	92.6	.3	98.6		
.4	41.3	.4	92.9	.4	98.7		
.5	42.5	.5	93.2	.5	98.8		
.6	43.9	.6	93.5	.6	98.9		
.7	46.7	.7	93.7	.7	99.0		
.8	48.0	.8	94.0	.8	99.1		
.9	49.5	.9	94.2	.9	99.1		

SECTION G

Table 9: *Conversion table for maturity scores in boys as given by Willems*

TOOTH	A	B	C	D	E	F	G	H
Central incisor	_	_	1.68	1.49	1.5	1.86	2.07	2.19
Lateral incisors	_	_	0.55	0.63	0.74	1.08	1.32	1.64
Canine	_	_	_	0.04	0.31	0.47	1.09	1.9
First premolar	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
Second premolar	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

SECTION: H.

Table 10: *Conversion table for maturity scores in girls as given by Willems*

TOOTH	A	B	C	D	E	F	G	H
Central incisors	_	_	1.83	2.19	2.34	2.82	3.19	3.14
Lateral incisors	_	_	_	0.29	0.32	0.49	0.79	0.7
Canine	_	_	0.6	0.54	0.62	1.08	1.72	2
First premolar	-0.95	-0.15	0.16	0.41	0.6	1.27	1.58	2.19
Second premolar	-0.19	001	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

APPENDIX II: PEARSON'S CORRELATIONS.

Correlations

		Gender	Age Cohort	CA	DA	CA-DA
Gender	Pearson Correlation	1	.006	.005	-.069	.065
	Sig. (2-tailed)		.941	.951	.368	.400
	Sum of Squares and Cross-products	42.573	1.327	1.083	-9.876	10.960
	Covariance	.250	.008	.006	-.058	.064
	N	171	171	171	171	171
Age Cohort	Pearson Correlation	.006	1	.998**	.678**	.777**
	Sig. (2-tailed)	.941		.000	.000	.000
	Sum of Squares and Cross-products	1.327	1256.187	1237.937	524.429	713.508
	Covariance	.008	7.389	7.282	3.085	4.197
	N	171	171	171	171	171
CA	Pearson Correlation	.005	.998**	1	.673**	.782**
	Sig. (2-tailed)	.951	.000		.000	.000
	Sum of Squares and Cross-products	1.083	1237.937	1223.622	514.275	709.347
	Covariance	.006	7.282	7.198	3.025	4.173
	N	171	171	171	171	171
DA	Pearson Correlation	-.069	.678**	.673**	1	.067
	Sig. (2-tailed)	.368	.000	.000		.387
	Sum of Squares and Cross-products	-9.876	524.429	514.275	476.593	37.682
	Covariance	-.058	3.085	3.025	2.803	.222
	N	171	171	171	171	171
CA-DA	Pearson Correlation	.065	.777**	.782**	.067	1
	Sig. (2-tailed)	.400	.000	.000	.387	
	Sum of Squares and Cross-products	10.960	713.508	709.347	37.682	671.665
	Covariance	.064	4.197	4.173	.222	3.951
	N	171	171	171	171	171

**. Correlation is significant at the 0.01 level (2-tailed).