A study to determine the accuracy of Gustafson's method of age estimation on adult teeth when applied to a sample of the population of the Western Cape

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ABSTRACT

Teeth are often used to assist in the identification of human bodies after death, especially in cases where the body is badly burned or decomposed, as teeth are usually preserved for a long period of time, even after most of the other tissues of the body have decomposed. Age estimation can play a significant role in order to help narrow down the spectrum of possible identities, for example from the missing person's database. Gustafson created a method of age estimation, using 6 age-related changes of teeth that occur after the eruption of the dentition. He then compiled a regression line from which the age of a tooth donor could be determined by examining attrition, change of the level of the periodontal attachment, secondary dentine deposition in the pulp, resorption of the root, apposition of cementum and translucency of the root. Gustafson's method of age estimation was based on Europeans from Sweden. This age estimation method has been used on unidentified individuals at the Salt River and the Tygerberg medico-legal laboratories, but the accuracy is questionable as to whether the method is applicable to the population of the Western Cape. The aim and objectives of this study were to test the accuracy of Gustafson's method on a sample of adults of known chronological age, to determine the degree of accuracy of the method and to evaluate the consistency of the method. Extracted mandibular central and lateral incisors and maxillary central incisors were used in this study. Two examiners independently used Gustafson's method of age estimation to estimate the ages of the donors of the teeth. This method was found to be inaccurate when applied to a sample of the adult population of the Western Cape.

Keywords: Forensic Dentistry, Age estimation, Teeth

DECLARATION

I declare that *A study to determine the accuracy of Gustafson's method of age estimation on adult teeth when applied to a sample of the population of the Western Cape* is my own work, that it has not been submitted for any degree or examination to any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

S. Chandler September 2013

Signed: .....

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Chapter 1

Introduction

Age determination or estimation is an important part of forensic dentistry. The use of teeth for this purpose can play a significant role in the process to identify a human body after death, especially in cases where the body is badly burnt or decomposed, as teeth are usually preserved for a long period of time, even after most of the other tissues have already disintegrated. Identification is usually undertaken by comparison of ante-mortem and postmortem dental records, when the identity of the deceased is suspected. In some cases however, when the identity of the body is not known, which means that no ante-mortem dental records or radiographs are available for comparison, age estimation can play a significant role in order to help narrow down possible identities, for example from the missing persons database (Metzger *et al.*, 1980; Rai *et al.*, 2006).

The use of teeth to estimate an individual's age can also sometimes be useful in the living. An example of this would be when teeth are used to estimate a suspect's chronological age if he or she has no birth certificate or other legal form documenting his or her birth (Rai *et al.*, 2006; Rai, 2008).

The age estimation of persons younger than 21 years is usually more accurate. This is done by taking a radiograph of the individual's jaw and comparing it to a chart showing the stage of the development of the dentition and the age associated with the course of this development (Metzer *et al.*, 1980).

In individuals older than 21 years, when the dentition's development has been completed, age estimation becomes more complicated (Metzer *et al.*, 1980; Vystreilova and Novotny, 2000).

Teeth however continue to show several different age-related changes, even after the formation and development of the dentition is complete. These changes can then give an indication of the person's dental age, which makes it possible to use this in the estimation of the individual's chronological age. The tooth changes include attrition, change of the level of the periodontal attachment, secondary

dentine deposition, resorption of the root, apposition of cementum, translucency of the root and an increase in the roughness of the root surface. Caries free teeth need to be used for this age estimation to eliminate the secondary dentine deposition that takes place within the pulp chamber (as a result of the carious process) (Burns and Maples, 1976; Singh and Gorea, 2010; Willershausen *et al.*, 2012).

These changes are also affected by certain other factors including a person's diet, eating habits, oral hygiene habits and medical history. The question then arises if it is possible that one method of age estimation can be accurate for all the people from around the world, even though their teeth will be affected and influenced by several different factors.

Chapter 2

Literature Review

2.1 Methods used for age estimation

In the past, several different techniques for the estimation of a person's dental age based on the facial and/or oral structures have been suggested. These include techniques based on morphological methods and those based on radiological methods. Some of the techniques can also be classified as invasive, which can mostly only be used in deceased individuals, and others as non-invasive, which can be used both in the living and the dead (Willershausen *et al.*, 2012).

This discussion will mainly focus on the morphological and invasive methods and techniques.

2.2 Gustafson's method of age estimation

In the year 1950, Gustafson suggested the following method for the estimation of age using teeth. He used six age-related changes:

- Attrition of the enamel and dentine
- Change of the level of periodontal attachment
- Extent of secondary dentine deposition within the pulp
- Apposition of cementum on the root surface
- Resorption of the root apex
- The transparency or translucency of the root (Gustafson, 1950)

Gustafson conducted his study in Sweden and used only Europeans. He applied his method to teeth that were extracted from persons of known age and then prepared into thin slices or sections. He used ground sections of 1.0 mm thickness to determine the translucency of the dentin and ground sections of 0.25 mm thick to determine the remaining five factors. Each of these changes in a specific tooth was then rated and given a value between 0 and 3. The sum of the values of each

change of each tooth, combined with the age of the individual (from whom the tooth was extracted) was then used to create a regression line. From this graph, the age of an unknown individual was then determined with reasonable accuracy (Gustafson, 1950; Metzer *et al.*, 1980; Willerhausen *et al.*, 2012).

Gustafson used the following formula or equation for linear regression:

Estimated age (in years) = 11.43 + (4.56 X overall value of added scores)

(Gustafson, 1950)

According to Gustafson, the average error in age estimation using this technique was about 3.63 years. He then also found that the estimation of an individual's age is even more accurate if more than one tooth from that individual is examined (Gustafson, 1950; Metzer et al., 1980; Willerhausen et al., 2012).

This study was however done only on Europeans from Sweden (Gustafson, 1950).

Over the years numerous studies have been conducted in order to either prove or disprove Gustafson's method of age estimation, as several researchers and investigators were convinced that there was an error in this method. Some of these researchers were of the opinion that Gustafson based his method on several assumptions that were most likely incorrect (Johanson, 1971; Maples, 1978; Senn and Stimson, 2010). These include the following:

- Gustafson assumed that these 6 criteria were all equally accurate and effective in the process of age estimation (Johanson, 1971; Maples, 1978; Senn and Stimson, 2010).
- He assumed that the rates at which the individual criteria change, are equal, resulting in the method of just adding them together (Johanson, 1971; Maples, 1978; Senn and Stimson, 2010).
- Gustafson also assumed that the age information obtained from the 6 different criteria is statistically independent, which was shown to be inaccurate (Johanson, 1971; Maples, 1978; Senn and Stimson, 2010).

The 6 criteria used in Gustafson's method of age estimation are also influenced by several different factors (other than aging) and may even have an influence on

each other, which Gustafson also did not take into account. These include the following:

- **Attrition** can be influenced by bruxism, diet, morphology of the teeth and dental arches, the direction and force of masticatory movements and the number of teeth present in the mouth (Richards and Brown, 1981; Ekfeldt, 1990; Cawson and Odell, 2002).
- **Secondary dentine** can be influenced by attrition, abrasion, periodontal disease and mechanical injury or irritation caused by dental procedures and caries (Neville *et al*., 2002).
- **Periodontal attachment level** can be influenced by periodontal disease (Cawson and Odell, 2002).
- **Cementum apposition** can be influenced by periapical periodontitis, root resorption and whether or not the tooth is in function (Cawson and Odell, 2002).
- **Root resorption** can be influenced by dental trauma, periapical periodontitis, excessive forces including mechanical forces caused by orthodontic forces and occlusal forces, hormonal imbalances and pressure from impacted teeth or benign neoplasms that press on the roots of adjacent teeth (Cawson and Odell, 2002; Neville *et al*., 2002).
- **Translucency** can be influenced by periodontal infection and diseases of the pulp of the tooth (Singhal *et al*., 2010).

Possibly as a result of these incorrect assumptions and additional influencing factors, most of these studies proved that this method was faulty, and resulted in several modifications to the original method (Bang and Ramm, 1970; Johanson, 1971; Burns and Maples, 1976; Maples and Rice, 1979; Monzavi *et al.*, 2003; Singh *et al.*, 2004).

2.3 Subsequent studies and modifications

During the studies that were subsequently conducted, following that done by Gustafson, researchers modified one of three areas. Some of the researchers

modified the number of age related changes used in age estimation (Maples, 1978; Lamendin *et al.*, 1992; Singhal *et al.*, 2010). Another group of researchers changed the method in which the data collected was analyzed (Johanson, 1971; Burns and Maples, 1976) and others changed the specific tooth on which the study was conducted (Johanson, 1971; Burns and Maples, 1976; Monzavi *et al.*, 2003).

2.3.1 Age related changes in the studies

Several researchers were of the opinion that it was unnecessary to use all 6 of the age related changes that were used by Gustafson. They were of the opinion that age could be estimated quite accurately by utilizing only some of these changes. These studies included the following:

- Dalitz (1962), as cited by Lucy *et al*. (1996) and Sebecic *et al.* (2010), found in his study that the resorption of the root and the build-up of the cementum could, according to his findings, be excluded from Gustafson's original method of age estimation without affecting the accuracy of the method. He also suggested that four of an individual's anterior teeth should preferably be used in this process, although this did not necessarily result in a more accurate outcome of determination of age. In the process to determine age, his study showed a standard deviation of about six years (Dalitz, 1962; Lucy *et al.*, 1996; Sebecic *et al.*, 2010).
- In 1970, Bang and Ramm decided to use only the translucency of the dentine of the root in their study. Their study proved that age could be fairly accurately estimated by continuously measuring the extent or the degree of root translucency alone. They created a curvilinear regression for each tooth to express the relationship between the individual's age and the extent or degree of the zone of translucency. Their study found an average error in the estimation of age of approximately 4.7 years in about 58% of the cases they examined (Bang and Ramm, 1970; Lucy *et al.*, 1996).

- Maples (1978) undertook a study to prove that fewer of the age-related changes or parameters could be used with similar or even improved accuracy for age estimation. He found that root resorption was the parameter with the weakest correlation with an individual's age and that it is unwise to use it in the method of age determination. According to him, the amount of secondary dentine present and the transparency of the dentine of the root were the best indicators of an individual's age. He also considered the second molar as the most useful tooth to utilize in the process to estimate age (Maples, 1978).
- Solheim (1980) was involved in several different studies. In 1980, he undertook a study that made use of teeth that were in situ. He used eight different variables that included two for the level of periodontal attachment, two for the amount of attrition, two for the changes and estimation of the root colour and two for the length of the crown and the sex of the individual. According to him, these changes could not be used separately and needed to be used in combination in order to achieve the greatest accuracy. He also found out that in most of the cases where the ages were over-estimated, the individual was younger than 40 years and in most of the cases where the ages were under-estimated the teeth came from individuals older than 50 years (Solheim and Sundnes, 1980).
- In 1992, a study was done by Lamendin *et al.* in which they used only two of the age-related changes originally used by Gustafson, namely the level of the periodontal attachment and the transparency or translucency of the root. They found an average error of about 10 years between the estimated age and the individual's real age (Lamendin *et al.*, 1992).
- Vystreilova and Novotny (2000) evaluated the results obtained in the estimation of age where two different methods were used. They used Kilian's method (1981) and that of Kashyap and Koteswara-Rao (1990). The method used by Kilian evaluated the six age-related

changes originally used by Gustafson and the method used by Kashyap and Koteswara-Rao evaluated only four of the age-related changes. This study found that the most accurate results for the estimation of age were obtained when all six of the age-related changes were included in the study and that the average error for the age estimation increased whenever one of these variables were not evaluated (Vystreilova and Novotny, 2000).

- In 2010, Singhal *et al*. analyzed only the length and the area of transparency of the root dentine in individuals from whom their ages were known (Singhal *et al.*, 2010). They based their study on the transparency of the root dentine which was considered an age-related change that showed the minimal response to pathological and environmental factors (Azaz *et al.*, 1977; Gustafson, 1950; Nalabandian *et al.*, 1960; Singhal *et al.*, 2010). They concluded that the age of an individual could be accurately determined by using the length and the area of translucency or transparency found in the root's apical section (Singhal *et al.*, 2010).

2.3.2 Other methods of data analysis

- In 1971, Johanson made use of all six of the changes that Gustafson originally used. His study demonstrated that it was possible to detect half-stages in the degree or extent of these changes, which resulted in the fact that he used seven stages in his scoring system. He then calculated a regression line, by using multiple regressions, which could then be used to estimate or determine the ages of unknown bodies or individuals. He managed to predict an individual's age to within a 5-year timeslot in about 78% of the cases examined (Johanson, 1971; Lucy *et al.*, 1996; Rai *et al.*, 2007; Sebecic *et al.*, 2010).

- Burns and Maples (1976), made use of a point value system that was based on the method used by Gustafson. Their study however was done on creating a regression line separately for every tooth using a geometrical point or locus, which they found to be more accurate than

the single analysis used by Gustafson. They also considered the individual's age, sex and race, the position of the tooth in the mouth and whether or not the person had suffered any form of periodontal disease in the past, as possible factors that could influence the changes originally used by Gustafson (Burns and Maples, 1976).

- In 1979, Maples and Rice undertook yet another study on the basis that Gustafson's method for the estimation of age was associated with multiple statistical mistakes or errors (Maples and Rice, 1979). They used multiple regression methods and proved that an error of nearly twice the value that Gustafson claimed, existed in the process of the estimation of age (as cited by Lucy and Pollard, 1995). They therefore derived a new, improved formula to estimate an individual's age (Maples and Rice, 1979). The new formula was:

Estimated age (in years) = (4.26 X overall value of added scores) + 13.45

They found an average error of about 7.03 years (Maples and Rice, 1979).

- Nkhumeleni *et al.* undertook a study in 1989 in an attempt to revise Gustafson's method for the determination or estimation of age. They redrew the regression line originally created by Gustafson and also recalculated the formula that Gustafson originally published. Their results were identical to the result obtained by Maples and Rice in 1979. According to the authors of this article, they found that the recalculated "new" formula is:

Estimated age (in years) = (4.26 X overall value of added scores) + 13.45

This is the exact formula created by Maples and Rice (1979). Nkhumeleni *et al.* also found a standard or average error of about 7.03 years, which again is identical to that found by Maples and Rice (1979). They discovered that in persons younger than 30 years, the

regression line created by Gustafson, under-estimated the individual's age by about 1 to 2 years. In persons older than 60 years, the regression line over-estimated the age also by about 1 to 2 years (Nkhumeleni *et al.*, 1989).

- In 1990, Kashyap and Koteswara-Rao used the same continuous scale as that used in the study previously done by Bang and Ramm (1970) to measure the extent of the translucency of the dentine of the root, attrition, secondary dentine and apposition of cementum. They worked out a separate regression line for every type of tooth geometrical point (or locus) by using this point as a function of the age. The mean value of these separate age estimations was then used to calculate an individual's age (Kashyap and Koteswara-Rao, 1990).

- Lucy *et al*. undertook a study in 1995, which compared three of the above-mentioned methods for the determination of age in adults. They measured the six age-related changes originally used by Gustafson, and then used Maples and Rice's version of the regression line (1979) originally created by Gustafson, the regression line created by Johanson (1971) and the regression line calculated by Bang and Ramm (1970) to estimate the individual's age. They concluded that the most accurate results in the determination of an individual's age can be obtained when more than one method for the estimation of age is combined (Lucy *et al.*, 1995).

- In 2013, Shrigiriwar and Jadhav undertook a study in India, using the 6 parameters of Gustafson's method of age estimation to estimate the ages of 80 cases. They added the scores of the 6 parameters and used the totals, in conjunction with the individual's real age, to draw up a new regression line (Shrigiriwar and Jadhav, 2013). They also derived a new regression formula:

Estimated age (in years) = (3.71 X overall value of added scores) + 16.03

Using this formula, they found an average difference between the known and estimated age of ± 4.43 years, which was more than the 3.63 years found by Gustafson (Shrigiriwar and Jadhav, 2013).

2.3.3 Teeth used in the different studies

- In 2003, Monzavi *et al.* undertook a study testing the accuracy of Gustafson's method for age estimation on cadavers from Iran. They also found that the most accurate results were obtained when all six of the age-related changes were used and when the first premolar was used as the tooth for examination. Their study found an average error in the estimation of age of about 6.4 years. They also suggested that when teeth that dried out are used, as opposed to freshly extracted teeth, it could have an influence on the accuracy of the estimation of the individual's age. An explanation for this occurrence was not put forward (Monzavi *et al.*, 2003).

- Also in 2003, Soomer *et al*. did a study using eight of the methods that were used in the past to estimate age in adults. These methods included those proposed by Bang and Ram (1970), Johanson (1971), Solheim (1980), Lamendin (1992) and Kvaal (1994) and entailed examining both in situ and sectioned teeth. The mean error of age estimation was assessed for every method. They found that more accurate results were obtained when teeth which were sectioned were used, as compared to teeth which were intact. The study concluded that every method for the estimation of age mentioned above provided a different mixture of precision, accuracy and procedure. According to the authors, every case of age determination should be evaluated and the method best suited for the particular situation chosen (Soomer *et al.*, 2003).

2.3.4 The different methods of age estimation compared

- In 2006, Reppien *et al*. studied and evaluated seven of the different methods for the estimation of age. They most often applied the methods used by Bang and Ramm (1970) and that used by Gustafson

(1950) and Johanson (1971). They found a mean difference of 4.5 years between the age that was estimated and the individual's actual age and concluded that these methods were indeed reliable (Reppien *et al.*, 2006).

2.3.5 Gustafson's method of age estimation replicated

- Singh *et al.* (2004) undertook a study (in Patiala) in order to re-evaluate the physiological age-related changes in teeth originally used by Gustafson. They found a mean difference of age of about 2.16 years between the estimated age and the individual's real age. They also found that attrition had a larger influence in the males examined. According to Singh this method can be continued to be used in the estimation or determination of age (Singh *et al.*, 2004).
- Bajpai (2011) undertook a study in Jaipur, replicating Gustafson's method of age estimation, to estimate the ages of 20 teeth (extracted from patients whose real age was known). He preferred to use canines, but premolars and incisors were also used. He used very strict exclusion criteria and excluded all patients with a drug and medical history, patients with trauma caused by occlusal forces and patients who presented with abnormal oral habits. Bajpai found a mean difference of 4.86 years between the real and the estimated ages, which was more than the mean difference of 3.63 years found by Gustafson (Bajpai, 2011).

It is obvious that Gustafson's method for the estimation of age is of great importance in forensic dentistry, and that it forms the basis for all the other subsequent techniques and methods that followed its development. The fact that the accuracy of this method has been disputed for several years cannot be ignored though.

Many studies have been performed over the years in order to either prove or disprove this method. These studies were done in several different countries including Sweden (Gustafson, 1950), Scandinavia (Bang and Ramm, 1970;

Johanson, 1971), France (Haertig *et al.*, 1985), Limpopo, South Africa (Nkhumeleni *et al.*, 1989), Australia (Richards and Millar, 1991), Germany (Lampe and Roetzscher, 1994), China (Li an Ji, 1995), England (Lucy *et al.*, 1995), America (Pigno *et al.*, 2001), Iran (Monzavi *et al.*, 2003) and India (Rai *et al.*, 2006; Shrigiriwar and Jadhav, 2013), to name just a few. None of these studies however were conducted in the Western Cape, in South Africa.

Gustafson's method of age estimation has been used on unidentified individuals at the Salt River and the Tygerberg medico-legal laboratories on a regular basis. The Western Cape does however have a population that is formed by numerous ethnic groups and cultures. A wide diversity in socio-economic circumstances, eating habits, oral hygiene habits and smoking habits also exist, which can all play a role in the age-related changes of a tooth.

This begs the question: Is Gustafson's method of age estimation of teeth accurate when applied to the people of the Western Cape?

Chapter 3

Aim, objectives and hypothesis

3.1 Aim

The aim of this study is to determine the accuracy of Gustafson's method of age estimation of adult teeth when applied to a sample of the adult population of the Western Cape.

3.2 Objectives

The objectives of this study are to:

- Test the accuracy of Gustafson's method of age estimation when applied to adult teeth from people of known chronological age of the Western Cape.
- Evaluate the degree of accuracy of this method when applied to adults of the Western Cape.
- Evaluate the consistency and uniformity of Gustafson's method of age estimation by comparing the results found by two independent examiners.

3.3 Hypothesis

Gustafson's method of age estimation does not fit the adult population group of the Western Cape.

Chapter 4

Methodology

This study was conducted as a descriptive study, with an analytical component. It included two examiners, each of whom independently estimated the ages of the teeth collected. Both examiners used the same tooth sections prepared for each case, but at different times. One examiner incidentally had more experience using dental age estimation than the other. (The level of experience of the examiners was not of particular importance for this study.) There was no time limit allocated to the age-estimation process and each examiner could use the time that he/she required to complete each case. The examiners did not know the chronological age of the individual from whom the tooth was extracted. The chronological age was only revealed during the comparison of the estimated age with the real age.

Caries-free central and lateral mandibular incisors (tooth numbers 32, 31, 41 and 42) and maxillary central incisors (tooth numbers 11 and 21) were collected from the UWC Oral Health Centre at Tygerberg Hospital. These teeth were collected after they were extracted as part of routine dental treatment, which resulted in only a limited number of teeth available for the study. As a result, an additional source of teeth was used. Caries-free central and lateral mandibular incisors and maxillary central incisors were harvested from the dissected cadavers used in the Anatomy and Histology Department of the Faculty of Medicine and Health Sciences of the University of Stellenbosch. These teeth were harvested with special permission from Prof. B. Page, Head of the Anatomy and Histology Department of the Faculty of Medicine and Health Sciences of the University of Stellenbosch.

Only caries-free mandibular central and lateral incisors (tooth numbers 32, 31, 41 or 42) and maxillary central incisors (tooth numbers 11 or 21) extracted from patients or cadavers of known chronological age, who were between the ages of 21 and 76 years, were included in this study.

Carious teeth, restored teeth, endodontically treated teeth and teeth that presented with either crown or root fractures were excluded from the study. Teeth that were extracted from patients or cadavers of unknown chronological age or extracted from patients younger than 21 years of age were excluded.

The teeth were stored in labeled specimen jars containing 10% Formalin. The teeth that were collected from the UWC Oral Health Centre at Tygerberg Hospital were stored in specimen jars with labels that showed the patient's name, sex, ethnic group, the date of birth, the date of extraction and the FDI tooth number of the extracted tooth (Appendix A.1). Each patient was also asked to complete a consent and information form (Appendix A.2) and received a separate information form to take home (Appendix A.3).

(Note: The consent forms were only completed by the patients from whom the teeth were extracted. The consent forms were unnecessary in the cases where the teeth were harvested from the cadavers.)

The teeth harvested from the cadavers were stored in labeled specimen jars showing the cadaver number and the FDI tooth number of the extracted tooth. Details regarding the date of birth, date of death, sex and ethnic group of each cadaver were obtained from Mr. April from the Anatomy and Histology Department of the Faculty of Medicine and Health Sciences of the University of Stellenbosch.

The teeth collected from patients were given random numbers for analytical purposes. The cadaver numbers were used for the teeth collected from the cadavers. The teeth were then sectioned in the long axis of the tooth (from the labial surface to the lingual surface), using the Isomet circular saw (Figure 1). The thickness of each section was standardized at 100μm.

Figure 1 Isomet circular saw used to cut the teeth.

Figure 2 Tooth section mounted on a glass microscope slide.

The tooth sections were subsequently mounted on glass microscope slides, embedded in DPX® (from Leica Microsystems) and covered with a glass cover slip (Figure 2).

Age estimation of each tooth was then undertaken independently by the two examiners using the Gustafson's method of age estimation (Appendix B). Using this method, the degree of attrition of enamel and dentine, change of the level of periodontal attachment, the extent of secondary dentine deposition within the pulp, the apposition of cementum on the root surface, the resorption of the root apex and the transparency or translucency of the root was given a value for each tooth. The range of the values was between 0 and 3, with the value 0 meaning the change is not present, and 3 meaning the change is severe (Gustafson, 1950; Metzger *et al.*, 1980; Willerhausen *et al.*, 2012).

The regression line compiled by Gustafson was then used to estimate the age of the individual from whom the tooth was extracted (Appendix B.10).

This estimated value was subsequently compared to the chronological age of the person from whom the tooth was extracted. The results of the comparisons were

statistically analyzed in order to determine the degree of accuracy of the Gustafson's method of age estimation.

Chapter 5

Results

A total number of 84 teeth were collected for this study, of which 29 teeth were excluded. The reasons for the exclusions are summarized in Table 1.

Table 1 A summary of the reasons for exclusion of 29 teeth from the study.

Number of teeth	Reason for exclusion
19	Date of birth of donor unknown
4	Caries on teeth
2	Patients did not sign consent forms
1	Restoration on tooth
2	Root fracture
1	Patient younger than 21 years

As a result, a total of 55 teeth were finally used to conduct the study. Of these 55 teeth, 52 teeth were harvested from cadavers and 3 teeth were extracted from patients.

The information obtained regarding the cadavers and patients from whom the teeth were harvested or extracted are summarized in Table 2.

Table 2 The information obtained regarding the cadavers and patients from whom the teeth were harvested or extracted.

Case Number	Gender	Ethnic group	Date of birth	Date of death/ extraction	Tooth number
K97-09	M	C	6/18/1972	11/11/2007	41
K84-10	M	C	12/14/1969	6/12/2010	41
K165-10	M	C	9/30/1948	11/19/2010	31
K06-11	M	C	9/15/1973	12/28/2010	41
K10-11	F	C	6/19/1966	12/23/2010	41
K13-11	F	B	6/18/1963	12/15/2010	41
K15-11	M	B	1/28/1978	12/27/2010	31
K18-11	F	C	1/7/1935	12/22/2010	31
K41-11	F	C	1/26/1982	4/5/2011	41
K43-11	F	C	2/15/1979	4/15/2011	42

Case Number	Gender	Ethnic group	Date of birth	Date of death/ extraction	Tooth number
K44-11	M	W	1/10/1963	4/15/2011	41
K46-11	M	C	11/5/1956	3/15/2011	41
K47-11	M	B	1/16/1947	3/28/2011	42
K55-11	M	B	5/3/1968	4/23/2011	41
K59-11	M	C	7/13/1977	5/13/2011	41
K64-11	F	C	12/25/1963	5/18/2011	41
K72-11	M	B	9/5/1975	5/7/2011	41
K75-11	M	B	1/5/1975	5/26/2011	31
K80-11	M	B	3/4/1973	6/18/2011	31
K101-11	M	C	7/14/1961	7/9/2011	11
K102-11	M	B	5/5/1962	7/9/2011	41
K120-11	F	C	1/30/1958	8/5/2011	41
K125-11	M	C	6/22/1972	8/24/2011	31
K126-11	M	C	8/2/1966	8/21/2011	31
K161-11	M	B	8/15/1963	11/15/2011	41
K179-11	M	C	12/1/1961	11/8/2011	41
K3-12	M	C	12/20/1969	12/11/2011	41
K6-12	M	C	10/5/1946	12/27/2011	42
K13-12	M	C	5/1/1955	1/11/2012	41
K16-12	F	C	3/17/1983	12/9/2011	41
K17-12	M	B	2/12/1960	1/19/2012	42
K18-12	M	C	12/1/1972	12/28/2011	41
K20-12	M	C	1/1/1963	12/14/2011	41
K25-12	M	B	10/10/1972	1/10/2012	41
K27-12	M	C	6/17/1945	1/25/2012	41
K28-12	F	B	1/1/1950	1/30/2012	32
K31-12	M	W	10/6/1966	2/10/2012	41
K52-12	M	C	3/21/1955	4/15/2012	41
K60-12	F	C	9/19/1990	4/30/2012	41
K67-12	M	C	1/1/1966	5/4/2012	41
K74-12	F	C	6/18/1979	5/30/2012	41
K75-12	M	C	6/25/1960	5/2/2012	31
K77-12	F	C	4/22/1980	5/12/2012	41
K78-12	M	C	3/26/1951	5/28/2012	31
K79-12	F	C	3/17/1963	6/2/2012	42
K81-12	M	C	5/23/1963	5/27/2012	41
K83-12	M	C	4/1/1953	6/2/2012	32
K86-12	F	C	10/23/1988	6/2/2012	41
K87-12	M	C	9/6/1988	6/6/2012	41

Case Number	Gender	Ethnic group	Date of birth	Date of death/ extraction	Tooth number
K98-12	M	B	1/1/1970	6/18/2012	31
K100-12	F	C	7/13/1966	6/29/2012	41
K147-12	M	B	12/13/1956	9/22/2012	41
P01-12	M	C	9/8/1991	8/2/2012	11
P03-12	M	C	8/2/1960	11/14/2012	41
P04-12	F	C	7/5/1960	8/3/2012	41

The age range of the tooth donors was between the ages of 21 and 76 years. The mean age of the sample was 45 years. Sixteen (16) of the donors were female and 39 were male. Thirty nine (39) of the donors were of the Coloured ethnic group of the Western Cape, 14 of the Black ethnic group and only 2 of the White ethnic group.

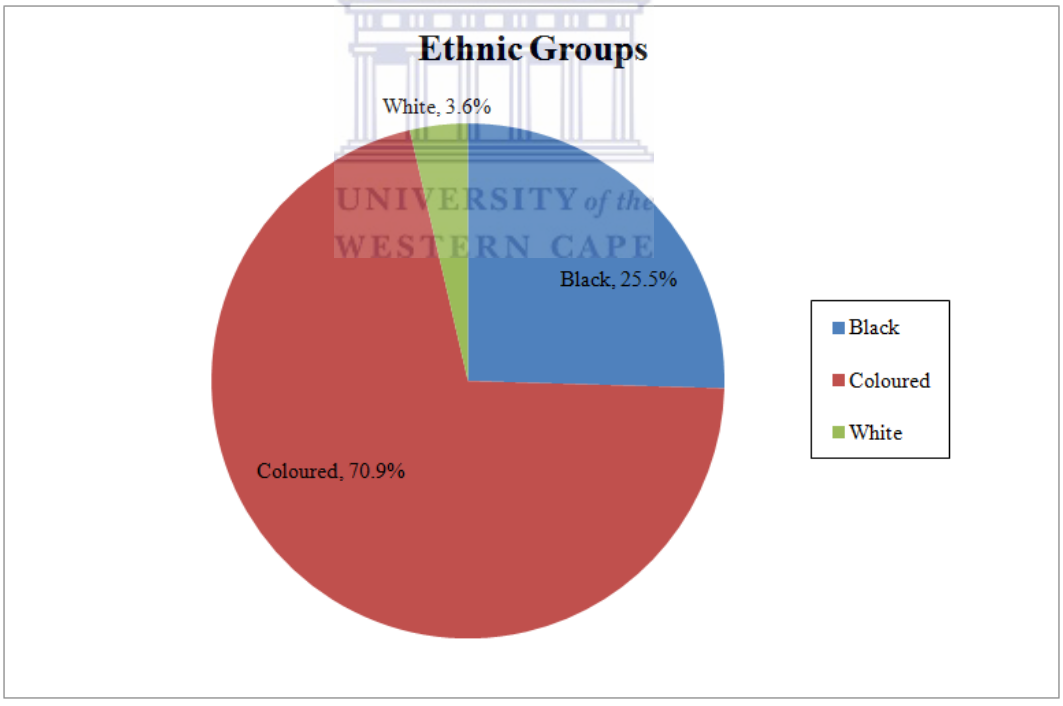

Figure 3 The distribution of the different ethnic groups found in the sample of this study.

(Note: The ethnic grouping is according to the voter demographics of South Africa. These ethnic groups are also similar to the RSA Government categorization on the death certificates. As most teeth were harvested from

cadavers, the 3 cases where the teeth were extracted from patients were also categorized according to this categorization.)

Gustafson's method of age estimation was subsequently used (independently by the two examiners) to determine the ages of the donors from whom the teeth were extracted. The results obtained by both examiners using the 6 criteria specified in Gustafson's method of age estimation are summarized in Table 3. The sum of these values for each case was then used to determine the estimated age. The estimated age of each donor was then compared to the chronological (real) age of that donor (Table 4).

Table 3 The results obtained by the two examiners using the 6 criteria of Gustafson's method of age estimation.

	Attrition		Secondary dentin		Periodontal Attachment Level		Cementum		Root Resorption		Translucency		Total	
Case number	**Examiner Number**													
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
K97-09	1	0.5	0.5	0.5	1	1	2	1.5	1	1	1	1.5	6.5	6
K84-10	1.5	1	3	3	3	2.5	3	2.5	0	0	3	3	13.5	12
K165-10	2.5	2.5	3	3	3	3	1	0.5	1	1	2	2	12.5	12
K06-11	1	1	0.5	0.5	1	1	1	1	2	1.5	2.5	3	8	8
K10-11	1	1	0.5	0.5	1	1	1	1	2	1.5	1.5	1.5	7	6.5
K13-11	1.5	1	1	0.5	2	2	2	2	0.5	0.5	1.5	2	8.5	8
K15-11	1	1	0.5	0.5	1.5	1	2	2	2	2	2	2.5	9	9
K18-11	2.5	2.5	3	2.5	3	2	2	1.5	3	3	3	2.5	16.5	14
K41-11	1	1	0.5	0.25	1	1	1	1.5	1	1	1	1	5.5	5.75
K43-11	1	1	1	1	2	2	1.5	1.5	0.5	1	0.5	1	6.5	7.5
K44-11	3	2.5	3	2.5	2	2	2	1.5	1	1.5	1.5	1	12.5	11
K46-11	1	1	0.5	0.5	1	1	1.5	1	0.5	1	1	1	5.5	5.5
K47-11	1	1	1	1.5	1	1	1.5	1	1	1.5	1.5	2	7	8
K55-11	0.5	0.5	0.5	0.5	1.5	1	2	2	1	1	1	1.5	6.5	6.5
K59-11	2	2	1	1	2	2	1	1	1	1	0.5	1	7.5	8
K64-11	1	1	1	0.5	1.5	1	1.5	1.5	1	1	1	1.5	7	6.5
K72-11	0	0	0.5	0.5	1.5	1	2	2	1	1	0	0.5	5	5
K75-11	2	2	3	3	1	1	2	1.5	2	2	1	1.5	11	11

	Attrition		Secondary dentin		Periodontal Attachment Level		Cementum		Root Resorption		Translucency		Total	
Case number	**Examiner Number**													
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
K80-11	1.5	1	1	1	1.5	1.5	2	2	1	0.5	1	1	8	7
K101-11	2	1.5	3	3	1	1	2	2	2	2	2	2	12	11.5
K102-11	1	1	3	3	2	2	2.5	2	1	1	1	1	10.5	10
K120-11	0.5	0.5	1	1	1	1.5	1.5	1.5	1	1	2	2	7	7.5
K125-11	1	1	0.5	0.5	1.5	1	1	1	0	0	2.5	3	6.5	6.5
K126-11	0	0	0.5	1	1	1	2	2	1	1	1	1.5	5.5	6.5
K161-11	2	1.5	1.5	1	1.5	2	2	2	0	0.25	1	1.5	8	8.25
K179-11	1.5	2	1.5	2	1.5	1.5	2	1	1	1	1.5	2	9	9.5
K3-12	1.5	1	1	1	2	1.5	2	1.5	2	2	1	1	9.5	8
K6-12	1	1	3	3	3	2.5	1.5	1.5	1.5	1.5	2	2	12	11.5
K13-12	1.5	1.5	1.5	1.5	1.5	1	2	2	2	1	1.5	2	10	9
K16-12	1	1	1	0.5	1	1	2	1.5	1	1	1	1	7	6
K17-12	1	1	1	1	2	1.5	1	1	0.5	1	1	2	6.5	7.5
K18-12	1.5	1	1.5	1.5	2	2	1.5	2	1	1	1	1.5	8.5	9
K20-12	0	0	3	3	1.5	1	1.5	2	0.5	0.5	0.5	1	7	7.5
K25-12	2	2	3	3	1.5	1	1	0.5	0	0	2	2	9.5	8.5
K27-12	2.5	2.5	3	3	3	2	1.5	2	1	1	2	2	13	12.5
K28-12	1	1	0.5	0.5	1.5	1.5	2	2	2	1.5	1.5	2	8.5	8.5
K31-12	1	1	0.5	0.5	3	2.5	1.5	1	0.5	0.5	1.5	1.5	8	7
K52-12	1	1	1.5	1.5	3	2.5	1.5	2	1	1	1.5	2	9.5	10
K60-12	1	1	1	0.5	1	1	1	1	0.5	1	1	1	5.5	5.5
K67-12	1.5	1	2	3	2	1.5	1	1	2	1	1.5	1	10	8.5
K74-12	1	1	0.5	0.5	1.5	2	1	1	1	1	1.5	2	6.5	7.5
K75-12	3	3	3	3	3	2	2	2	2	2	1.5	1.5	14.5	13.5
K77-12	1.5	1	1	1	1	1	2	2	1	0.5	0.5	1	7	6.5
K78-12	1	1	0	0.25	2	2	1.5	1	0.5	0.5	2	2	7	6.75
K79-12	2	1.5	3	3	2	2	2	2	1	1	1	1	11	10.5
K81-12	1	1	1	1	1	1	1	1	1	1	1	1.5	6	6.5
K83-12	2.5	2.5	2	2	2	2	2	2	2	2	3	2.5	13.5	13
K86-12	0	0.25	0.25	0.25	3	2	2	2	2	1.5	0	0.5	7.25	6.5
K87-12	1	0.5	3	2.5	1.5	1	2	2	1	0.5	1.5	2	10	8.5
K98-12	1	1	1	1	2	1	1	2	2	2	1	1	8	8

	Attrition		Secondary dentin		Periodontal Attachment Level		Cementum		Root Resorption		Translucency		Total	
Case number	**Examiner Number**													
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
K100-12	1.5	1	1	1	1.5	2	1	1	1	1	1	1.5	7	7.5
K147-12	2	2	3	3	3	3	1.5	1	1	1	1.5	2	12	12
P01-12	1	1	0	0.25	1	1	1	0.5	0.5	1	2.5	2.5	6	6.25
P03-12	1.5	1	3	3	1.5	2	2	1.5	2	1.5	2	2	12	11
P04-12	0.5	0.5	1.5	1.5	3	2	1	1	2	1	0.5	1,5	8.5	7.5

Table 4 A comparison of the estimated ages (obtained using Gustafson's method of age estimation) and the chronological (real) ages of the tooth donors.

Case number	**Estimated age by Examiner Number**		**Chronological (real) age**
	1	**2**	
K97-09	44	41	35
K84-10	80	72	40
K165-10	75	72	62
K06-11	51	51	37
K10-11	46	44	44
K13-11	54	51	47
K15-11	57	57	32
K18-11	94	83	76
K41-11	39	40	29
K43-11	44	49	32
K44-11	75	67	48
K46-11	39	39	54
K47-11	46	51	64
K55-11	44	44	43
K59-11	49	51	33
K64-11	46	44	47
K72-11	36	36	35
K75-11	67	67	36
K80-11	51	46	38
K101-11	72	70	50

Case number	Estimated age by Examiner Number		Chronological (real) age
K102-11	65	62	49
K120-11	46	49	53
K125-11	44	44	39
K126-11	39	44	45
K161-11	51	52	48
K179-11	57	60	49
K3-12	60	51	42
K6-12	72	70	65
K13-12	62	57	56
K16-12	46	41	28
K17-12	44	49	51
K18-12	54	57	39
K20-12	46	49	48
K25-12	60	54	39
K27-12	78	75	66
K28-12	54	54	62
K31-12	51	46	45
K52-12	60	62	57
K60-12	39	39	21
K67-12	62	54	46
K74-12	44	49	32
K75-12	85	80	51
K77-12	46	44	32
K78-12	46	45	61
K79-12	67	65	49
K81-12	41	44	49
K83-12	80	78	59
K86-12	47	44	23
K87-12	62	54	23
K98-12	51	51	42
K100-12	46	49	45
K147-12	72	72	55
P01-12	41	42	20
P03-12	72	67	52
P04-12	54	49	52

When the estimated ages as calculated by Examiner 1 (using Gustafson's method of age estimation) were compared to the chronological (real) ages of the donors, 0% was accurate, 16.4% of the cases showed a difference of less than 5 years between the estimated and real ages, 23.6% with a difference of between 5 and 10 years, 38.2% with a difference between 10 to 20 years and 21.8% showed a difference of more than 20 years (Figure 4). The mean of the differences (average error) between the real and estimated ages (for Examiner 1) was 13.7 years. The median was 13.0 years and the standard deviation was 9.38 years.

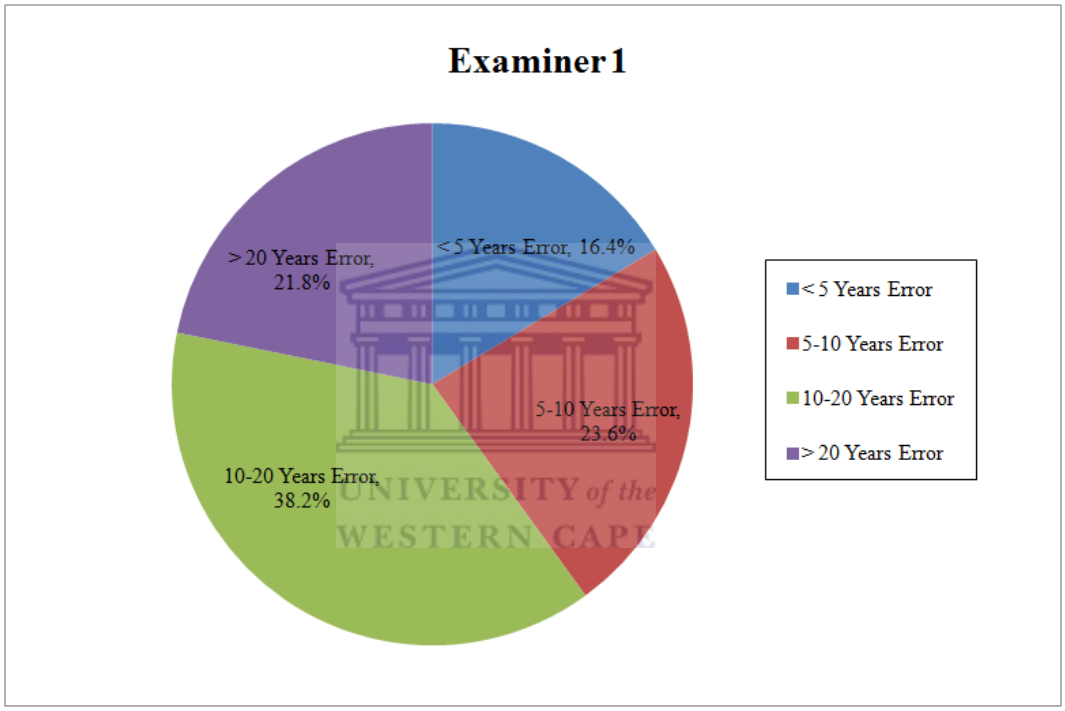

Figure 4 The distribution of the percentages of the sample that shows the differences, in years, between the real and the estimated ages for Examiner 1.

When the estimated ages as calculated by Examiner 2 (using Gustafson's method of age estimation) were compared to the chronological (real) ages of the donors, 0% was accurate, 25.5% of the cases showed a difference of less than 5 years between the estimated and real ages, 21.8% with a difference of between 5 and 10 years, 38.2% with a difference between 10 to 20 years and 14.5% showed a difference of more than 20 years (Figure 5). The mean of the differences (average error) between the real and estimated ages (for Examiner 2) was 11.6 years. The median was 10.5 years and the standard deviation was 8.52 years.

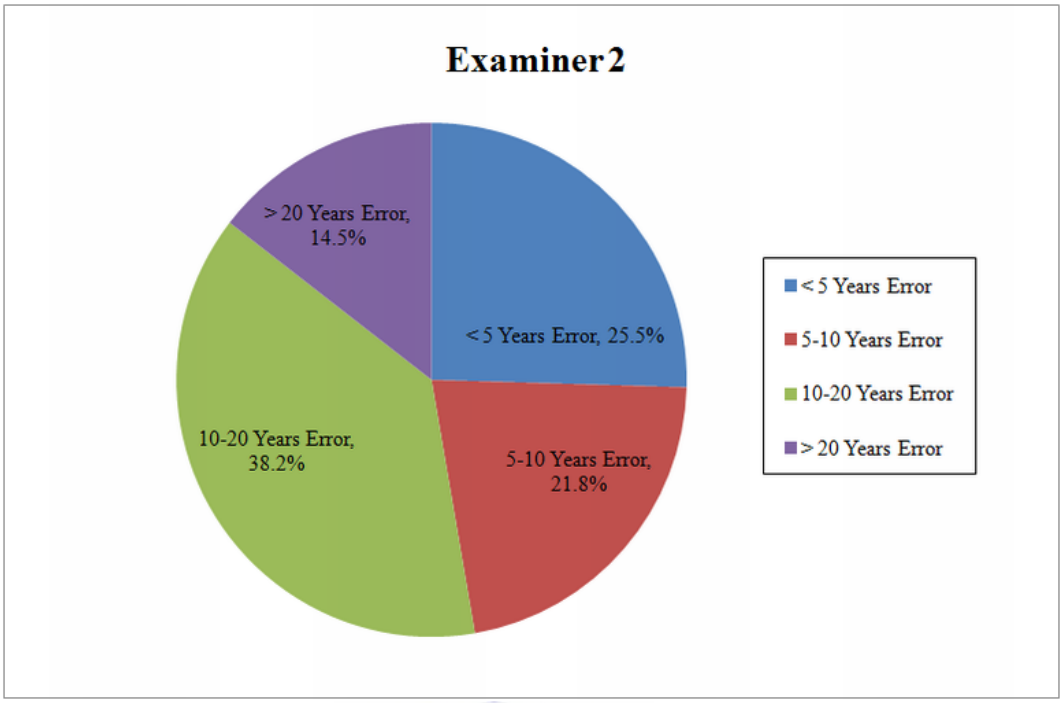

Figure 5 The distribution of the percentages of the sample that shows the differences, in years, between the real and the estimated ages for Examiner 2.

When examining the scatter plot (Figure 6) showing the difference between the real ages and the estimated ages on the one axis, and the real ages on the other axis, the ages were over-estimated in most cases by Examiner 1. The ages were over-estimated in all the cases where the donors were younger than 45 years of age. It is only in donors 45 years of age and older that Examiner 1 under-estimated the ages in 10 cases.

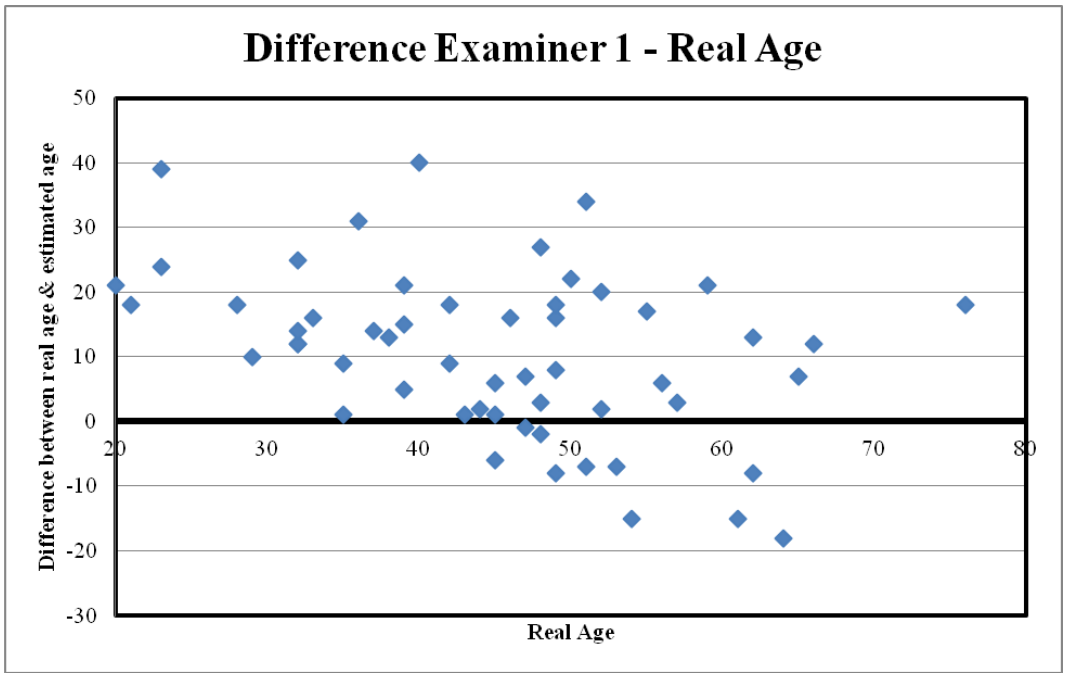

Figure 6 Graph showing the distribution of the cases where the real ages were over-estimated in 45 cases and under-estimated in 10 cases by Examiner 1.

When examining the scatter plot (Figure 7) showing the difference between the real ages and the estimated ages on the one axis, and the real ages on the other axis, the ages were over-estimated in most cases by Examiner 2. The ages were over-estimated in all the cases where the donors were younger than 45 years of age. It is only in donors 45 years of age and older that Examiner 2 under-estimated the ages in 10 cases.

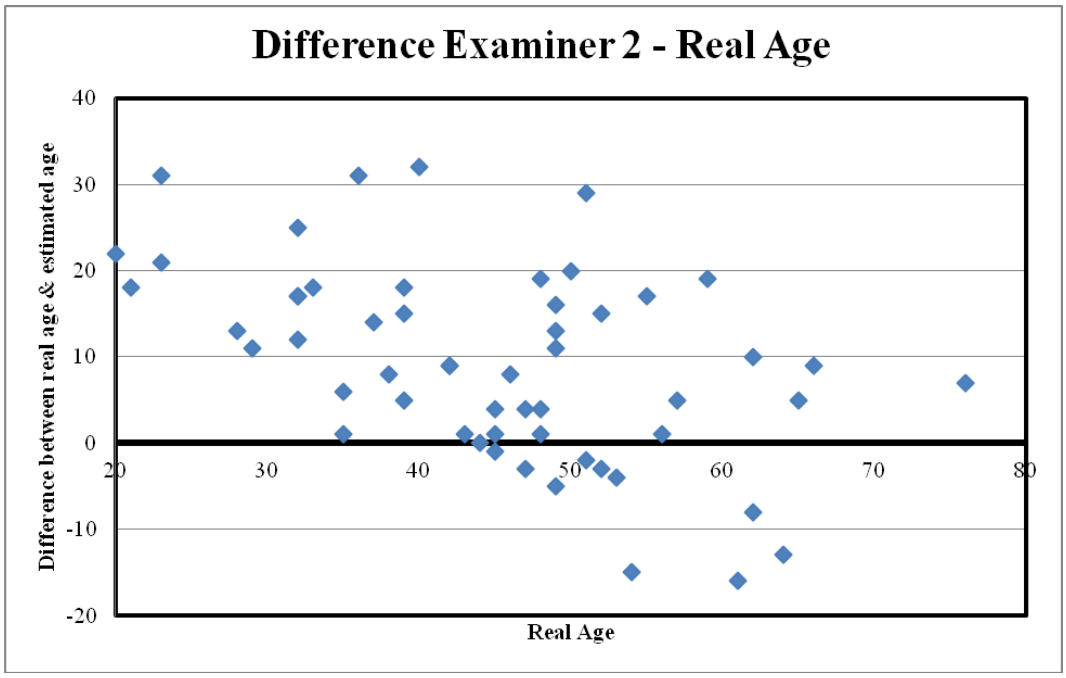

Figure 7 Graph showing the distribution of the cases where the real ages were over-estimated in 45 cases and under-estimated in 10 cases by Examiner 2.

5.1 Statistical analysis

- Using the Student's t-test and p-value (Deacon, accessed 2013; Lowry, 1999-2013) to compare the mean differences (between the estimated ages and real ages) as found by Examiners 1 and 2, it was established that there was not a statistically significant difference between the results found by Examiners 1 and 2, as the p-value > 0.05.

n_1 – sample size for Examiner 1 (55)

n_2 – sample size for Examiner 2 (55)

x_1 – mean found by Examiner 1 (13.7)

x_2 – mean found by Examiner 2 (11.6)

σ_1 – standard deviation found by Examiner 1 (9.38)

σ_2 – standard deviation found by Examiner 2 (8.52)

σ_d^2 – variance of the difference between the means

$\sigma_d^2 = (\sigma_1^2/ n_1) + (\sigma_2^2/ n_2)$

$= (9.38^2/55) + (8.52^2/55)$

$= 2.92$

σ_d = square root of 2.92

$= 1.71$

$t = (x_1 – x_2)/ \sigma_d$

$= (13.7 – 11.6)/1.71$

$= 1.23$

When the t-table is entered at $(n_1 + n_2 –2)$ degrees of freedom (Deacon, accessed 2013; Lowry, 1999-2013), a p-value of > 0.05 is found, which means the difference is not statistically significant.

- Using the Student's t-test and p-value (Deacon, accessed 2013; Lowry, 1999-2013) to compare the mean differences (between the estimated ages and real ages) as found by Examiner 1 and Gustafson, it was established that there was a statistically significant difference between the results found by Examiner 1 and Gustafson, as the p-value < 0.05.

  n_1 – sample size for Examiner 1 (55)

  n_2 – sample size for Gustafson (41)

  x_1 – mean found by Examiner 1 (13.7)

  x_2 – mean found by Gustafson (3.63)

  σ_1 – standard deviation found by Examiner 1 (9.38)

  σ_2 – standard deviation found by Gustafson (3.63)

  σ_d^2 – variance of the difference between the means

  In the original study done by Gustafson, he found that both the average deviation (standard deviation) and the mean error were 3.63 years (Gustafson, 1950).

$$\sigma_d^2 = (\sigma_1^2/ n_1) + (\sigma_2^2 / n_2)$$

$$= (9.38^2/55) + (3.63^2/41)$$

$$= 1.92$$

σ_d = square root of 1.92

$$= 1.39$$

$$t = (x_1 – x_2)/ \sigma_d$$

$$= (13.7 – 3.63)/1.39$$

$$= 7.24$$

When the t-table is entered at $(n_1 + n_2 –2)$ degrees of freedom (Deacon, accessed 2013; Lowry, 1999-2013), a p-value of < 0.05 is found. This means that there is a statistically significant difference between the mean error found by Examiner 1 and Gustafson.

- Using the Student's t-test and p-value (Deacon, accessed 2013; Lowry, 1999-2013) to compare the mean differences (between the estimated ages and real ages) as found by Examiner 2 and Gustafson, it was established that there was a statistically significant difference between the results found by Examiner 2 and Gustafson, as the p-value < 0.05.

  n_1 – sample size for Examiner 2 (55)

  n_2 – sample size for Gustafson (41)

  x_1 – mean found by Examiner 2 (11.6)

  x_2 – mean found by Gustafson (3.63)

  σ_1 – standard deviation found by Examiner 2 (8.52)

  σ_2 – standard deviation found by Gustafson (3.63)

  σ_d^2 – variance of the difference between the means

  In the original study done by Gustafson, he found that both the average deviation (standard deviation) and the mean error were 3.63 years (Gustafson, 1950).

$$\sigma_d^2 = (\sigma_1^2/ n_1) + (\sigma_2^2 / n_2)$$

$$= (8.52^2/55) + (3.63^2/41)$$

$$= 1.64$$

σ_d = square root of 1.64

$$= 1.28$$

$$t = (x_1 – x_2)/ \sigma_d$$

$$= (11.6 – 3.63)/1.28$$

$$= 6.23$$

When the t-table is entered at $(n_1 + n_2 –2)$ degrees of freedom (Deacon, accessed 2013; Lowry, 1999-2013), a p-value of < 0.05 is found. This means that there is a statistically significant difference between the mean error found by Examiner 2 and Gustafson.

Chapter 6

Discussion

Gustafson's method of age estimation is based on 6 criteria, namely attrition, secondary dentine, level of periodontal attachment, cementum apposition, root resorption and root translucency. As mentioned earlier in the literature review, the above-mentioned criteria are influenced by several different factors. These factors include bruxism, diet, number of teeth present in mouth, oral health and habits, orthodontic and occlusal forces and hormonal imbalances (Richards and Brown, 1981; Ekfeldt, 1990; Cawson and Odell, 2002; Neville *et al*., 2002).

All these factors that may possibly affect the different criteria used in Gustafson's method, may result in an inaccurate estimated age. As most of the teeth used in this study were harvested from cadavers, it is impossible to know the specific individual's diet, habits, life style and medical history. These different factors, together with the inaccurate assumptions made by Gustafson, may be the reason why there is such a major difference in this study between the estimated ages (calculated by using Gustafson's method of age estimation) and the individual's real age. Bajpai, who replicated Gustafson's method of age estimation, excluded all patients with a history of traumatic occlusion, any drug or medical history and those with abnormal teeth or oral habits. As a result, the difference found in his study between the estimated and real ages were much smaller than the difference found in this study (Bajpai, 2011).

The mean difference (average error) between the estimated ages and the chronological ages was 13.7 years for Examiner 1 and 11.6 years for Examiner 2, with standard deviations of 9.38 years and 8.52 years respectively. Gustafson claimed that the average error in age estimation using this technique was about 3.63 years (Gustafson, 1950). There is clearly a statistically significant difference between the average error claimed by Gustafson and those found in this study (p-value < 0.05). The results found in this study are also different from those found in other similar studies that were recently done by Bajpai, who found a mean

difference of 4.86 years between the estimated and chronological ages (Bajpai, 2011) and Shrigiriwar and Jadhav who found a mean difference of ± 4.43 years (Shrigiriwar and Jadhav, 2013). These results support the hypothesis of this study and show that Gustafson's method of age estimation is not applicable for the Western Cape's adult population.

This study also found that the ages were over-estimated in most cases by both Examiner 1 and 2, especially in the cases where the donors were younger than 45 years of age. In donors 45 years of age and older, 10 cases were under-estimated. This is consistent with the results found by Solheim and Sundnes (1980). They also found that over-estimation of ages mostly occurred in individuals younger than 40 years and under-estimation in individuals older than 50 years of age (Solheim and Sundnes, 1980).

Mandibular central and lateral incisors (teeth numbers 32, 31, 41 and 42) were mainly used in this study. Maxillary central incisors (tooth number 11) were used in two cases. The teeth chosen for this study usually are, together with the first permanent molars, the first permanent teeth to appear in the mouth. Mandibular central incisors (teeth numbers 31 and 41) usually erupt between the ages of 6-7 years. Mandibular lateral incisors (teeth numbers 32 and 42) and maxillary central incisors (teeth numbers 11 and 21) usually erupt between the ages of 7-8 years (Ash, 1993; Proffit, 2000). Anterior teeth are usually more easily extracted than molars.

The anterior permanent teeth are present in the mouth and exposed to the oral environment for the greatest length of time, and would presumably give the most accurate results when used in age estimation. Other studies have however used several different teeth and have proclaimed more accurate results than those found in this study. This includes studies done by Maples (1978) who used second molars, Monzavi *et al.* (2003) who used first premolars and Bajpai (2011) who used canines, premolars and incisors (in order of preference) (Maples, 1978; Monzavi *et al.*, 2003; Bajpai, 2011).

The different scores used in Gustafson's method of age estimation are based on the examiners impression of the 6 criteria of the individual tooth as seen under the

microscope. As a result, inexperienced examiners find the method quite difficult to use. Inexperienced examiners are therefore usually more likely to obtain less accurate results. However, in this study, it was found that Examiner 2, who in actual fact had less experience than Examiner 1, was more accurate in the estimation of the ages. Although the difference between the results found by Examiner 1 and Examiner 2 were not statistically significant ($p > 0.05$), a method that uses scientific measuring devices to accurately measure the different criteria used in Gustafson's method of age estimation need to be developed, which will help examiners to obtain an even more uniform result.

The results support the hypothesis and prove that Gustafson's method of age estimation is not applicable for the adult population of the Western Cape.

The limitations of this study include the small sample size and the relatively small demographic area in which the teeth were collected. The small sample size is however due to the very strict exclusion criteria. The sample size (55 teeth) in this study is still larger than the sample size originally used by Gustafson (41 teeth) and more recently used by Bajpai (20 teeth) (Gustafson, 1950; Bajpai, 2011).

It is possible that the distribution of the ethnic groups in the present study may be different if the sample size of the study and the demographic area, in which the teeth are collected, is larger. This in turn might have an effect on the accuracy of the method used to estimate an individual's age. Further studies are therefore necessary which will ideally consist of a larger sample size and a wider demographic area in which the teeth are collected.

Chapter 7

Conclusion

Gustafson's method of age estimation was derived more than 60 years ago and was based only on the teeth of Europeans. The present study was undertaken to test the hypothesis that the age estimation of Gustafson was not applicable to the population of the Western Cape. The results showed that Examiner 1 and Examiner 2 over-estimated the ages of 45 of the 55 individuals. Both examiners under-estimated the ages of 10 cases. All the cases where the ages were under-estimated were of individuals who were over 45 years of age. In the 45 cases where the ages were over-estimated the chronological age range was from 21 to 76 years of age. No accurate age estimation was achieved on the sample by either examiner.

The difference between the results found by Examiner 1 and Examiner 2 were not statistically significant ($p > 0.05$). The results of the two independent examiners were found to be consistently and uniformly inaccurate when attempting dental age estimation of the sample.

When the mean difference between the estimated and the chronological ages as found by Examiner 1 and Examiner 2 were compared to the mean found by Gustafson, a statistically significant difference was shown ($p < 0.05$). This further proves that this method of age estimation is not accurate when applied to the people of the Western Cape.

7.1 Further research proposal

- An extended study is necessary, which has to consist of a much larger sample size. The samples will also have to be collected from a wider demographic area.
- A new method that utilizes scientific measuring devices to accurately measure the different criteria used in Gustafson's method of age estimation need to be developed.
- In this study, a new regression line will be drawn up, from which the ages of the adult population of the Western Cape can be accurately determined. It may be necessary to test the different ethnic groups separately and to possibly draw up an individual regression line for each ethnic group.
- It will have to be determined which of the 6 criteria used in Gustafson's method of age estimation are more important, appropriate and effective to accurately estimate the ages of the adult population of the Western Cape.

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APPENDICES

APPENDIX A Labels and Forms

A.1 Label for Sample Bottle

Patient Name: .....

Date of Birth	d	d	m	m	y	y	y	y
Ethnic Group	Black	Coloured	White	Asian	Sex	M	F	
Date of Extraction	d	d	m	m	y	y	y	y
Tooth Number (FDI)	32	31	41	42	11	21		
Dr. S. Chandler				0832775682				

A.2 Consent and Information form accompanying the sample bottle (English and Afrikaans)

MSc (Forensic Dentistry) study

Dr. S.Chandler **Prof. V.M.Phillips**

0832775682 **Consent and Information form**

Section A: Patient

Dear patient

I am currently busy with a research study to estimate a person's age from his/her teeth.

The research is being done only on teeth that are extracted as part of routine dental treatment.

I would like to request your permission to use your extracted teeth as part of my research studies. Participation is voluntary and your dental treatment will not be affected by this study.

Your details will not be published and will remain confidential. No remuneration can be offered.

I, Mr./Mrs./Ms. ……hereby give permission that my extracted teeth may be used for research purposes. I understand and accept all the information mentioned above.

Signature …… Date ……..

Section B: Dentist

To whom it may concern:

I am currently collecting extracted caries-free mandibular incisors (teeth no. 32,31,41 and 42) and maxillary central incisors (teeth no. 11 and 21) for research purposes.

Your help in this matter will be greatly appreciated. Please place the above-mentioned teeth in the sample bottles provided. All the teeth collected from one patient can be placed in the same bottle, but each patient must have a separate bottle (which means 1 patient's teeth per bottle).

Kindly complete this part of the information form along with the label on the sample bottle, as this information is crucial for the study. (Please mark the blocks with an X where applicable.)

Patient name:……

Date of birth	d	d	m	m	y	y	y	y

Ethnic group	Black	Coloured	White	Asian	**Sex**	M	F

Date of extraction	d	d	m	m	y	y	y	y

Tooth number(FDI):	32	31	41	42	11	21

Please keep the sample bottles (with teeth) along with the completed information forms, and I will come and collect it.

Your help is much appreciated.

Dr. S. Chandler

MSc (Forensiese Tandheelkunde) studie

Dr. S.Chandler **Prof. V.M.Phillips**

0832775682 **Informasie en Toestemming vorm**

Seksie A: Pasiënt

Geagte Pasiënt

Ek is besig met 'n navorsing studie om 'n persoon se ouderdom te bepaal vanaf sy of haar tande.

Die navorsing word slegs gedoen op tande wat verwyder/getrek word as deel van roetine tandheelkundige behandeling.

Ek wil graag u toestemming vra om u verwyderde /getrekde tande te gebruik as deel van my navorsing studies. Deelname aan die studie is vrywillig en u tandheelkundige behandeling sal nie beïnvloed word deur die studie nie.

U persoonlike inligting sal vertroulik gehou word en sal nie gepubliseer word nie. Geen vergoeding is beskikbaar vir die deelname in die studie nie.

Ek, Mnr./Mev./Me. ……gee hiermee my toestemming dat my verwyderde/getrekde tande gebruik mag word vir narvorsing. Ek verstaan en aanvaar al die inligting wat hierbo genoem word.

Handtekening…….. Datum……..

Seksie B: Tandarts

Geagte Tandarts

Ek is besig om verwyderde kariesvrye mandibulêre snytande (tand no. 32,31,41 en 42) en maksillêre sentrale snytande (tand no. 11 en 21) bymekaar te maak vir navorsings-doeleindes.

U hulp sal baie waardeer word. Plaas asb. die bogenoemde tande in die verskafde monster botteltjies. Al die tande van 1 pasiënt kan in dieselfde botteltjie geplaas word, maar elke pasiënt moet sy eie botteltjie hê. (1 Pasiënt se tande per botteltjie).

Vul asb. hierdie deel van die vorm en die etiket op die botteltjie in. Hierdie inligting is baie belangrik vir die studie. (Merk asb. met 'n X waar van toepassing).

Pasiënt se naam:……

Geboortedatum	d	d	m	m	y	y	y	y

Etniese groep	Swart	Kleurling	Wit	Asiaties	**Geslag**	M	V

Datum van tand verwydering	d	d	m	m	y	y	y	y

Tand nommer (FDI):	32	31	41	42	11	21

Hou asb. die monster botteltjies (met die tande) en die ingevulde vorms en ek sal dit kom haal.

U hulp word baie waardeer.

Dr. S. Chandler

A.3 Patient information forms (English and Afrikaans)

MSc (Forensic Dentistry) study

Dr. S.Chandler — **Prof. V.M.Phillips**

0832775682

Patient Information Form

Dear patient

Teeth are often used to estimate a person's age, either in the identification process after death or in the living in people who do not have any legal form of identification.

Gustafson's method of age estimation is frequently used for this purpose. This method uses six age-related changes of teeth to determine a person's age.

I am currently busy with a research study to estimate a person's age from his/her teeth using this method. The objective is to find out how accurate this method is when applied to the people of the Western Cape and to create a new, more applicable method if this one is found to be inaccurate.

The research is being done only on teeth that are extracted as part of routine dental treatment. This means that only teeth that were extracted as part of your original treatment plan will be collected for this study.

I would like to request your permission to use your extracted teeth as part of my research studies.

Participation in this study is voluntary and your dental treatment will not be affected by this study.

Your details will not be published and will remain confidential.

No remuneration can be offered.

Your participation is much appreciated.

Dr. S. Chandler

MSc (Forensiese Tandheelkunde) studie

Dr. S.Chandler **Prof. V.M.Phillips**

0832775682 **Pasiënt Informasie Vorm**

Geagte Pasiënt

Tande word gereeld gebruik om 'n persoon se ouderdom te bepaal. Dit word gedoen na 'n persoon se dood in die identifikasie proses, of in lewendige persone wat nie 'n wettige vorm van identifikasie het nie.

Gustafson se metode van ouderdomsbepaling word gewoonlik gebruik vir hierdie doel. Hierdie metode gebruik ses ouderdoms-verwante verskille van tande om 'n persoon se ouderdom te bepaal.

Ek is besig met 'n navorsing studie om 'n persoon se ouderdom te bepaal vanaf sy of haar tande deur hierdie metode te gebruik. Die doel van die studie is om uit te vind hoe akkuraat dié metode is wanneer dit gebruik word vir die mense van die Wes-Kaap en om 'n nuwe metode, wat meer van toepassing is, saam te stel indien Gustafson se metode onakkuraat is.

Die navorsing word slegs gedoen op tande wat verwyder of getrek word as deel van roetine tandheelkundige behandeling. Dit beteken dat tande alleenlik gebruik sal word vir hierdie studie indien dit verwyder of getrek is as deel van u oorspronklike behandelingsplan.

Ek wil graag u toestemming vra om u verwyderde /getrekde tande te gebruik as deel van my navorsing studies.

Deelname aan die studie is vrywillig en u tandheelkundige behandeling sal nie beïnvloed word deur die studie nie.

U persoonlike inligting sal vertroulik gehou word en sal nie gepubliseer word nie.

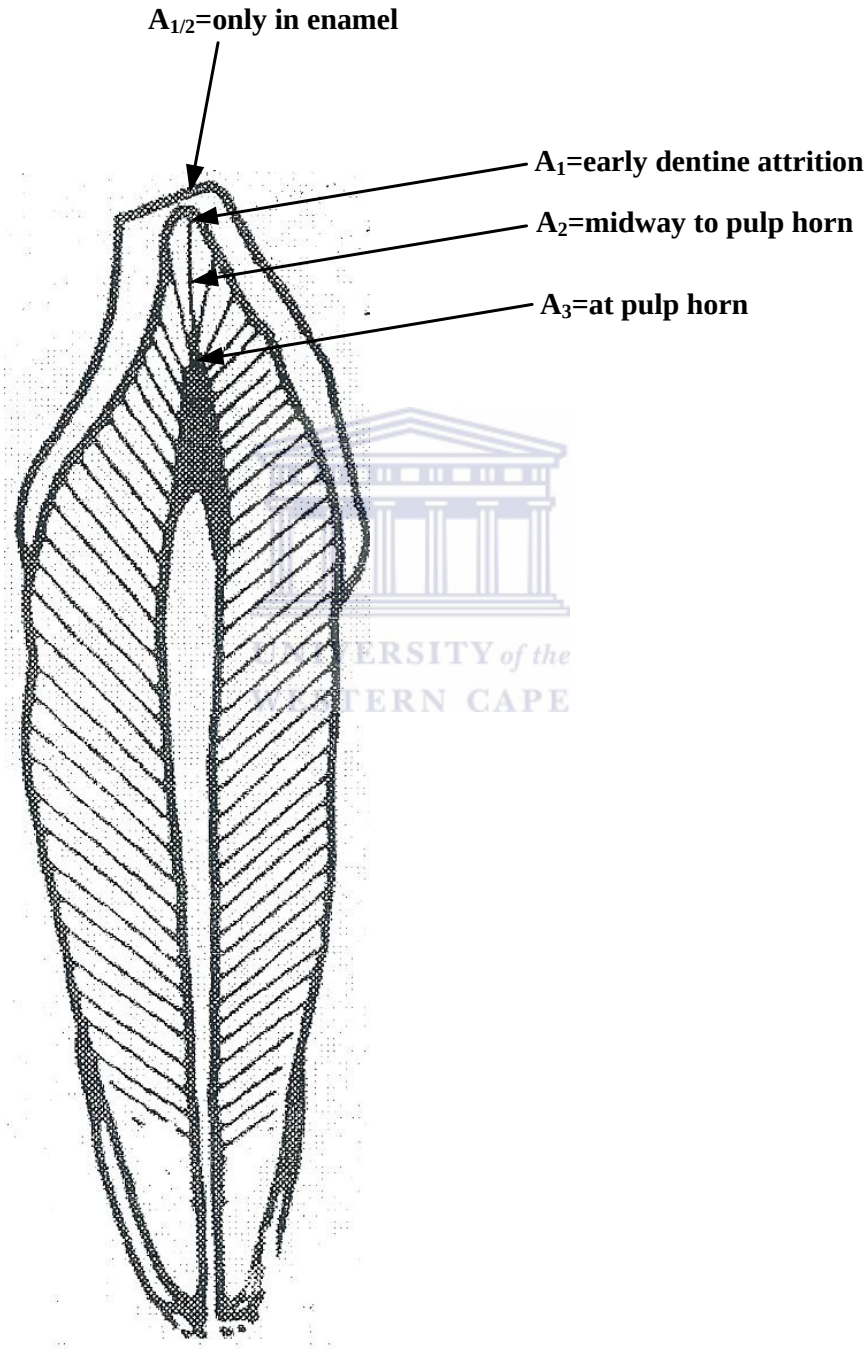
Geen vergoeding is beskikbaar vir die deelname in die studie nie.

U deelname aan die studie word waardeer.

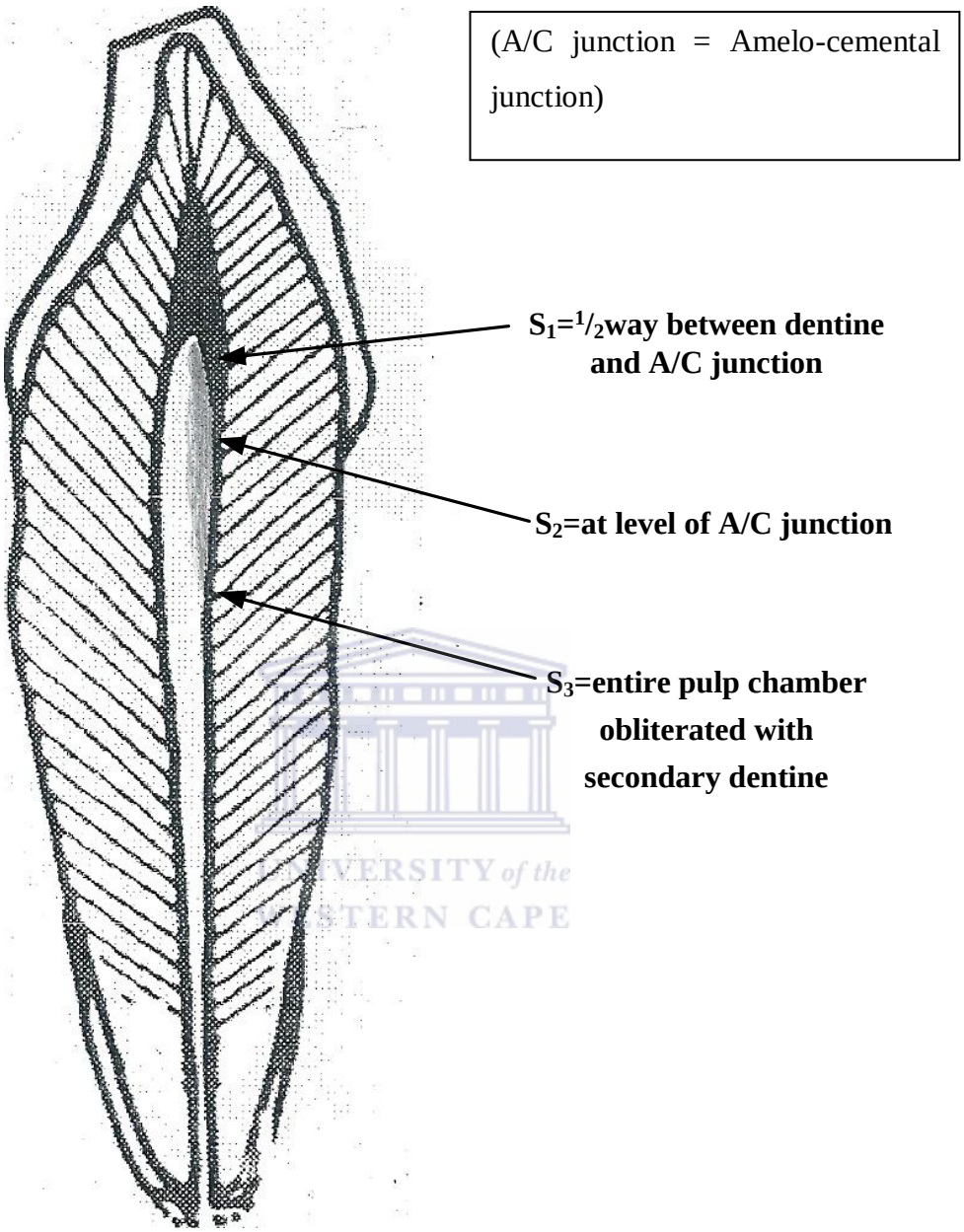
Dr. S. Chandler

APPENDIX B Gustafson's method of age estimation

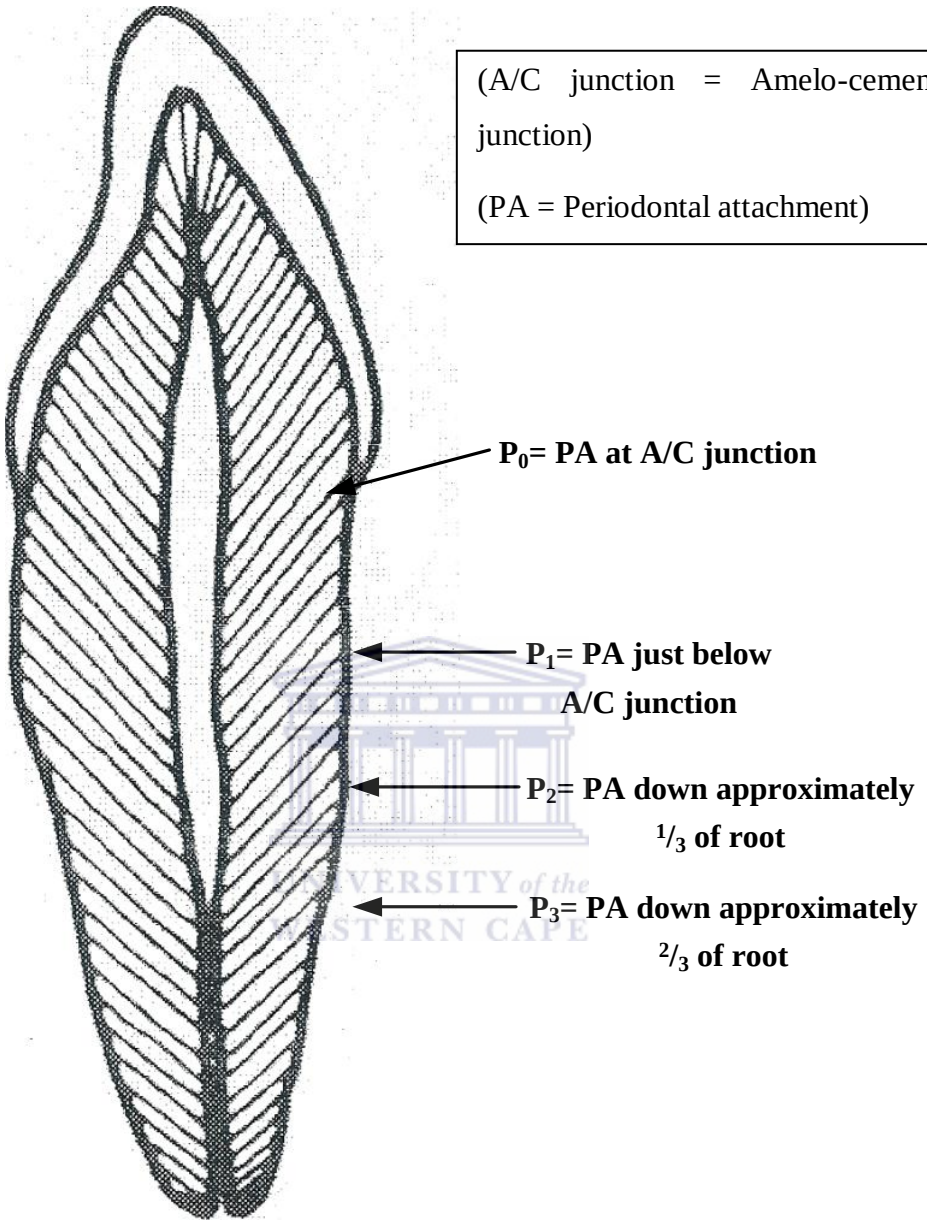
B.1 Attrition



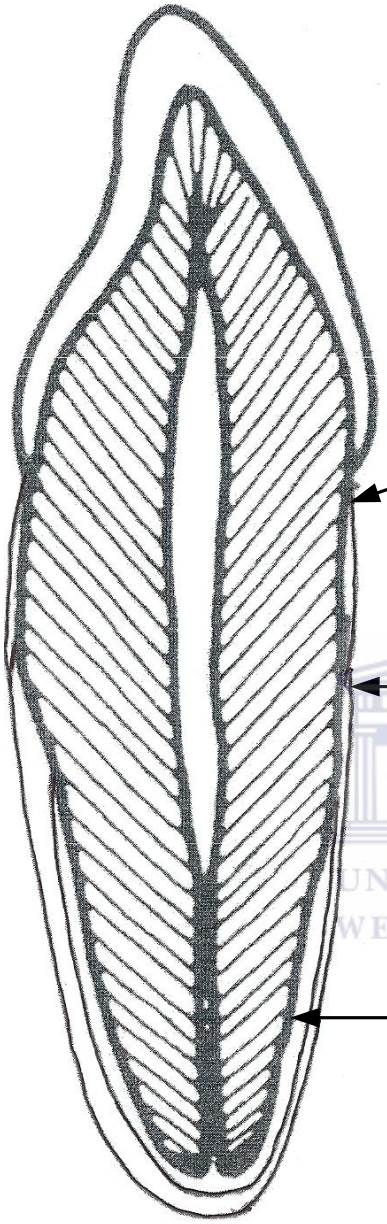
B.2 Secondary dentin



B.3 Level of periodontal attachment



B.4 Cementum (A)



Secondary (or cellular) cementum deposition will start at the apex of the root and then extend towards the amelo-cemental junction (A/C).

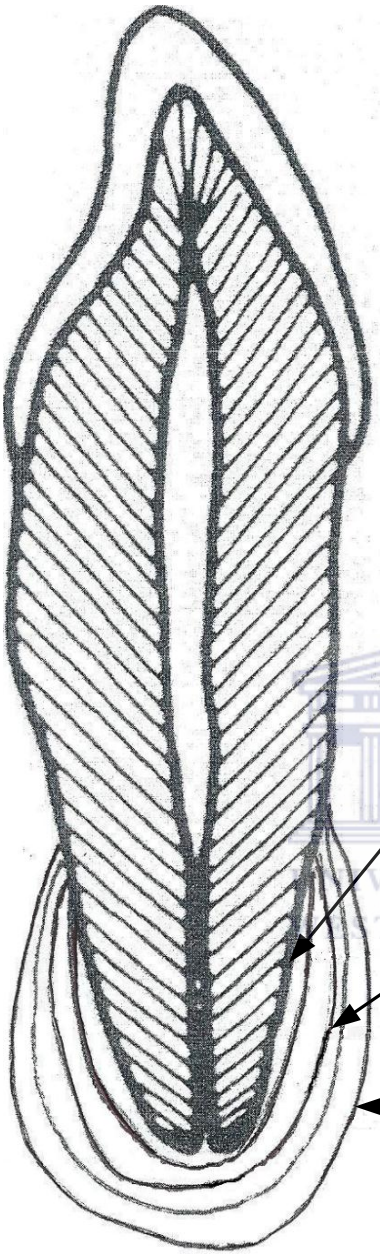
C_3 = Secondary cementum deposition extends to or close to the A/C juntion.

C_2 = Secondary cementum deposition extends approximately $^2/_3$ of the root.

C_1 = Secondary cementum deposition extends approximately $^1/_3$ of the root.

B.5 Cementum (B)

The deposition of cementum can also take place in the form of hypercementosis. A thick ball of cementum then forms at the apex of the root.

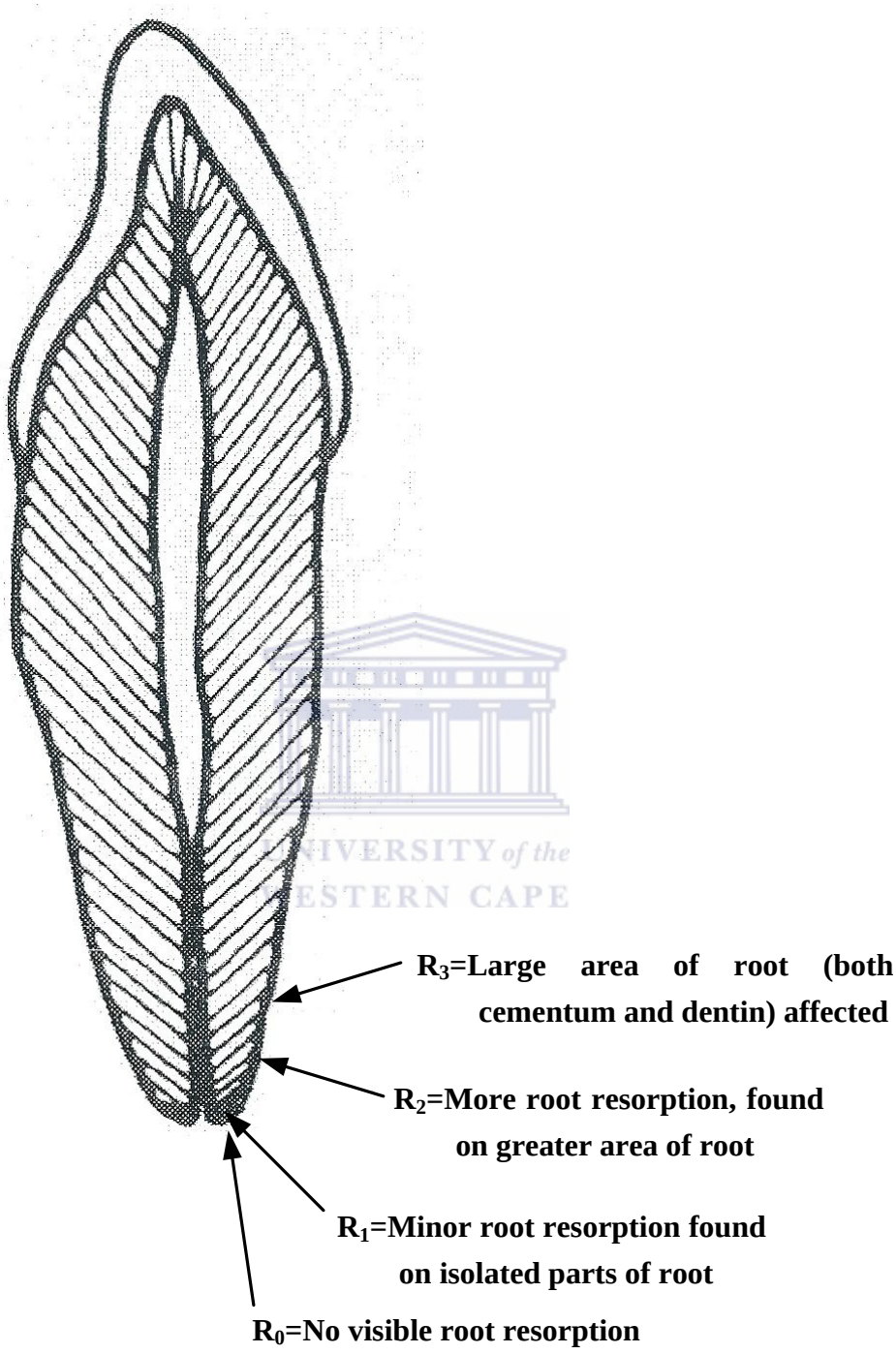


C_1 = A thin layer of secondary cementum had formed at the root apex.

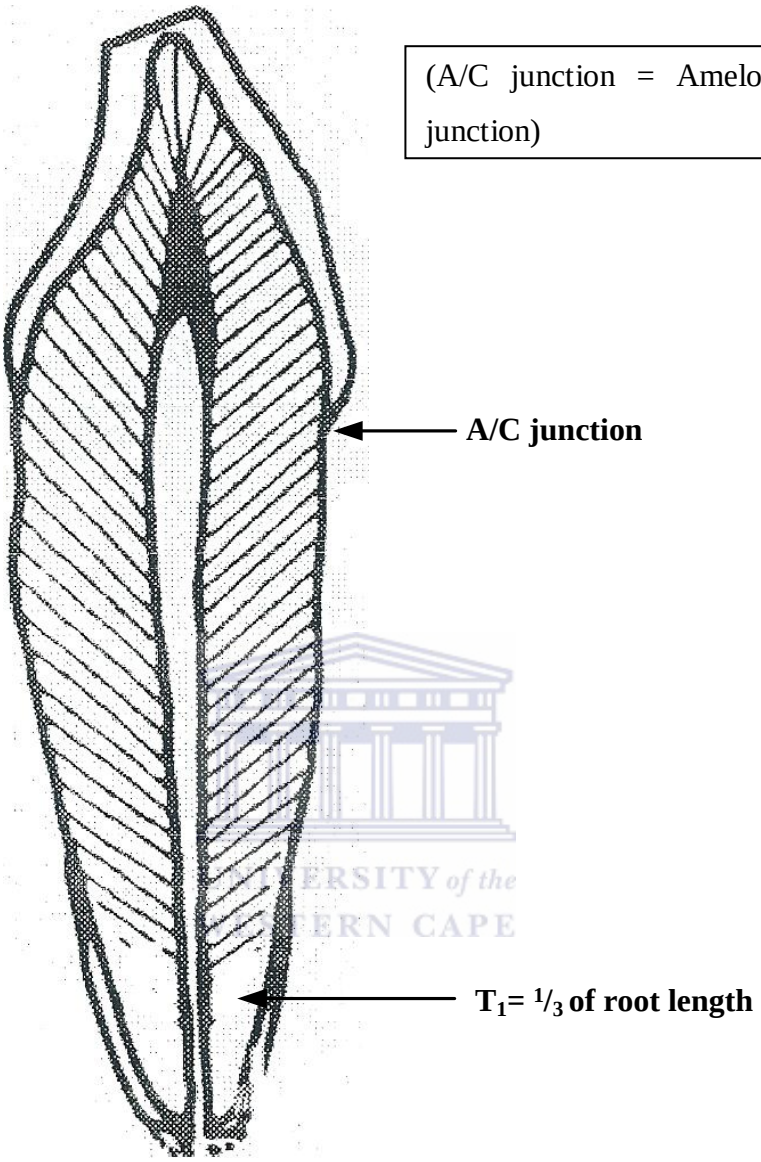
C_2 = The layer of secondary cementum formed is substantial.

C_3 = A thick layer of secondary cementum had formed at the root apex.

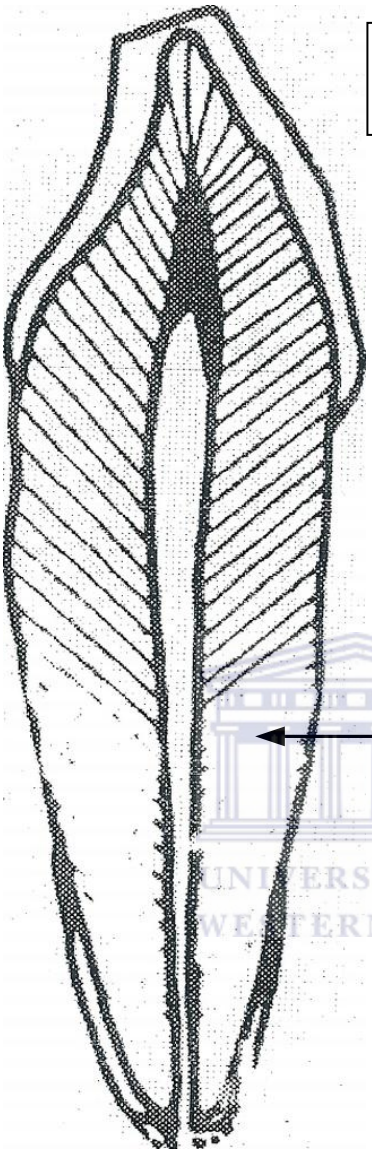
B.6 Root resorption



B.7 Translucency (T_1)



B.8 Translucency (T_2)

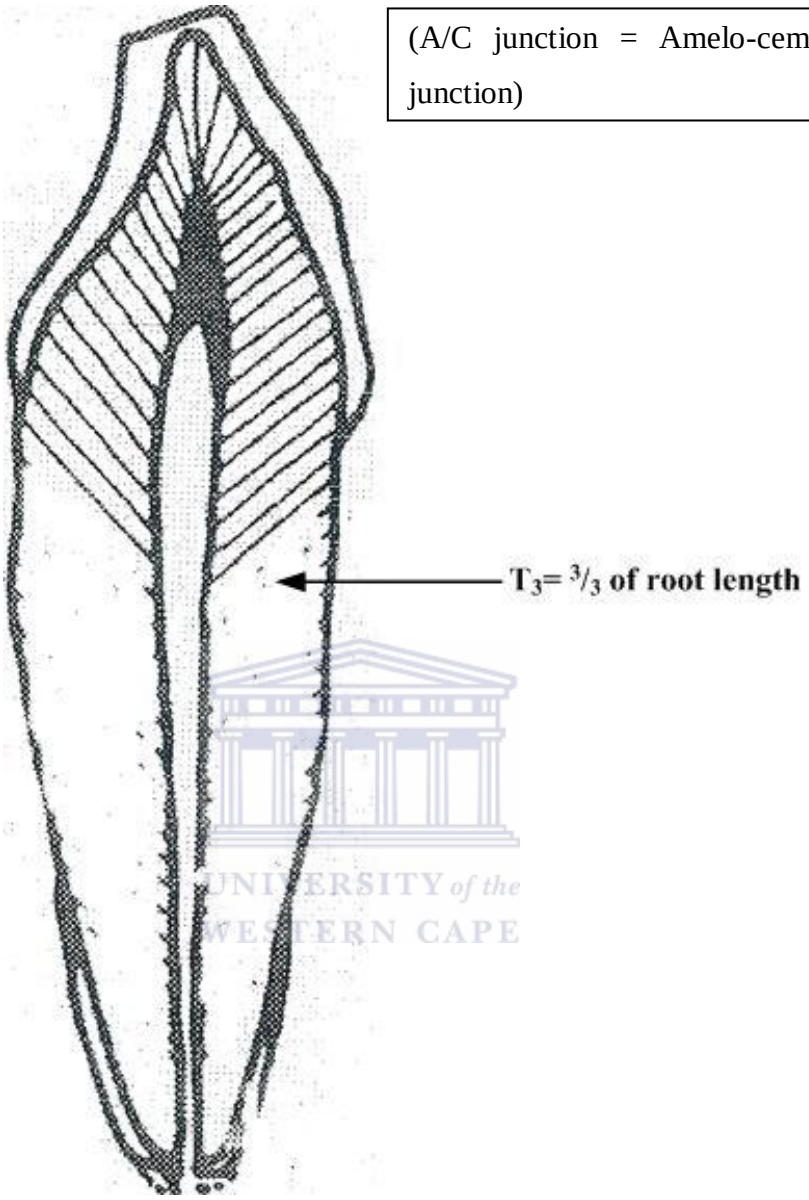


(A/C junction = Amelo-cemental junction)

T_2= $^2/_3$ of root length

B.9 Translucency (T_3)

(A/C junction = Amelo-cemental junction)



B.10 Gustafson's regression line