A Comparison of the dental age estimation methods of Phillips and Proffit in a sample of South African Children at the Tygerberg Dental Faculty

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Dr. ALYA ISAM ELDIN GAFAR ELGAMRI

Student number: 3410883

Supervisor: Dr. Nadia Mohamed

Co-supervisor: Dr. Athol Hudson

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Alya Isam Eldin Gafar Elgamri

KEYWORDS

Dental age

Physiological age

Chronological age

Estimation

Comparison

Proffit

Phillips tables

Panoramic radiograph

ABSTRACT

Background

Dental age is an indicator of the physiological maturity of growing children. Different methods for estimating the dental age in comparison to the chronological age were proposed in the literature.

Objective

The aim of this study was to compare the accuracy of two methods i.e. the Phillips and Proffit methods in estimating the dental age in a sample of South African children at the Tygerberg dental faculty.

Methods

A retrospective study was conducted by randomly selecting 100 panoramic radiographs with known chronological age. The sample contained an equal number of girls and boys (50 in each group) and the chronological age ranged between 6 and 11 years. Dental age for each radiograph was estimated using the Phillips and the Proffit methods respectively. The mean difference between dental and chronological age was calculated. Dental and chronological ages were compared using overall bias and random errors.

Results

The results showed that for the girls' sample, the Phillips method underestimated the age by 4 months which is statistically significant (p-value =0.03). The Proffit method underestimated the age by 2 days which is not statistically significant (p-value =0.97). Both methods however have the same frequency of random errors.

For the boys' sample, Phillips' method underestimated the age by 6 months which is statistically significant (p-value <0.0001). Proffit's method underestimated the age by 2 months which is not statistically

significant (p-value= 0.15). The Phillips method was shown to have fewer random errors in boys.

Discussion

The above mentioned results showed that for dental age estimation for girls, Proffit's method would be more appropriate. This rationale is explained by the conclusion that it only underestimates the age by 2 days and has the same frequency of random errors as Phillips' method. However, if one had to choose between the two methods for boys, the situation should be evaluated carefully. For boys, the Phillips method has fewer random errors but a larger overall bias (6 months) whereas Proffit's method has more random errors but less overall bias (2 months). The choice between the two methods should therefore depend on the purpose of the estimation. If the method is used for estimating the age in a single individual with an unknown chronological age, Phillips' method would be more preferable. However, if the method is used for age estimation in populations with a known mean chronological age, Proffit is preferred.

Conclusion

Proffit's description for dental development has been shown to be accurate in estimating the DA. It may therefore be considered to be a legitimate DA estimation method and not just a developmental description for the dentition.

November 2015

DECLARATION

I declare that "A comparison of the dental age estimation methods of Phillips and Proffit in a sample of South African children at the Tygerberg Dental Faculty", is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Alya Isam Eldin Gafar Elgamri

November 2015

Signed: . 

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Finally, I wish to extend my gratitude to **Professor Phillips** for his assistance.

DEDICATION

To my everything

My mother Mahasin & My father Issam

To my knights

Ammar, Amro & Abdelghafor

To my joy

Hyam

To my rock

Omer

Nothing could have been possible without your endless love and support

Thank you

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LIST OF ABBREVIATIONS

DA: Dental age

MFH: Moorrees, Fanning and Hunt

SD: Standard deviation

CI: Confidence intervals

N: Number of cases

Prob. 1: The proportion of errors smaller than one

LIST OF ADDENDA

CHAPTER 1
INTRODUCTION

Age is an important evaluation tool in human biology (Smith, 1991). There are essentially two types of age, namely, chronological age and physiological age. Chronological age is also called calendric age and is defined as "the time elapsed after birth to death" (Engel, 2004). It is often described in days, weeks, months and/ or years (Engel, 2004). Physiological age is also known as developmental or biological age and refers to the age of the tissue system e.g. the skeletal system or the dentition (Smith, 1991). Unlike chronological age, physiological age is not uniform among different individuals (Moorrees *et al*., 1963). Thus, the importance of assessing age is to consider the chronological age as a reference point and to compare it to the physiological age in order to assess the maturity status of tissue systems (Phillips, 2008).

Numerous methods have been proposed in the literature to estimate the physiological age, i.e. somatic, skeletal, sexual and dental ages (Demirjian *et al*., 1985). Dental age (DA) is defined as "the morphological state of an individual's dentition without reference to their actual age'' (Grover *et al*., 2012). When compared to somatic, skeletal and sexual ages, DA was found to be less variable in assessing age from 5 months intra- uterine to 15 years of age (Demirjian *et al.*, 1985). It was found that DA is more resistant to environmental changes such as developmental insults and hormonal changes (Townsend & Hammel, 1990; Garn *et al*., 1965). DA is therefore considered to be the best indicator of chronological age in children (Smith, 1991).

DA estimation has been used in medico-legal issues as well as in dentistry. In medico-legal aspects, DA estimation is a valuable tool for estimating the age of unknown individuals such as illegal immigrants and people who have lost their birth certificates (Crossner & Mansfeld, 1983). It also plays an important role in determining the eligibility of adolescents for certain activities such as obtaining driving licenses and voting (Hag-Mahmoud, 2012). Furthermore, the age of

children is an important determining factor which can influence the court's decision regarding custody in divorce cases, especially in instances where the parents' claims differ (Hag-Mahmoud, 2012). Age estimation is primarily requested for the recruitment of adolescents for military services especially in developing countries and in juveniles who are accused of committing major crimes such as murders and rape (Hag-Mahmoud, 2012). Inaccurate age estimation will have major legal consequences in all of the above-mentioned aspects (Hag-Mahmoud, 2012).

Applications of DA in dentistry differ, depending on the field of investigation. In forensic dentistry, DA is a vital tool in narrowing the investigation range and in identifying skeletal remains (Phillips, 2008). In clinical dentistry (e.g. paediatric dentistry and orthodontics), DA estimation is important for diagnosis and treatment planning since children with the same chronological age can be at different maturation stages. Accordingly, different treatment strategies are proposed for different stages of maturity e.g. after extraction of a primary tooth, the need for space maintenance cannot be determined without knowing the DA of the child (Proffit *et al*., 2007). DA is useful in evaluating the overall growth and maturation of the patient to determine the best time for intervention in order to stop the development of dental problems especially in interceptive orthodontics (Proffit *et al*., 2007). Furthermore, DA estimation is used for educational purposes such as teaching the concept of dental development at universities and academic institutions (Hillson, 1996).

DA can be estimated by two different approaches, i.e. by using tooth eruption or tooth formation (Demirjian, 1978). DA estimation by tooth eruption is achieved by examining the mouth and estimating the age according to the teeth that are present or absent. The most common DA estimation method using this approach is the well-known diagram published by Schour and Massler (1944). This diagram was based on a small number of children and divided the dental development into 22 stages. Later, Buikstra and Ubelaker (1994) published a new chart based on the

American population and this was recognized as the standard reference for eruption throughout the world (Phillips, 2008).

Studies evaluating DA estimation using the above mentioned charts reported that estimating the DA according to tooth eruption is simple, quick, economical and fairly non-invasive because it only involves looking inside the child's mouth (Gillett, 1998; Moorrees & Kent, 1978). However, it was found to be not completely accurate (Phillips, 2008) because eruption is a continuous process starting inside the bone and continuing until the appearance of the first sign of occlusal wear (Hillson, 1996; Haavikko, 1974). Therefore, the use of a single event like the emergence of the tooth through the gingiva to represent a continuous process i.e. tooth eruption, is not expected to be accurate (Smith, 1991).

Tooth eruption can be affected by local factors such as thickening of the oral mucosa, lack of space, presence of eruption cysts and systemic factors such as nutritional status and endocrine problems (Alvarez & Navia, 1989; Infante & Owen, 1973). Tooth eruption may differ between populations because of the variations in ethnic background and genetic make-up (Lewis & Garn, 1960). Clinically, estimating the DA by tooth eruption may be challenging because there is a period when the child has no teeth erupting into the oral cavity (Leurs *et al*., 2005). Tooth formation was therefore suggested as an alternative approach to estimate the DA.

Tooth formation includes secretion of organic matrix, mineralization and maturation (Garn *et al*., 1965). The formation of teeth through different morphological stages can be visualized on radiographs (Logan & Kronfeld, 1933). Each stage of tooth development is given a certain score and from these scores DA can be calculated. These systems are thus called scoring systems (Smith, 1991). The most common DA estimation methods using scoring systems are the Moorrees, Fanning and Hunt method (1963), Demirjian, Goldstein and Tanner method (1973) and Gustafson and Koch chart (1974).

Although scoring systems are more complicated, time consuming and labour intensive than tooth eruption, they are more accurate in estimating the DA (Alvarez and Navia, 1989). Tooth formation is under genetic control. It is therefore more resistant to environmental changes such as trauma and nutritional status (Lavelle, 1976). Furthermore, scoring systems use the summation of the developmental stages from different teeth which reduces the chance of errors when compared to using a single event such as tooth eruption (Demirjian *et al*., 1973).

CHAPTER 2
LITERATURE REVIEW

The idea behind using a 'method' to estimate the DA is to either predict the closest point to the chronological age or to assess the maturation stage of the individual (Cameriere *et al*., 2008). In order to test the accuracy of the DA estimation methods, studies made use of populations with known chronological age to determine how close the tested method could predict the real age (Phillips, 2008).

In 1963, the Moorrees, Fanning and Hunt (MFH) method, which was derived from radiographs of American children, was published. It consisted of a chart illustrating the developmental stages of permanent tooth formation from the canine to the third molar where the average age of each stage was noted (Moorrees *et al*., 1963). Smith (1991) reworked the Moorrees data and questioned the accuracy of the MFH charts when applied to non-American children. Furthermore, the standard deviations (SD) of each developmental stage were too broad to estimate the age correctly (Smith, 1991).

The MFH method was followed by the Demirjian method. Demirjian, Goldstein and Tanner (1973) published a method which was based on radiographs from French-Canadian populations. Demirjian's tables illustrated the developmental stages of seven mandibular teeth. The incisors were included but the third molar was excluded. Weighted scores were assigned to each developmental stage. The summation of the scores indicated a maturity index which could be converted to chronological age using the tables (Demirjian *et al*., 1973). This method is considered to be the most popular method of DA estimation (Maber *et al*., 2006).

Due to its publicity, the Demirjian method generated a large debate in the literature regarding its accuracy when applied to populations other than the French-Canadian populations. It was found to be accurate in estimating the DA when used in Romanian and Australian populations for most age groups

(Ogodescu *et al*., 2011; Farah *et al*., 1999). However, it failed to estimate the DA accurately when tested in populations from South Africa, Brazil, India, Venezuela, Turkey, western China, Egypt, Malaysia, republic of Macedonia, Pakistan and Saudi Arabia (Phillips & Van Wyk Kotze, 2009b; Eid *et al*., 2002; Grover *et al*., 2012; Feijóo *et al*., 2012; Cruz-Landeira *et al*., 2010; Nur *et al*., 2012; Li *et al*., 2012; El-bakary *et al*., 2010; Mani *et al*., 2008; Ambarkova *et al*., 2014; Sukhia *et al*., 2012; Baghdadi & Pani, 2012).

In 1974, Gustafson and Koch developed another method by using a collection of radiological, anatomical and eruption data to construct a 'tooth developmental diagram' which represents tooth formation and eruption (Gustafson & Koch, 1974). When compared to Demirjian's method in a German population, Gustafson and Kochs' method showed a large intra-observer and inter-observer error which could limit its use in epidemiological studies (Olze *et al*., 2005).

Demirjian's method was re-visited by Willems (2001). Willems used data from a Belgian population sample and simplified Demirjian's table by eliminating the maturity index and direct conversion of the developmental stages into dental ages (Willems *et al*., 2001). Willems' method was compared to different methods namely, Demirjian, Nolla, and Haavikko in Bangladeshi and British Caucasian populations and it was found to be the most accurate method in these populations (Maber *et al*., 2006).

A more recent method was suggested by Cameriere in 2006 where a computer program was used to analyse panoramic radiographs in an Italian sample. A relationship was then constructed between age and the measurement of open apices in immature teeth (Cameriere *et al*., 2006). Cameriere's method was tested in European populations and was found to be more accurate than the Demirjian and Willems methods (Cameriere *et al*., 2008). Cameriere's method can however only estimate the DA of younger children accurately because it is dependent on the open apices of immature teeth (Cameriere *et al*., 2006).

Most of the DA estimation methods did not distinguish between boys and girls. The reason for this is that these methods were originally designed for forensic purposes where the gender of the remains was mostly unknown (Phillips, 2008).

The difference in maturation between girls and boys is an accepted fact in the literature (Demirjian & Levesque, 1980). This difference is due to biological, developmental and hormonal variations between the two genders (Al-Emran, 2008). Girls are found to be more advanced than boys in general maturity parameters such as height (Al-Shehri *et al*., 2007), sexual maturation (Prahl-Andersen *et al*., 1979), and skeletal development (Van Venrooij-Ysselmuiden & Van Ipenburg, 1978). Studies on dental development have found girls to be between one and six months ahead of boys in dental maturation (Demirjian & Levesque, 1980). The majority of the studies which tested the accuracy of DA estimation reported variations in the values obtained for over- and underestimation in boys and girls for various DA methods. These values are however unpredictable. Where a method may overestimate the age of girls in a particular population, the same method can underestimate the age of girls in a different population (Eid *et al*., 2002; Mani *et al*., 2008; El-Bakary *et al*., 2010; Feijóo *et al*., 2012).

Although there is extensive literature using the above-mentioned methods, these studies are difficult to review and compare. This is due to the diversity in age groups, age distribution across the groups, ethnic origin of the studied populations, sample size and statistical analysis (Olze *et al*., 2005). Some studies have evaluated the accuracy of a single method while others have looked at the combination of several methods (Crossner & Mansfeld, 1983; Mornstad *et al*., 1995). Furthermore, some studies were conducted in living children while others were conducted on skeletal remains. All these factors contributed to the difficulty in reaching a consensus on which was the best method for DA estimation (Liversidge, 1994; Rai & Anand, 2006).

Furthermore, the validity of all of the above-mentioned methods should be examined very carefully before using them to estimate DA. These methods were based on specific populations i.e. the reference population which has its own ethnic complexity and background (Phillips & van Wyk Kotze, 2009b). Therefore, using these methods in different populations will always carry the risk of inaccuracy (Olze *et al*., 2005).

To overcome the risk of inaccuracy due to the differences in ethnicity, population-specific tables were suggested to match the diversity of each population group rather than using the standard age estimation methods such as Demirjian and MFH blindly in all populations (Baghdadi, 2013; Almeida *et al*., 2013; Sukhia *et al*., 2012).

Specific tables were generated for each population in the following countries: Southern Finland, India, Korea, Saudi Arabia, Pakistan and South Africa (Kataja *et al*., 1989; Koshy & Tandon, 1998; Sarker *et al*., 2013; Lee *et al*., 2011; Baghdadi, 2013; Sukhia *et al*., 2012; Phillips & van Wyk Kotze, 2009a). These specific tables were tested in their own reference populations and found to be more accurate than standard methods. For example, Baghdadi's tables (2013) were compared to Demirjian's method in Saudi populations, and were found to be more accurate. Similarly, Phillips' tables were found to be more accurate in the South African population when compared with the Demirjian and MFH methods (Phillips & van Wyk Kotze, 2009b).

The main limitation of population-specific tables is that they are constructed from limited sample sizes which are not enough to overcome the intra-population variability and multi-ethnicity within a single population (Baghdadi & Pani, 2012; Sarkar *et al*., 2013). More studies are therefore needed to calibrate and test the accuracy of these tables in their reference populations before they can be recommended as an accurate method for DA estimation (Sarkar *et al*., 2013; Li *et al*., 2012).

The Phillips tables (Phillips & van Wyk Kotze, 2009a) are population-specific tables which were designed to match the diversity of the South African population. Phillips generated these tables after the series of murders which took place in Cape Town in 1980's where 18 children were murdered (Phillips, 2008). The bodies of these children were discovered after 3 years and their identification required multiple investigations because they were decomposed. Age estimation of the remains was one of the most important steps during the investigation. Different age estimations were carried out i.e. skeletal, sexual and dental. In order to estimate the DA of these children, forensic scientists used the Demirjian and MFH methods (Phillips, 2008). However, the results of these estimations turned out to be inaccurate and this complicated the course of the investigation. This incident highlighted the need for DA estimation tables which are specific and accurate in the South African population (Phillips, 2008).

Phillips' tables were published in 2009 and consisted of 3 tables (Tygerberg, Indian and Nguni) derived from 1476 panoramic radiographs of South African children from different ethnic groups (White, Coloured, Indian and Black) in Cape Town. The sample was not separated according to gender. Phillips' tables were based on the same developmental stages as the MFH method, namely, cusp initiation, cusp coalescence, cusp outline completion, crown half formation, crown three quarters formation, crown complete formation, root initiation, cleft initiation (molars only), root one quarter formation, root half formation, root three quarters formation, root completion, apex one half completion and apex completion (Appendix A). The tables were designed for 8 mandibular teeth i.e. central and lateral incisors, canine, first premolar, second premolar, first molar, second molar and third molar (Phillips & van Wyk Kotze, 2009a).

Phillips' tables were tested in a sample of South African children and adolescents, between the ages of 3 and 16 years. The study used three different age estimation methods, namely, Demirjian, MFH and Phillips' tables. Phillips' tables were found to be the most accurate method for DA estimation if the ethnic origin is

known i.e. White, Coloured, Indian and Black (Phillips & van Wyk Kotze, 2009b).

Phillips' tables were also tested in a Sudanese Arab population where the study sample comprised 204 panoramic radiographs (with an equal number of boys and girls). They ranged in age from 6 to 16 years and were divided into 10 age groups. Demirjian's method and Phillips' tables (Tygerberg, Indian and Nguni) were used to estimate the DA of each radiograph. The results demonstrated that the Tygerberg table was the most accurate method for estimating the DA. However, it overestimated the age of girls by 2.5 months and underestimated the age of boys by 1 month (Hag-Mahmoud, 2012). The author mentioned that the over- and underestimation were due to the differences in the ethnic background between the Sudanese sample and the South African populations for which the tables were constructed. He however recommended the use of Phillips' Tygerberg table for DA estimation in the Sudanese population after applying a corrective equation to compensate for the overall bias (Hag-Mahmoud, 2012).

Phillips' tables are relatively new but there is evidence to support their use in the South African population. The main advantage of Phillips' tables over the other methods is that they were derived from different ethnic groups and are more representative of the South African population (Philips & van Wyk Kotze, 2009a).

The Proffit description for DA has been widely accepted in academia because it is simple and straightforward. It has been used frequently as a teaching tool to explain the concept of DA to dental students at universities throughout the world (including University of the Western Cape). It is a mixed approach which combines the advantages and disadvantages of the previously mentioned DA estimation methods (Proffit *et al*., 2007). It uses tooth eruption but also evaluates tooth formation and mineralization on a radiograph (Proffit *et al*., 2007).

Proffit divided the development of the dentition into several dental ages which are described according to three major conditions, namely, teeth that have erupted, the

amount of root resorption of primary teeth and the amount of development of the permanent teeth (Proffit *et al*., 2007).

Proffit suggested eight (8) stages from DA six (6) to DA fifteen (15) (Proffit *et al*., 2007). He stated that the eruption of the mandibular centrals and upper and lower first molars occur at 6 years of age. At 7 years, the main event is the eruption of the maxillary central and mandibular lateral incisors with the crown of the canine and premolars starting to form on the radiograph. At DA 8 years, the clinical appearance of the maxillary lateral incisor is the only observation which extends into the clinical latency period. This lasts for 2 or 3 years (Proffit *et al*., 2007).

DA 9 and 10 are only visible on the radiograph. At the age of 9, a third of the root formation of the mandibular canine and first premolar are present. The root of the maxillary canine, first and second premolars also start to form. At DA 10, the root formation advances from a third to a half in the mandibular teeth and in the maxillary first premolar, with completion of mandibular incisors roots (Proffit *et al*., 2007). DA 11 is a clinical stage where the eruption of the mandibular canines, first premolar and maxillary first premolar occurs. At DA 12 years, all the remaining succedneous teeth erupt and finally DA 13, 14 and 15 will show complete root formation of the above teeth (Proffit *et al*., 2007).

Although, Proffit's DA estimation has been used in dental faculties of South African universities including UWC, it has never been considered to be a DA estimation method per se. It has therefore never been tested scientifically against any of the other methods.

The only method for DA estimation that has been tested and proven to be accurate in the South African population is Phillips' method (Philips & van Wyk Kotze, 2009a; Philips & van Wyk Kotze, 2009b).

The question was raised regarding the reliability of teaching Proffit's DA estimation description as a gold standard at universities while there is no evidence to support its accuracy. This study was therefore designed to test the accuracy of the theoretical description of DA stages provided by Proffit and adopted by the universities against the Phillips' method which is the most accurate and scientifically tested method in South African children. The results of this study should either support the universities' policy by providing them with scientific evidence for the use of Proffit's method or by recommending some changes in the curriculum.

CHAPTER 3
AIMS AND OBJECTIVES

3.1.Aim

To compare the accuracy of the Phillips and Proffit methods of estimating the dental age from panoramic radiographs in a sample of patients presenting at the Department of Paediatric Dentistry at the Tygerberg dental faculty.

3.2.Objectives

- To determine which method is more accurate in estimating the DA in the selected group of patients.
- To investigate if there is any significant difference between the DA estimation of girls and boys.

3.3.Null hypothesis

There is no difference in the accuracy of Proffit and Phillips' age related tables when applied to a sample of South African paediatric patients.

CHAPTER 4
MATERIALS AND METHODS

4.1.Study design

A retrospective cross-sectional study was carried out.

4.2.Study population and sample size

The study population consisted of the available panoramic radiographs taken from the records database of the Department of Paediatric Dentistry (University of the Western Cape). The sample size consisted of 100 radiographs which were divided into 5 age groups between the ages of 6 and 10 years. Each age group contained 20 radiographs i.e. 10 boys and 10 girls.

4.3.Sampling strategy

Patients report to the dental faculty in a random order and thus the radiographs are also stored in a random order. Records are saved as patient cases. Panoramic radiographs were sorted according to chronological age and sex by someone other than the researcher. The age at the last birthday was taken as the chronological age for purposes of sorting the radiographs initially. Panoramic radiographs that met the inclusion criteria were selected.

4.3.1. Inclusion criteria

- Good quality panoramic radiographs.
- Patients with a chronological age between 6 and 10 years.
- The date on which the panoramic radiographs were taken had to be recorded.
- There also needed to be information regarding the gender and date of birth.

4.3.2. Exclusion criteria

- Radiographs of poor quality.
- Radiographs with gross pathology.
- Bilateral congenitally missing permanent teeth. If a tooth was only absent on one side, the contralateral tooth was assessed. If teeth were absent bilaterally, the radiograph was excluded.

4.4.Ethical considerations

The protocol was submitted to the Senate Research Ethics Committee of the University of the Western Cape for approval. Permission to carry out the study was received (Ethics approval reference number: 14/9/3).

Privacy of the participant data found in the folders was respected and confidentiality was strictly maintained. Patient names were not used; rather case numbers were assigned to ensure patient anonymity and confidentiality. No direct patient evaluation was done in this study. Only panoramic radiographs of patients were used. Informed consents would have already been obtained during the initial clinical evaluation. Permission was sought from the superintendent of the facility to access patient records.

Records of folder numbers, chronological age and sex were kept separately. The primary researcher (the author) did not know the chronological age or gender of the child during the data collection phase. After the DA was estimated, the chronological age and gender were included in the data capture sheet.

4.5.Dental radiographs

All dental radiographs used in the study were soft copies of panoramic radiographs. The panoramic radiographs were saved as JPEG image files and were viewed using the Photo gallery programme. This enabled auto corrections, contrast, colour adjustment and zooming if necessary.

4.6.Data collection

Data collection was done using two forms i.e. one for each DA estimation method (See Appendices C and D). Each panoramic radiograph was assessed using both the Phillips and Proffit criteria for DA as described below.

4.6.1. Application of Phillips' method for DA estimation

Of the three different age related tables that Phillips constructed for a sample of South African children, only the Tygerberg table was used in this study (Appendix A). This table was derived originally from the archival records of patients treated at Tygerberg hospital.

The developmental stage for each tooth was determined from either the right or left mandibular quadrant of each panoramic radiograph according to the quadrant which was clearer. Only teeth with open apices were used to estimate the DA.

In cases where a tooth (e.g. lateral incisor) was unclear in both quadrants, the unclear tooth was excluded because according to Phillips, omitting a single tooth will not affect the average of the DA (Phillips, 2008). In cases where early loss of primary teeth was evident, the non-extraction side was used. Some teeth presented as an intermediate developmental stage. If there was no clear-cut answer, the more advanced stage was calculated. In cases where the investigator was in doubt between two different developmental stages, Professor Phillips was consulted in person to determine the correct stage.

The DA related to the assigned developmental stage for each tooth was determined from Phillips' Tygerberg table. The sum of the dental ages of all the teeth in the quadrant was calculated and then divided by the number of teeth examined. The number obtained was recorded as the DA of the patient according to Philips' table.

4.6.2. Application of Proffit's method for DA estimation

The DA was also estimated according to Proffit's description as described in the literature review (Refer to Chapter 2 page 11). These developmental ages were arranged in a descriptive table (Appendix B). This was used as guide for age estimation using Proffit's method.

4.6.3. Calculation of actual chronological age

The date of birth was subtracted from the date on which the radiograph was taken. The calculation gave the age in years. The age was approximated to two decimal points.

4.7.Validity and reliability

The sample was only examined by the author who was blinded as to the chronological age and the gender of the child when estimating the DA. Twenty percent of the sample was re-examined after 2 weeks for intra-observer reliability. Calibration of the author was done personally with Professor Phillips.

4.8.Data analysis

The data was entered into a Microsoft Excel 2010 spreadsheet.

4.8.1. Statistical analysis

Data was analyzed statistically using (Stata software version 14). Descriptive statistics were calculated for the quantitative variables as mean, standard deviation and upper and lower 95% confidence intervals (CI).

4.8.2. Accuracy evaluation

The accuracy of the tested methods in this study was defined by how closely the estimated DA was to the chronological age.

The DA recorded using each of the two methods was subtracted from the chronological age. A positive number was considered to be an overestimation while a negative number was considered an underestimation.

CHAPTER 5

RESULTS

5.1.Intra-observer reliability

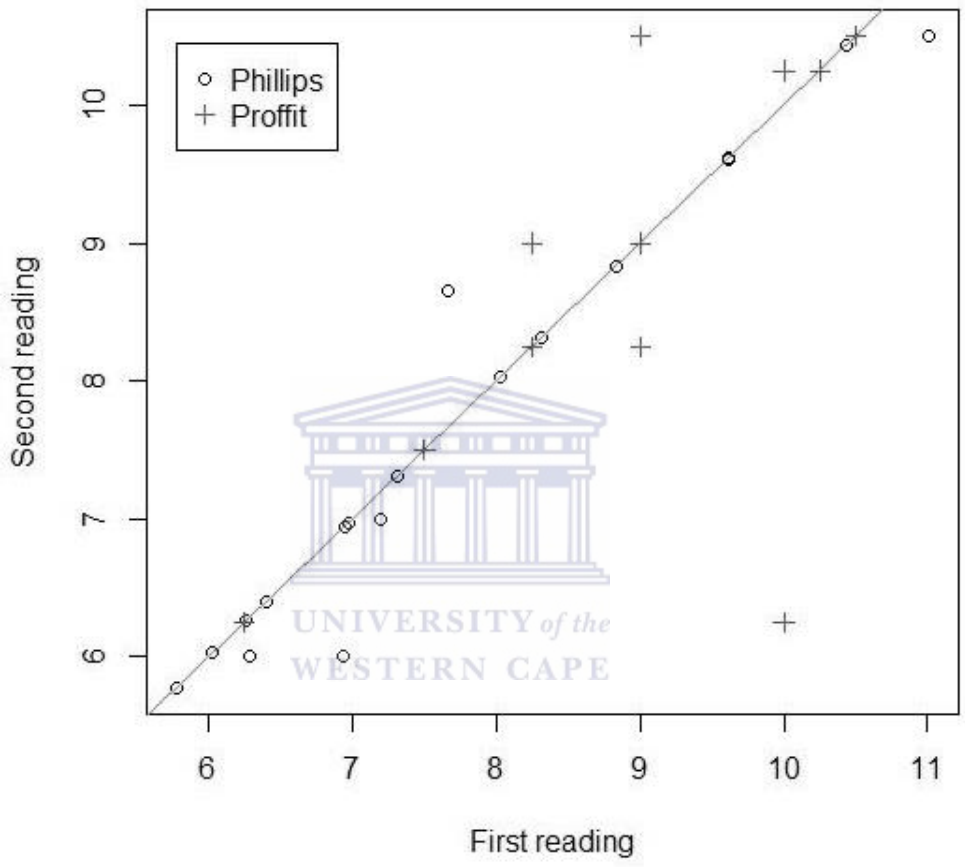

Figure 1: Intra-observer reliability

5.2.Distribution of the sample

Table 1: Distribution of the sample according to chronological age and gender

Age group	Girls			Boys			Total
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**
(5.9 - 6.9]	9	6.427	0.228	9	6.553	0.266	18
(6.9 - 7.9]	9	7.500	0.282	10	7.401	0.273	19
(7.9 - 8.9]	11	8.295	0.320	10	8.401	0.323	21
(8.9 - 9.9]	10	9.215	0.267	12	9.423	0.348	22
(9.9 - 11]	11	10.455	0.314	9	10.380	0.218	20
Total	50	-	-	50	-	-	100

N: number of cases

SD: standard deviation

5.3.Girls' sample

5.3.1. Girls' sample: DA estimated by Phillips' method

Table 2: Girls' sample: DA estimated by Phillips' method

Chronological age	N	Mean of estimated DA	95% confidence limits
(5.9 - 6.9]	9	6.332	6.037 - 6.627
(6.9 - 7.9]	9	7.589	7.034 - 8.143
(7.9 - 8.9]	11	8.487	8.124 - 8.850
(8.9 - 9.9]	10	8.781	7.987 - 9.575
(9.9 - 11]	11	9.121	8.312 - 9.930

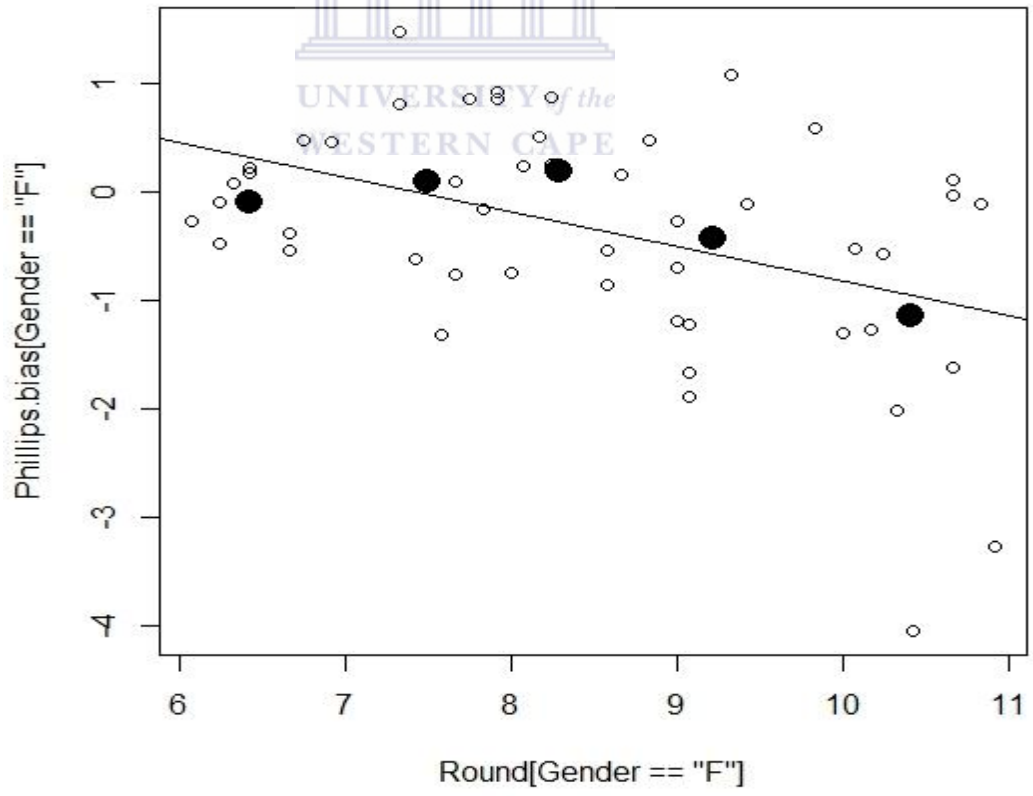

Figure 2: Phillips' bias plotted against chronological age for girls

5.3.2. Girls' sample: DA estimated by Proffit's method

Table 3: Girls' sample: DA estimated by Proffit's method

Chronological age	N	Mean of estimated DA	95% confidence limits
(5.9 - 6.9]	9	6.417	6.000 - 6.833
(6.9 - 7.9]	9	7.833	7.076 - 8.591
(7.9 - 8.9]	11	8.614	8.007 - 9.221
(8.9 - 9.9]	10	9.325	8.671 - 9.979
(9.9 - 11]	11	9.750	8.899 - 10.601

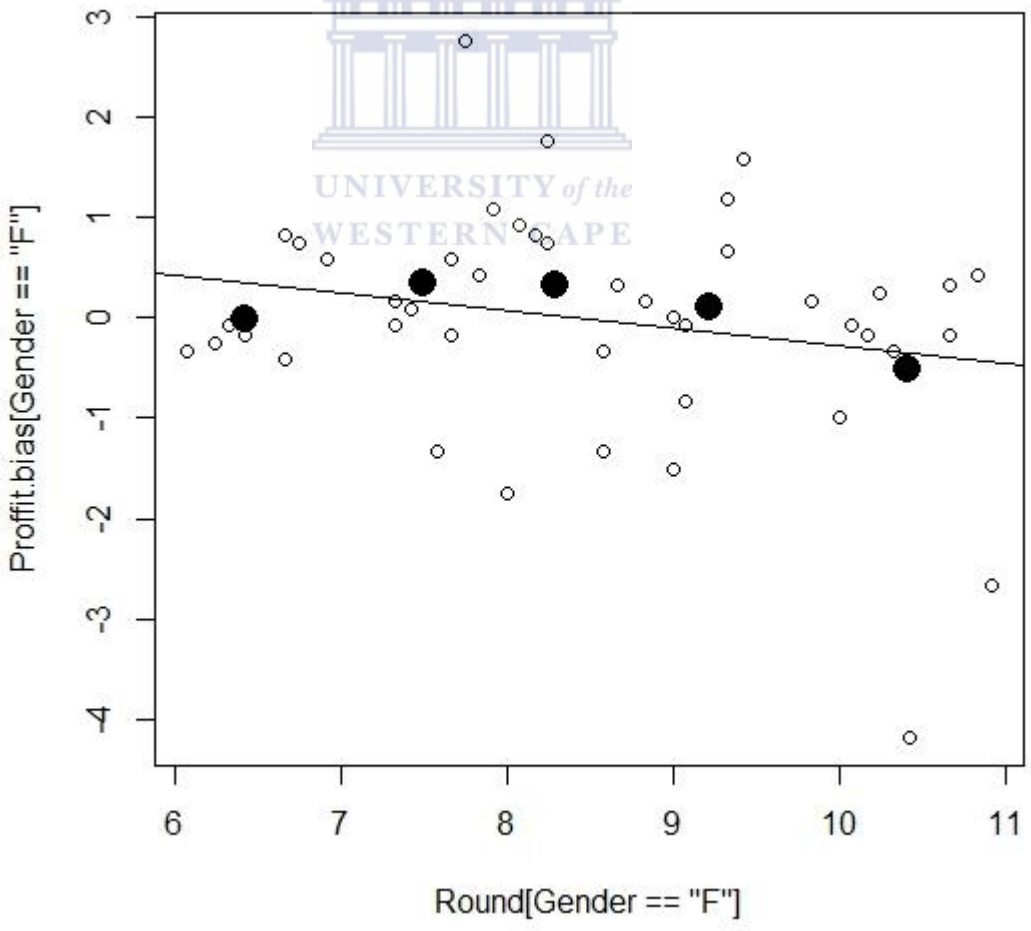

Figure 3: Proffit's bias plotted against chronological age for girls

5.4.Boys' sample

5.4.1. Boys' sample: DA estimated by Phillips' method

Table 4: Boys' sample: DA estimated by Phillips' method

Chronological age	N	Mean of estimated DA	95% confidence limits
(5.9 - 6.9]	9	6.226	5.913 - 6.538
(6.9 - 7.9]	10	6.765	6.385 - 7.145
(7.9 - 8.9]	10	8.013	7.381 - 8.645
(8.9 - 9.9]	12	9.014	8.592 - 9.437
(9.9 - 11]	9	9.689	9.033 - 10.345

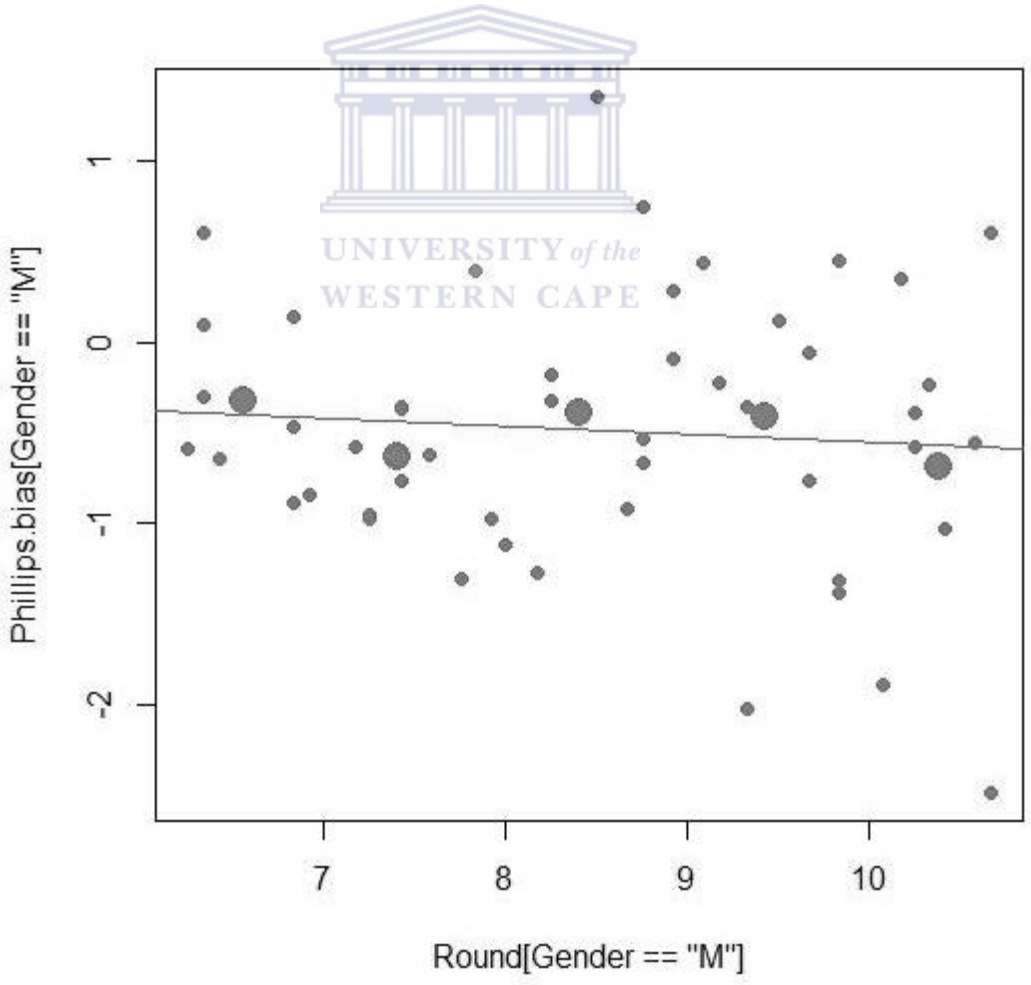

Figure 4: Phillips' bias plotted against chronological age for boys

5.4.2. Boys' sample: DA estimated by Proffit's method

Table 5: Boys' sample: DA estimated by Proffit's method

Chronological age	N	Mean of estimated DA	95% confidence limits
(5.9 - 6.9]	9	6.444	6.081 - 6.808
(6.9 - 7.9]	10	7.075	6.330 - 7.820
(7.9 - 8.9]	10	7.925	6.856 - 8.994
(8.9 - 9.9]	12	9.854	9.393 - 10.315
(9.9 - 11]	9	9.500	8.779 - 10.221

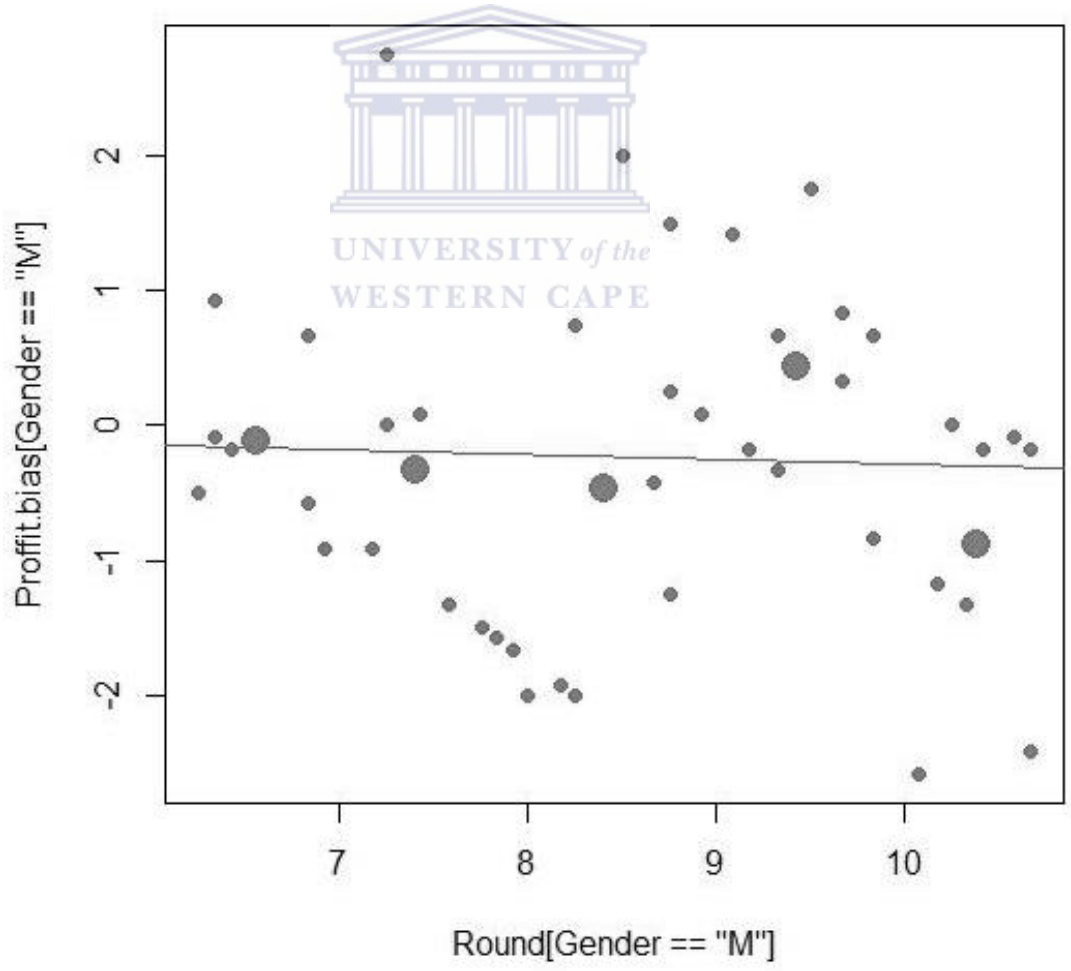

Figure 5: Proffit's bias plotted against chronological age for boys

5.5.Random errors: Phillips vs Proffit

Table 6: Means of absolute errors

Group	Mean	Prob. 1
Phillips girls	0.786	0.70
Proffit girls	0.751	0.80
Phillips boys	0.561	0.88
Proffit boys	0.864	0.64

Prob. 1: the proportion of errors smaller than 1.0

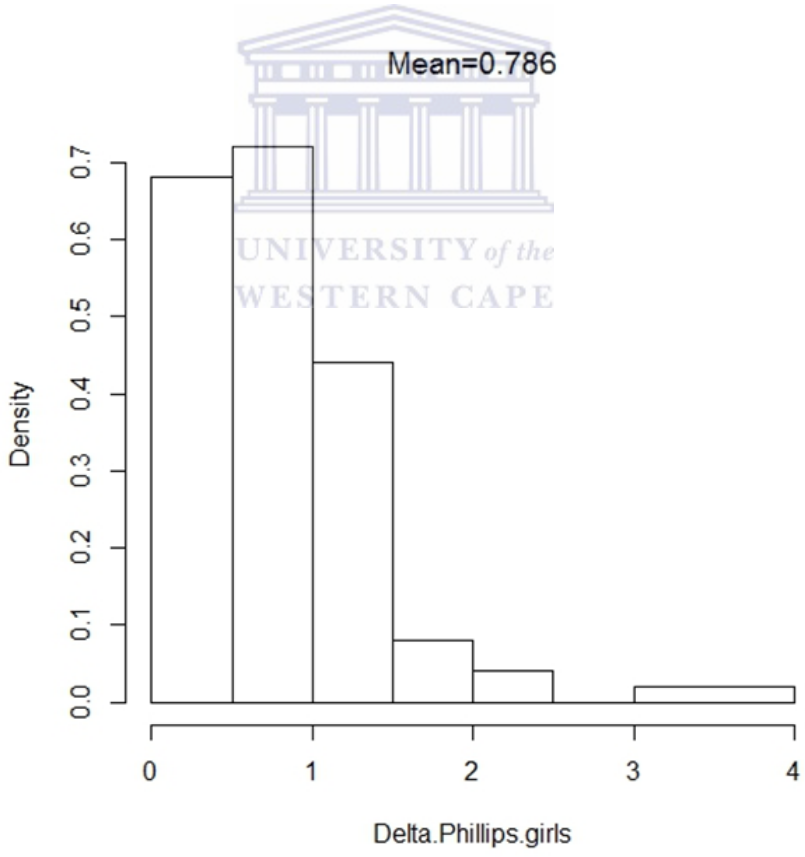

Figure 6: Frequency of random errors of Phillips' method in girls

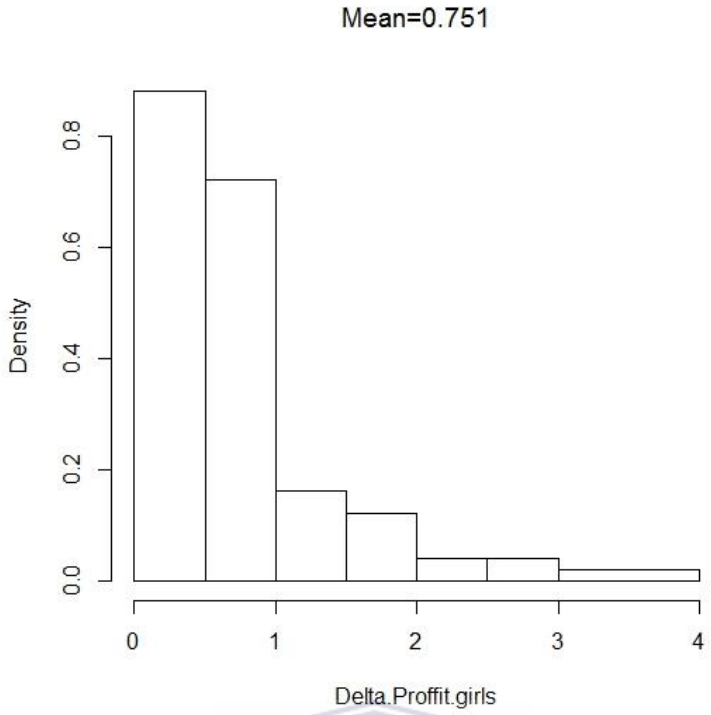

Figure 7: Frequency of random errors of Proffit's method in girls

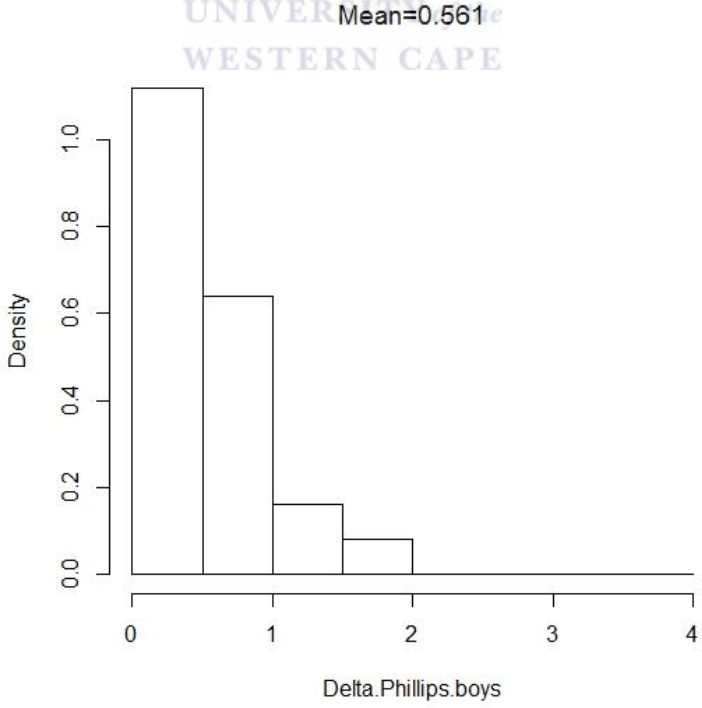

Figure 8: Frequency of random errors of Phillips' method in boys

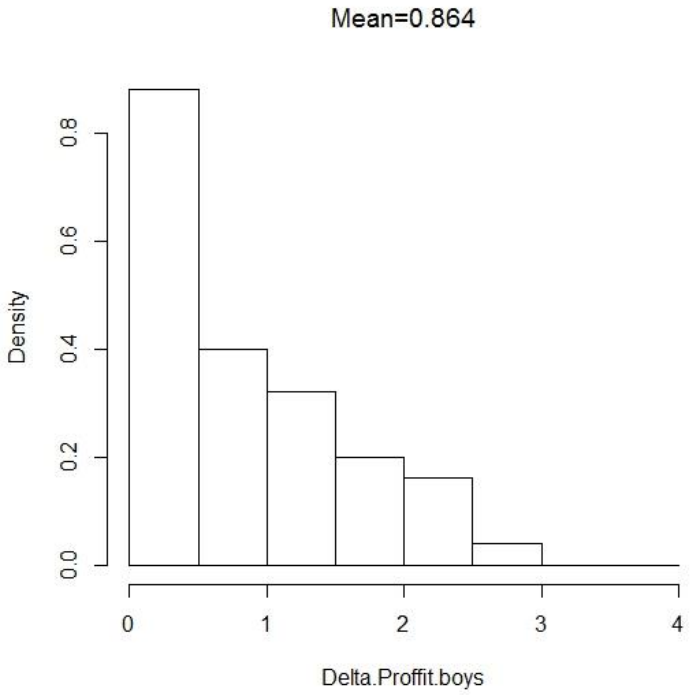

Figure 9: Frequency of random errors of Proffit's method in boys

CHAPTER 6
DISCUSSION

6.1.Intra-observer reliability

Intra-observer reliability was tested to determine the presence or absence of bias. Bias is defined as the difference between the expected value and the true value of the parameter being estimated. To assess the intra-observer reliability, 20% of the sample (i.e. 20 radiographs) was re-examined after 2 weeks. The mean difference between the first and the second readings was calculated. The mean differences for both the Phillips and Proffit methods were not statistically significant, i.e. p-value = 0.5575 and 0.6453 respectively. The results demonstrated in Figure 1 (see page 18) show that the readings obtained by the examiner for both methods are reliable and unbiased.

6.2.Distribution of the sample

The sample size was 100 cases consisting of an equal number of girls and boys (50 radiographs in each). Initially, each age group contained 10 radiographs which were chosen according to the chronological age at the last birthday. However, after the final analysis, the exact chronological age was calculated by subtracting the date of birth from the date on which the radiographs were taken. Thus, slight differences in the number of radiographs in each age group were detected in the final distribution. The final sample was divided into 5 age groups between the ages of 6 and 11 years. These age groups (with the final number of radiographs in each age group) are represented in Table 1 (see page 19). The round bracket indicates that the first value is not included in this age group and the square bracket indicates that the last value is included.

6.3.Girls' sample

6.3.1. Girls' sample: DA estimated by Phillips' method

According to Table 2 (see page 20), the Phillips overall mean bias in girls is -0.3392 and the p-value is 0.03. This indicates that Phillips' method underestimates the age in the girls by approximately 4 months. This underestimation was found to

be statistically significant. This means that Phillips' method is biased when estimating DA in girls. Figure 2 (page 20) shows small and large dots. The small dots represent the individual observations while the large dots are the age group means. The observations lie predominantly in the negative bias region indicating underestimation. The line in figure 2 is a linear regression line with intercept= 2.354, slope= -0.318 and p-value= 0.002 which is statistically significant. Therefore, the underestimation using Phillips' method appears to be age dependent. It is positive at the smaller age groups i.e. from 6 to 8.9 years and negative at the larger age groups i.e. from 9 to 11 years. This means that at the younger age groups, the bias is less significant. It is however more significant in the older age groups. So, the older the patient, the more likely the Phillips method is to underestimate the age. Therefore, Philips' method is more accurate if used between the ages of 6 and 8.9 years. This could be explained by the availability of the maximum number of developing teeth in the radiograph at this age interval. As the number of teeth increase, the accuracy of the method will increase. On the other hand, in the larger age groups (9 to 11 years) the central incisors and first molar would have reached the apex closure stage and would therefore be excluded from the calculation according to Phillips' method. Therefore, the reduced number of teeth available to be used in the DA estimation may account for the decrease in accuracy.

6.3.2. Girls' sample: DA estimated by Proffit's method

According to Table 3 (page 21), Proffit's overall mean bias in girls is -0.005 and the p-value is 0.97. This means that the Proffit method tends to underestimate the age by approximately 2 days in girls which is not statistically significant. Furthermore, Figure 3 (page 21) shows a linear regression for Proffit bias which gives a line with intercept= 1.469, slope= -0.174 and p-value = 0.11 which is not statistically significant. Therefore, unlike the Phillips method, there is no overall bias and there is no age dependent bias. So this means that Proffit's method was unbiased in estimating the age in girls.

6.4.Boys' sample

6.4.1. Boys' sample: DA estimated by Phillips' method

Phillips' overall mean bias in boys is -0.4864 and the p-value is <0.0001 (Table 4, page 22). This means that the Phillips method tends to underestimate the age of boys by approximately 6 months and this underestimation is statistically significant. This is also demonstrated in Figure 4 (see page 22) where the observations lie predominantly in the negative bias region. The underestimation is shown to be constant through all the age groups as demonstrated by a line with intercept= -0.121, slope= 0.043 and p-value = 0.58 which is not statistically significant. This shows that the underestimation in the boys sample is not age dependent in contrast to the girls' sample.

These results are contrary to those reported by Hag-Mahmoud (2012) who investigated the accuracy of the Phillips method in a sample of Sudanese children. The author found that Phillips' method overestimated the age of girls by 2 and half months and underestimated the age of boys by only 1 month. This overall bias was statistically insignificant. However, the difference between the present study and Hag-Mahmoud's study (2012) could be explained by the difference in age groups, age distribution across the groups, ethnic origin and statistical analysis between the two studies.

6.4.2. Boys' sample: DA estimated by Proffit's method

According to Table 5 (see page 23), Proffit's overall mean bias in boys is -0.235 and the p-value is 0.15. This means that the Proffit method tends to underestimate the age of boys by approximately 2 months and this underestimation is not statistically significant. Furthermore, Figure 5 (page 23) shows that the underestimation is constant through all age groups as demonstrated by a line with intercept=-0.051, slope= -0.034 and p-value = 0.78 which is not statistically significant. This shows that the underestimation in the boy's sample is not age dependent as is the case in the girls' sample.

6.5.Random errors: Phillips vs Proffit

The accuracy of age estimation does not depend only on the overall bias of the estimating procedure. The random errors associated with the overall bias are extremely important. The frequency distribution of the random errors for Phillips and Proffit are represented in histograms (see Figures 6, 7, 8 and 9 on pages 24-26). The magnitude of these errors can be compared and the proportion of errors smaller than 1 has been calculated statistically. Histograms 6 and 7 indicate that the mean error according to Proffit is greater than the mean error according to Phillips for girls. However, this is not statistically significant.

Histograms 8 and 9 indicate that the mean error according to Proffit is greater than the mean error according to Phillips for boys. The proportion of errors for Phillips (0.88) and Proffit (0.64) indicates a statistically significant p-value of 0.002 (Table 6, page 24). This means that Phillips' method will have fewer random errors compared to Proffit when DA estimation is done on boys.

6.6.Phillips' reading: Overview

Phillips' method has been shown to be more accurate than the MFH method and the Demirjian's method when estimating DA in South African children (Phillips & van Wyk Kotze, 2009b).

However, the present study showed that Phillips' method predominantly underestimated the age in this sample of South African girls and boys by 4 and 6 months respectively and the overall bias was statistically significant. This means that Phillips' method was biased when applied to the study sample. This was not an expected outcome as the Phillips method was derived originally from a sample of South Africa children. However, the relative inaccuracy in this sample could be due to different reasons. Phillips originally constructed three different tables according to ethnicity i.e. Tygerberg, Indian and Nguni tables (Phillips & van Wyk Kotze, 2009a). In the present study, only the Tygerberg table was used for the whole sample. However, it is highly likely that the sample (100 radiographs) was mixed in ethnicity and that could explain the overall bias.

The Phillips' method is a scoring system which depends on multiple readings of the developmental stages for 8 permanent teeth. Although the intra-observer reliability score showed unbiased results (Figure 1 on page 18) subjectivity of the readings cannot be completely excluded (Li *et al*., 2012). Furthermore, distinguishing between the different developmental stages could be very difficult especially when the tooth presented as a borderline stage. It is difficult to judge whether a half or a third of the root has formed if you don't know the final root length (Leurs *et al*., 2005). The absence of the intermediate stage (i.e. one third of the root completed) may contribute to the biased estimation (Li *et al*., 2012).

Phillips' method also included the mandibular third molar which is known for its variability and unpredictability (Garn *et al*., 1962). According to Miles (1963), DA estimation using the third molar can produce an error of 2 years. This may have affected the scoring system and led to bias in the overall results.

The result of this study supports the argument that population specific tables may not be very accurate within the reference population because of the intrinsic variation which is difficult to explain.

6.7.Proffit's readings: Overview

The results of age estimation in girls and boys show that Proffit's method is unbiased in this study population. However, there are no other studies in the literature to allow for comparison with the present study. Proffit published his description of DA in 1986. It has however not been compared to the other DA estimation methods in the literature. It has always been considered to be an academic tool for teaching the concept of DA estimation and explaining the developmental stages of the permanent dentition. It has been used extensively as a clinical tool in interceptive orthodontics and paediatric dentistry as a guide for the timing of treatment such as in space maintenance, serial extraction and appliance therapy (Proffit *et al*., 2007). Despite the value of Proffit's description, it has not been considered as a bona fide DA estimation method. This explains the absence of any comparative literature.

6.8.Limitations

Information regarding the ethnicity of the current sample was not available and thus the ethnic specific tables could not be applied. Phillips' Tygerberg table was used for the whole sample regardless of the ethnic background.

Despite these limitations, the final results of the present study indicate the value of both methods in relation to mass disasters as well as epidemiological studies.

CHAPTER 7
CONCLUSIONS AND RECOMMENTATIONS

7.1.Conclusion

When comparing the Phillips and Proffit methods in DA estimation, it is difficult to conclude which method is more accurate as this decision depends on different factors. The results concluded that gender, overall bias and random error should all be taken into consideration. The overall bias could be compensated for by adding or subtracting the amount of bias obtained from the statistical analysis. This calculation can however only be done if the chronological age is known. On the other hand, it is not possible to compensate for the random error because it is not known where and when it can occur.

It can be concluded that if one had to choose between the two DA estimation methods for girls, Proffit's method would be more appropriate. This rationale is explained by the conclusion that it only underestimates the age by 2 days and has the same frequency of random errors as Phillips' method. However, if one had to choose between the two methods for boys, the situation should be evaluated carefully. For boys, the Phillips method has fewer random errors but a larger overall bias (6 months) whereas Proffit's method has more random errors but less overall bias (2 months).

The choice between the two methods should therefore depend on the purpose of the estimation. If the method is used for estimating the age in a single individual with an unknown chronological age e.g. for forensic and immigration purposes, the method with less random error would be more preferable (i.e. Phillips). However, if the age estimation method is used for age estimation in populations with a known mean chronological age e.g. epidemiological studies, the method with less overall bias is preferred (i.e. Proffit).

7.2.Recommendations

Based on the results of this study, the author recommends the following:

- Proffit's description for dental development has been shown to be accurate in estimating the DA. It may therefore be considered to be a legitimate DA estimation method and not just a developmental description for the dentition.
- Proffit's description is simple and easy to apply and has therefore been used as an academic tool by universities (including University of the Western Cape). In contrast, Phillips' method is more complicated especially where the training of undergraduate students is concerned.
- The present study has proven that, despite its simplicity, Proffit's age estimation is a scientifically valid method. Its incorporation in university curricula should therefore be supported.
- The accuracy of Proffit's method should be tested in different population groups and be compared to other well-known age estimation methods in the literature.
- Gender specific tables for Phillips' method may need to be considered.
- Each age estimation method in this study should be used for the prescribed intentions to ensure the most plausible result.

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APPENDICES

1. Appendix A

Dental Age Related Table for Tygerberg Children (SD in years)

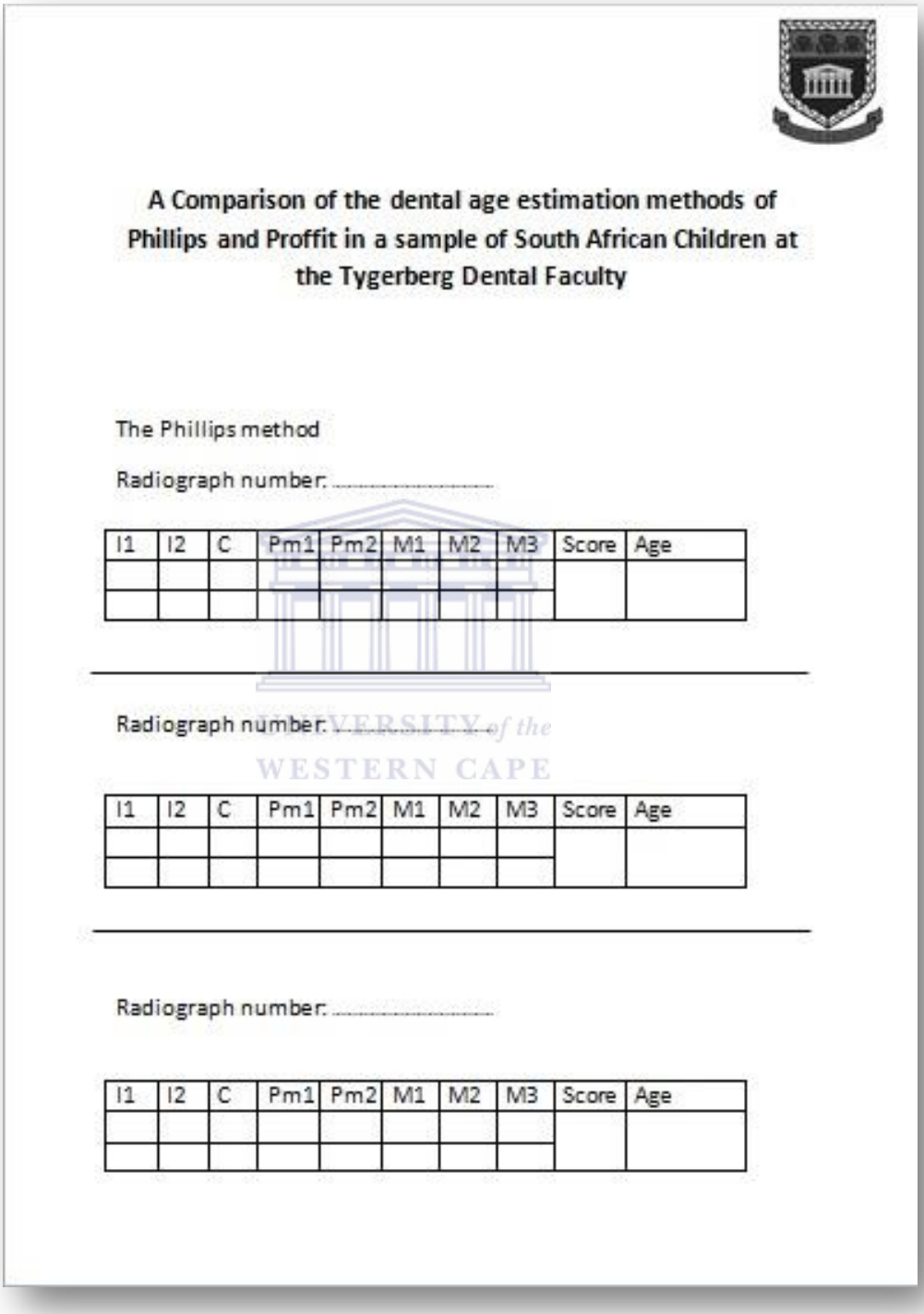
	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F					4.44 (0.85)			8.85 (1.39)
Ci					4.74 (1.06)		4.13 (0.64)	9.29 (1.16)
Cco					4.97 (0.74)		4.74 (1.47)	10.40 (1.34)
Coc				3.26	4.78 (1.00)		4.75 (0.53)	10.98 (1.05)
Cr1/2			4.14	4.65 (0.65)	5.30 (0.80)		5.42 (0.82)	12.08 (1.12)
Cr3/4		3.96 (0.27)	4.70 (0.75)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

(Ci) Cusp initiation, (Cco) Cusp coalescence, (Coc) Cusp outline completion, (Cr½) Crown half formation, (Cr¾) Crown three quarters formation, (Crc) Crown complete formation, (Ri) Root initiation, (Cli) Cleft initiation (molars only), (R ¼) Root one quarter formation, (R ½) Root half formation, (R ¾) Root three quarters formation, (Rc) Root completion, (A½) Apex one half completion and (Ac) Apex completion.

2. Appendix B

Age (years)	Characteristics
6	• Eruption of 1st permanent molar. • Eruption of mandibular central incisors.
7	• Eruption of maxillary central incisors. • Eruption of mandibular lateral incisors. • Crown completion of canines and premolars.
8	• Eruption of maxillary lateral incisors.
9	• Third of root completion of mandibular canines and 1st premolars. • Root formation begins of 2nd mandibular premolars and 1st maxillary premolars. • Root formation Just beginning of maxillary canines and 2nd premolars.
10	• Half root completion of mandibular canines, 1st premolars and maxillary 1st premolars. • Significant root development of maxillary canines, 2nd premolars and mandibular 2nd premolars. • Root completion of mandibular incisors. • Near root completion of maxillary lateral incisors.
11	• Eruption of mandibular canines, 1st premolars and maxillary 1st premolars.
12	• Eruption of remaining succedaneous teeth.

3. Appendix C



A Comparison of the dental age estimation methods of Phillips and Proffit in a sample of South African Children at the Tygerberg Dental Faculty

The Phillips method

Radiograph number: .....

I1	I2	C	Pm1	Pm2	M1	M2	M3	Score	Age

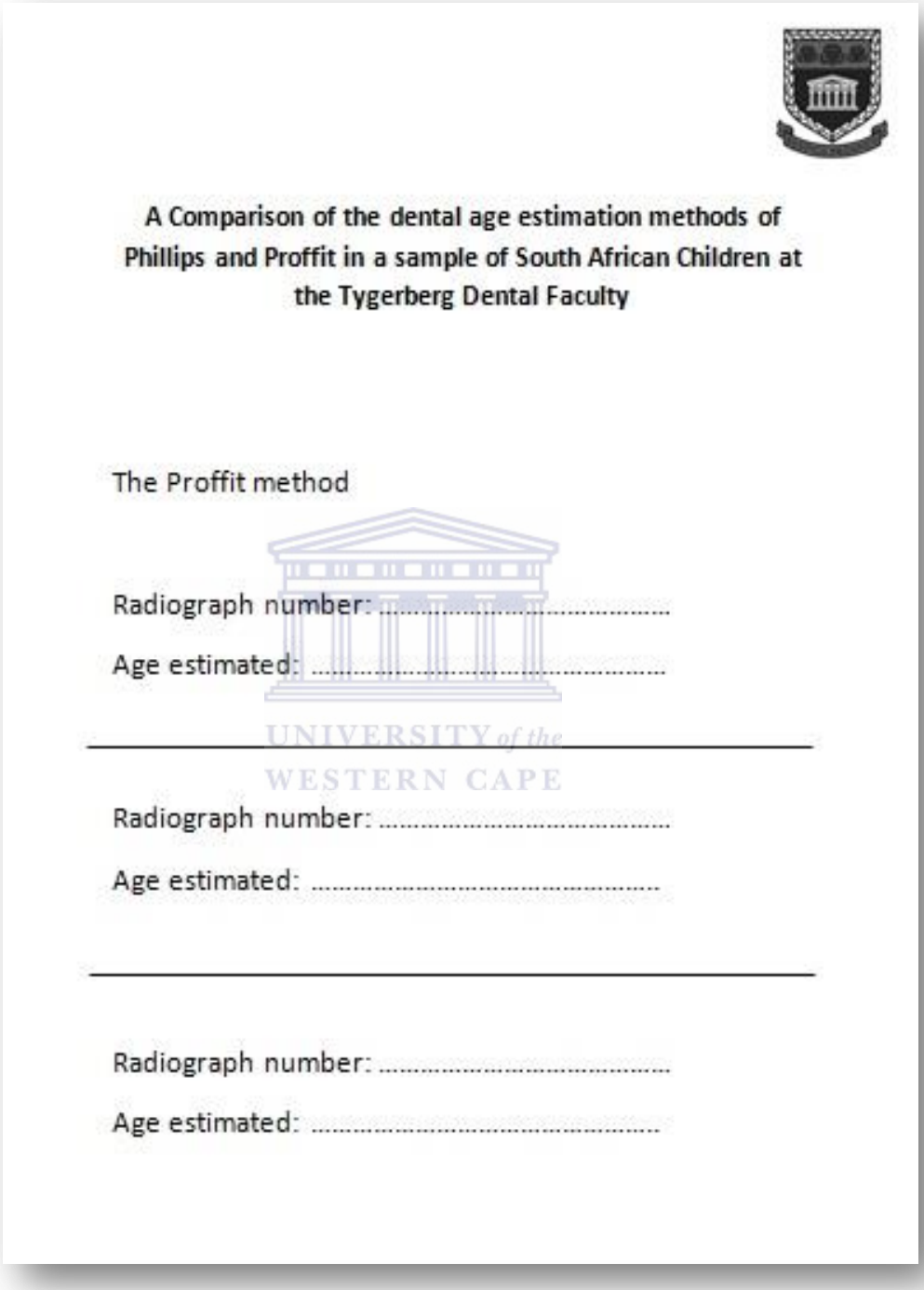
Radiograph number: .....

I1	I2	C	Pm1	Pm2	M1	M2	M3	Score	Age

Radiograph number: .....

I1	I2	C	Pm1	Pm2	M1	M2	M3	Score	Age

4. Appendix D



A Comparison of the dental age estimation methods of Phillips and Proffit in a sample of South African Children at the Tygerberg Dental Faculty

The Proffit method

Radiograph number: .....

Age estimated: .....

Radiograph number: .....

Age estimated: .....

Radiograph number: .....

Age estimated: .....