Cone Beam Computed Tomography Evaluation of Midpalatal Suture Maturation in a Select Western Cape Sample

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A minithesis submitted in partial fulfilment of the requirements for the degree of MChD in the Department of Orthodontics, University of the Western Cape, Cape Town, South Africa,

2019

KEYWORDS

Cone beam computed tomography

Midpalatal suture maturation

Midpalatal suture

Ossification

Chronological age

Skeletal maturity indicator

Rapid maxillary expansion

Surgically assisted rapid palatal expansion

ABSTRACT

Introduction

There is controversy in the literature regarding the ideal treatment timing for rapid maxillary expansion. The successful use of rapid maxillary expansion (RME) has largely been limited to young patients with chronological age being a determinant of the patency of the midpalatal suture. However, there is consensus in the literature that chronological age is not a valid indicator of skeletal age. Additionally, conventional radiology and histology has revealed that the midpalatal suture may be patent in young adults (<25 years of age), with successful RME shown in these patients.

Aim

To determine whether the maturation stage of the midpalatal suture can be predicted by using a classification based on its morphology as observed on cone-beam computed tomography images (CBCT).

Materials and Methods

The sample consisted of 216 patients, 125 female and 91 male, aged 7 to 78 years, who were selected from the radiographic archives of the University of Western Cape. The patients had cone-beam computed tomography images in their initial hospital files. These images were exported to the OnDemand3D^{R} software program (Cybermed Inc, South Korea). The most central axial cross-sectional slices were used to evaluate the suture morphology. The images were interpreted by two

examiners who had been calibrated to evaluate the suture morphology according to five maturational stages; namely stages A-E. Inter and intra-rater reliability were quantified by Cohen's weighted kappa and the Stuart-Maxwell test for bias. The values were 0.94 and 0.92 respectively.

Results

The results of the present study demonstrated a statistically significant association between gender and midpalatal suture maturation (MPSM) stage; it was observed that the proportion of males in stages A/B was higher than in the other stages whereas MPSM stages C, D and E displayed a greater prevalence in females.

Ossification of the midpalatal suture increased with chronological age; the proportion of those aged <12y was higher in stage A/B compared to the other stages while the proportion of those aged >=30y was higher in stage E compared to stages A-C. However, large variations in the degree of closure of the midpalatal suture among subjects of the same age group were observed. Therefore, chronological age is not a useful diagnostic parameter to predict the ossification of the midpalatal suture.

Conclusions

CBCT is a valid tool to assess the patency of the midpalatal suture as a diagnostic aid in the clinical decision between conventional RME and SARPE in patients whose RME treatment appears equivocal.

DECLARATION

I declare that "*Cone Beam Computed Tomography Evaluation of Midpalatal Suture Maturation in a Select Western Cape Sample"* is my own work, that it has not been submitted for any degree or examination in any university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name. Ridwaana Carim   Date: 16 May 2019

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Signature of Candidate

ACKNOWLEDGEMENTS

I wish to express my gratitude to:

Professor Amenah Shaikh, my supervisor, for her time, guidance, motivation and mentorship during the completion of my thesis.

Dr Shoayeb Shaik, my co-supervisor for his guidance and advice on the experimental design, data collection and interpretation.

Dr Petra Gaylard of Data Management and Statistical Analysis (DMSA) for her help with the statistical analysis.

Professor Angela Harris and all my consultants in the Department of Orthodontics, University of Western Cape (UWC), for their support and guidance throughout my orthodontic training.

My fellow registrars for grappling with the challenges of registrarship together and making these past four years truly memorable. Through all the "ups and downs" we made it.

DEDICATION

This thesis is dedicated to my parents, siblings and nieces. You are the light of my life. I thank you for your unrelenting love, support and guidance.

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LIST OF ABBREVIATIONS

CBCT- Cone beam computed tomography

CT – Computed Tomography

CVM – Cervical vertebral maturation

FOV - Field of view

HWR- Hand wrist radiograph

MARPE- Miniscrew-assisted rapid palatal expansion

MPR - Multiplanar reformatting

MPSM – Midpalatal suture maturation

N – Newtons

OR – Odds Ratio

PACS - Picture archiving and communications system

RME – Rapid maxillary expansion

RPE – Rapid palatal expansion

SARPE – Surgically assisted rapid palatal expansion

SMI – Skeletal maturity indicators

UWC – University of Western Cape

Yrs – Years

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CHAPTER 1

1.0 INTRODUCTION

Rapid maxillary expansion (RME) or rapid palatal expansion (RPE) is a commonly used procedure in orthodontics to correct a transverse deficiency of the maxilla and to increase the maxillary arch perimeter in patients who present with mild crowding (crowding of < 5mm) of the dental arches (Bishara and Staley, 1987). RME has also been advocated in the spontaneous correction of Angle Class II malocclusions (Guest *et al.,* 2010) and to facilitate protraction facemask treatment for the early correction of skeletal Class III malocclusions (Da Silva Filho *et al.*, 1998).

The concept of maxillary expansion was reportedly first introduced by Angell in 1860 (cited in Bishara and Staley, 1987). RME remained controversial for nearly a century until Haas (1961) published the results of a study on the rapid expansion of the maxillary dental arch by opening the mid-palatal suture. This validated the use of RME in routine orthodontic practice (Timms, 1999).

It is estimated that the incidence of maxillary transverse constriction in the deciduous and mixed dentitions is 8% to 18% of patients having orthodontic consultations (De Silva Fo *et al.*, 1991). The incidence of maxillary transverse deficiency in skeletally mature people could not be ascertained from the literature (Suri and Taneja, 2008).

The successful use of RME has largely been limited to growing patients and entails the splitting of the midpalatal suture with an appliance that applies high forces of 15–50 newtons to the maxillary and circummaxillary sutures (Lagravere *et al.*, 2005). In patients with further residual or surplus skeletal growth this treatment results in mainly orthopaedic expansion. On the contrary, when it is used for the adult patient or the skeletally mature patient, more dento-alveolar tipping as opposed to skeletal expansion with a more unstable outcome is displayed. Excessive dental tipping is not desirable as it may lead to periodontal complications like loss of attachment, fenestrations, dehiscences and root resorption (Bishara and Staley, 1987). Therefore, the aim of RME is to optimize the skeletal expansion with indiscernible dento-alveolar expansion.

An understanding of the growth, development and ossification of the midpalatal suture is essential in predicting the response to RME in a young child, adolescent or young adult. Growth of the nasomaxillary complex follows a cephalo-caudal pattern; hence skeletal maturation involves progressive closure of the midpalatal and circummaxillary sutures. This leads to increased impedance to RME and eventual failure to separate the hemimaxillae (Proffit *et al*., 2013).

During the infantile period, the suture is a broad gap between the maxillary bones and is filled with connective tissue which appears radiolucent on radiographs as it is not mineralised.

As maturation progresses into the juvenile stage, bony spicules begin to form on the margins of the suture, resulting in a mixture of non-mineralised connective tissue and calcified bone. During the adolescent period, these bony spicules begin to interdigitate leading to calcification and fusion of the suture (Melsen, 1975).

Using autopsy specimens, (Persson and Thilander, 1977) observed fusion of the midpalatal suture in subjects ranging from 15 to 35 years of age. The material consisted of specimens prepared for histology from three areas of the midpalatal suture; namely from a section immediately posterior to the incisive foramen, from a region immediately anterior to the transverse suture and from right side of the transverse suture itself. Their study reported that the mid-palatal suture may be ossified during the juvenile period, however some patients in the third decade showed no signs of fusion. This was later confirmed in a histological study by Knaup *et al.* (2004) and in a computed tomography (CT) study by Korbmacher *et al.* (2007). These authors demonstrated that patients at the ages of 54 and 71 years respectively may show no signs of fusion of this suture. These findings indicate that there is individual variability in the fusion of the midpalatal suture that may be independent of chronologic age. Furthermore, sutural ossification was shown to occur from posterior to anterior and to vary between the genders (Persson and Thilander, 1977; Knaup *et al*., 2004).

To circumvent the complications associated with conventional RME in skeletally mature patients, miniscrew-assisted rapid palatal expansion (MARPE) may be used to increase the possibility of orthopaedic changes in the midface especially in post-pubertal patients, as well as to minimize the negative dentoalveolar consequences that may occur with expansion (Cantarella *et al*., 2018). MARPE is essentially another method of RME that is bone supported as opposed to conventional tooth supported RME appliances.

The surgical approach is another medium used to expand the maxilla. This method is generally employed in young adults and older patients when the midpalatal suture has already fused or when the maxillary transverse constriction is greater than normal. This method entails an intraoperative widening of the maxilla through a multipiece LeFort I osteotomy or a surgically assisted rapid palatal expansion (SARPE) (Suri and Taneja, 2008; Yao *et al.,* 2015). The midsagittal osteotomy line is favoured for SARPE; the rationale being the considerable ossification that has to be weakened in this region (Knaup *et al.*, 2004). However, Proffit *et al*. (2013) have reported that surgical expansion of the maxilla is the least stable of all orthognathic procedures. Furthermore, SAPRE is associated with a large range of adverse surgical complications and morbidity (Suri and Taneja, 2008).

The clinical decision between RME or SARPE to treat maxillary deficiency has traditionally been based on the chronological age of the patient. However, the individual variability in the ossification and fusion of the midpalatal suture has led to a lack of consensus in the literature regarding the age at which transverse maxillary deficiency should be treated surgically (Wertz and Dreskin, 1977; Suri and Taneja, 2008) as successful nonsurgical RME has been reported in young adults with a mean age of mean age of 29 years, 9 months (Handelman *et al*., 2000) and 19 years, 7 months of age (Stuart and Wiltshire, 2003).

In addition to chronological age, other indicators of midpalatal suture maturation (MPSM) that have been proposed include sutural morphology as assessed on occlusal radiographs (Lehman *et al*, 1984), skeletal maturity indicators (SMI) as appraised on a hand-wrist radiograph (HWR) (Revelo and Fishman, 1994), cervical vertebral maturation (CVM) indicators evaluated on lateral cephalograms (Baccetti *et al.,* 2001) as well as the recently suggested five-stage classification of midpalatal suture maturation (MPSM) by Angelieri and colleagues (Angelieri *et al*., 2013).

SMI's and CVM were developed to predict the timing of facial growth, and not to directly quantify facial skeletal maturity (Baccetti *et al*., 2002). Revelo and Fishman (1994) demonstrated that there is an association between SMI's and midpalatal suture maturation, however, only fifty percent of the total midpalatal suture was ossified by the end of puberty.

The occlusal radiograph which is often used for assessing the palatal suture has proven to be unreliable. The limitations encountered includes inadequate visualization of the posterior aspect of the intermaxillary suture because of the superimposition of the vomer and the external structure of the nose on the midpalatal suture (Wehrbein and Yildizhan, 2001). This can lead to misinterpretation of the fusion stage of the midpalatal suture. Furthermore, it is surmised that the midpalatal suture is a straight-running oronasal suture and that the radiographic path projects through this suture. However, the midpalatal suture may not always run in a straight path. If the midpalatal suture is not visible on an occlusal radiograph, it may be because the suture runs in an oblique direction relative to the x-ray path. Therefore a “radiologically closed” midpalatal suture is not analogous to a histologically closed suture (Wehrbein and Yildizhan, 2001).

To circumvent the limitations associated with conventional radiographs, Angelieri *et al*. (2013) described a 5-stage classification system for the midpalatal suture with the use of CBCT images. The authors used the histological classification of Melsen (1975), Persson *et al.* (1978) and Cohen (1993) to define MPSM on CBCT images. These researchers were able to show that the midpalatal suture was not fused in 12% of adult patients (Angelieri *et al.,* 2017). Clinically, it is this subgroup of patients who are difficult to identify. The results of the latter study also validated the cadaver studies that showed no fusion of the mid-palatal suture in subjects of ages 27 years, 32 years, 54 years and even 71 years (Persson and Thilander 1977; Knaup *et al*., 2004; Korbmacher *et al.,* 2007).

Mellion *et al*. (2013) reported that SMI and CVM provides no tangible advantage relative to chronological age in either assessing or predicting the timing of facial growth. However, a more recent study showed strong correlations between SMI’s, CVM and MPSM and relatively weak correlations between gender, chronological age and MPSM (Jang *et al.,* 2016).

In light of the above reports in the literature, the aim of this study was to evaluate midpalatal suture maturation as observed on CBCT images in a population sample attending the University of the Western Cape (UWC). Research on age-specific characteristics of sutural morphology is an important factor to consider for orthodontic treatment planning in patients with constricted maxillary widths. Should maxillary palatal expansion be needed, the use of RME appliances may not produce the desired skeletal effects after synostosis of the midpalatal suture since the resultant effects of RME would largely be dental and unstable. Therefore, a reliable and reproducible tool is needed to determine a more valid diagnostic method for these patients so that an appropriate approach to treatment can be implemented. This will obviate the negative effects of undesired dento-alveolar movement and subsequent periodontal deterioration that may accompany RME procedures when inappropriately used.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Anatomy and maturation of the midpalatal suture

The palate is formed by the palatine processes of the maxillary bones anteriorly and the horizontal plate of the palatine bones posteriorly. The midpalatal suture is the midline suture of the hard palate. It runs anteroposteriorly and divides the palate into right and left halves. This suture is continuous with the intermaxillary suture between the maxillary central incisor teeth. It lies posterior to the incisive canal and connects the palatine processes of the maxillary bones. Between the maxillary and palatine bones there is the transverse suture that runs transversely across the palate between the maxillae and the palatine bones. This suture lies perpendicular to the midpalatal suture (Standring, 2015)

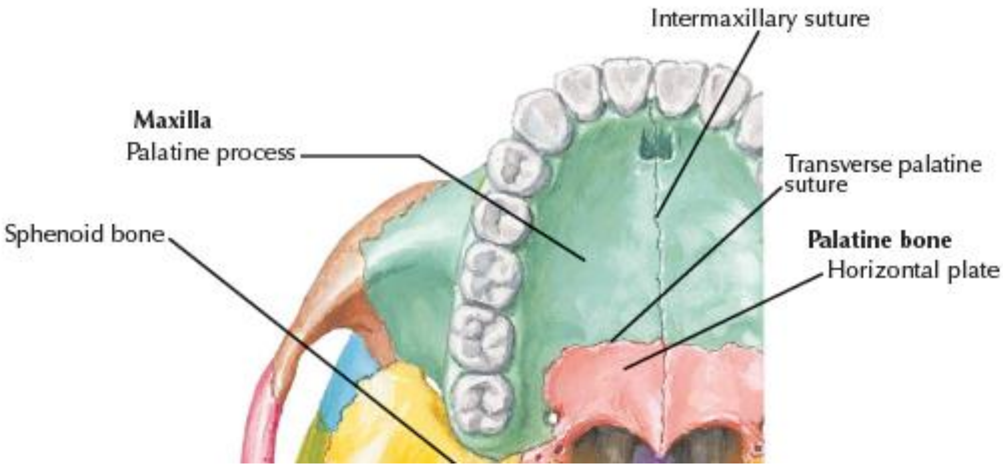

Figure 1: Anatomy of the hard palate (Norton, 2012).

With the use of histology, the midpalatal suture has been described as an end-to-end type of suture that displays distinct changes in its anatomy during growth (Cohen, 1993).

The commencement of obliteration in cranial sutures has been described as a continuous process originating from the suture margins. However, the histology of the start of obliteration of the midpalatal suture is unique. The ossification process in the midpalatal suture is initiated with the formation of bone spicules from the sutural margins along with islands of acellular and inconsistently calcified tissue that is located within the suture (Persson *et al*., 1978; Cohen 1993; Korbmacher *et al.*, 2007). The number of spicules increase with maturation and eventually form many scalloped areas that are close to each other and are separated in some areas by connective tissue. As maturation proceeds, interdigitation increases. This is followed by fusion of the suture that progresses from posterior to anterior (Knaup et al., 2004). Concomitantly with sutural ossification there is resorption of cortical bone in the sutural ends and formation of cancellous bone (Cohen, 1993; Angelieri *et al*., 2013).

Regarding the growth activity of the midpalatal suture, contradicting opinions have been enunciated. Scott reported that growth in the suture terminated at the age of 1 year (Scott, 1956).

In a histological study, Latham observed growth at the age of 3 years (Latham, 1971), whilst Persson identified growth in the suture at the age of 13 years (Persson, 1973 cited in Melsen, 1975). With the aid of implant studies, Bjork and Skieller (1974) confirmed that the growth activity in the midpalatal suture continued for a protracted period than was previously believed.

Palatal growth and suture morphology from birth to adulthood (0 to 18 years of age) were investigated by Melsen (1975). With the aid of histological samples from 60 subjects (33 boys and 27 girls), the author described the maturation process. The maturation of the midpalatal suture was divided into three stages according to the stages of development described by Bjork and Helm (1967). The first stage is the infantile period, in which the suture is very broad and Y-shaped, with the vomerine bone lodged in a groove between the maxillary bones. In the second stage, the juvenile period, bony spicules form on both margins of the suture. This causes a "wavy" appearance of the suture. In the final stage, the adolescent period, the bony spicules become increasingly interdigitated, giving the suture a more tortuous appearance.

A follow up study revealed that the ''adult'' stage of the suture exhibited synostoses as well as multiple bony bridge formations across the suture (Melsen and Melsen, 1982).

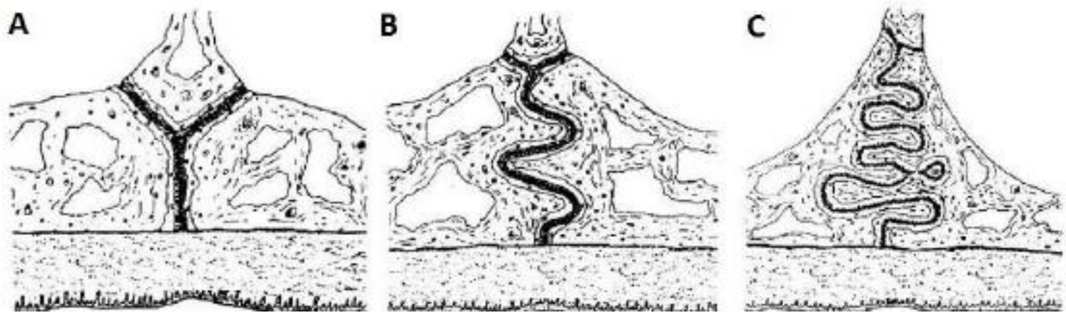

Figure 2: Stages of midpalatal suture maturation in a frontal cross-section. The stages are (A) the infantile period, (B) the juvenile period, and (C) the adolescent period (from Melsen, 1975).

After the ages of 15 in girls and 17 in boys, both the transverse and midpalatal sutures consist of a narrow sheet of connective tissue with inactive osteoblasts. However, Melsen (1975) conceded that histology failed to determine the exact age of closure; i.e. the time point of complete ossification. Histological studies demonstrate inherent limitations in that they represent only a small part of the entire antero-posterior suture length. Therefore, they provide no reliable documentation to the start of physiologic approximation of the suture and exclude a possible approximation outside of these representative areas (Persson and Thilander, 1977).

Persson and Thilander investigated palatal suture closure in subjects aged 15-35 years and reported that fusion of the midpalatal suture begins in the posterior region of the suture, then progresses to the anterior portion. The midpalatal suture also showed inter-individual variation with regard to the start of closure and the rate of progression of closure with age. Different regions of the same suture ossified at different times. The study reported that the mid-palatal suture may be ossified during the juvenile period, however the greatest activity occurred between 20 and 25 years of life. The oldest subject with no signs of ossification was a 27-year-old woman, whilst the earliest ossification was observed in the posterior part of the midpalatal suture in a 15-year-old girl (Persson and Thilander, 1977).

Knaup *et al*. (2004) analysed tissue blocks from the autopsy material of 22 subjects between the ages of 18 to 63 years to determine the width and degree of obliteration of the midpalatal suture. The authors found significant differences in the human midpalatal suture width between younger and older subjects.

The earliest ossifications were observed in the posterior region of a 21-year-old man. The oldest subject without ossification was a 54-year-old man. These observations confirmed the study of Persson and Thilander (1977) who also reported a progression of ossification from posterior to anterior. However, the authors reported that all ossification values were very low. The mean obliteration in the older subjects (>25 years) was only 3.11% of the entire suture area.

The percentage of ossified regions between the different palatal regions (anterior, middle, posterior) amongst the younger (≤ 25 years) and older (>25 years) age groups did not exhibit statistical significance, however, age-related consideration of the distribution of the obliterations delineated that they were mainly in the posterior section in the younger age group. These authors asserted that the presence or absence of midpalatal suture ossification is secondary to the actual percentage of the suture that may be ossified (Knaup *et al*., 2004).

The results of a three-dimensional (3-D) micro-CT analysis showed no statistically significant correlation between progressive closure of the suture and chronological age (Korbmacher *et al*., 2007). The obliteration values that were reported in this study were very low in all age groups. The minimum obliteration value of 0% was seen in a 71-year-old female whilst the maximum value of 7.3% was found in a 44-year old male. These obliteration values were considerably lower than those that were revealed in the histological study by Persson and Thilander (1977) and Knaup *et al*. (2004). The former study showed maximum obliteration rates of 17% whilst the latter study showed maximum obliteration values of 13.10%.

The authors reasoned that the differences in the mean obliteration index between their study and the histological studies were the different diagnostic techniques used, as well as the higher number of slices that 3-D micro-CT provides (Korbmacher *et al*., 2007).

However, with regards to RME, a five percent midpalatal sutural ossification has been set as the limit for splitting the intermaxillary suture (Persson and Thilander, 1977). Based on the above research, the five percent ossification limit will not be reached in most patients younger than 25 years of age (Stuart and Wiltshire, 2003).

2.2. Biomechanics of Sutures

Cranial and facial sutures are connective tissue joints between skull bones that act as sites for bone growth, as well as the absorption and transmission of mechanical stresses generated from either endogenous forces like mastication or exogenous forces such as orthopaedic loading (Mao *et al.*, 2003).

The suture's ability to withstand, absorb and transmit mechanical stresses is related to its primary function of growth. Appropriate mechanical stimuli mediate sutural growth, therefore sutural morphology may be a reflection of the loading conditions under which the suture is subjected to (Mao, 2002). According to Herring and Teng (2000), if a suture functions to reduce stresses transmitted throughout the facial skeleton, the bone at the sutural margins should show more deflection than the surrounding bone. The complexity of sutural interdigitations increase as the magnitude of the load increases. The more complex the interdigitation, the greater are the amounts of deflection that the suture experiences. Sutures become more interdigitated in areas of high stress in order to prevent the bones from becoming disarticulated (Herring, 1993).

Kokich (1976) put forth the suggestion that the age at which sutural synostosis occurs is directly determined by extrinsic functional demands affecting that specific suture area. Functional loading due to mastication is a significant factor in osteogenesis at suture fronts and in the craniofacial skeleton. A soft diet leads to a reduction in masticatory function that is associated with less bone apposition in the facial sutures (Katsaros *et al.*, 2006).

Burn *et al.*(2010) measured the stress and strain experienced at the interparietal, interfrontal and internasal sutures of pigs with strain gauges. These measurements revealed that diet dependant mastication influenced midline sutures. A hard diet resulted in extensive sutural deformation compared to a softer diet . It was thus hypothesized that a softer diet reduced the functional load on the maxillary sutures by altering midline suture growth and bone apposition. It was surmised that a soft diet will have a similar effect in humans, resulting in decreased transverse growth and potential functional aberrations like a posterior crossbite.

2.3 Three-Dimensional Imaging with Cone-Beam Computed Tomography

The literature is replete with studies that have assessed changes to the maxillary transverse dimension with study models or conventional radiographs (Flores-Mir, 2013). However, conventional radiographs present with inherent drawbacks that render it difficult to discern the dentoalveolar effects from the orthopaedic effects. These limitations include magnification of the anatomical area closer to the x-ray source, distortion and superimposition of adjacent structures. To overcome these limitations, 3-D imaging techniques such as CBCT have been advocated.

CBCT is a modern image acquisition technique that has revolutionised the dental field. It utilises a cone-shaped x-ray beam that is directed to a detector. The gantry that houses the source and detector rotates around the patient to produce a series of two-dimensional images. Complex algorithms reconstruct the original acquisition to form a 3-D data set in the x, y and z axis. This provides the three planes that allow us to examine the volume namely: axial, coronal and sagittal (Miles, 2013).

CBCT provides a scanning technique of greater resolution and enables a more precise representation of the midpalatal suture in vivo with minimal image distortion and without any overlapping anatomical structures. It can therefore be an essential tool to aid in the appraisal of midpalatal suture maturation. This will assist with the treatment decision between tooth-anchored RME, MARPE or SARPE (Liu *et al.*, 2015).

Radiography should always be in accordance with the As-Low-As-Reasonably-Achievable Principle (ALARA) and Sedentex CT guidelines because of the attributable lifetime radiation risk (SEDENTEXCT project consortium 2012).

CBCT delivers an effective radiation dose between 20 and 100 microsieverts. This surpasses the conventional two-dimensional panoramic radiograph that has an effective radiation dose between 4 and 10 microsieverts, the cephalometric radiograph that has an effective radiation dose between 3 and 5 microsieverts and a full mouth series that ranges from 12 to 58 microsieverts (Pauwels *et al*., 2012; Tadinada *et al*., 2018). This is dependent on the field of view (FOV), scan time, milliampere setting, peak kilovoltage, voxel size, sensor sensitivity and CBCT imaging unit used. CBCT imaging should be used discriminately in cases where the limitations of two-dimensional imaging impede accurate diagnosis and treatment planning, or justification is apparent that it will provide additional information. Therefore it is indicated in cases where the benefits of CBCT imaging will surpass the associated radiation risk bar the additional cost incurred to the patient (Silva e*t al.*, 2008).

To date, there is a paucity of studies that utilise CBCT imaging for assessing maxillary constriction (Tadinada *et al*., 2018). There are several studies that have assessed the 3D effects of RME treatment on the skeletal and dento-alveolar structures (Garrett *et al*., 2008; Bazargani *et al.*, 2013) and those that have compared different expansion modalities namely; slow maxillary expansion compared to RME

(Martina *et al.*, 2012) and bone anchored to tooth anchored RME (Lagravere *et al.*, 2010).

Rungcharassaeng and colleagues (2007) used CBCT images to quantitatively assess buccal crown inclinations, buccal marginal bone thickness and buccal marginal bone levels in the maxillary posterior teeth after RME. The results of their study indicated that the buccal crown tipping as well as a reduction of both buccal bone thickness and buccal marginal bone levels of the maxillary posterior teeth are immediate effects of RME. These effects can be correlated with the subjects chronological age and initial buccal bone thickness. These results are in accordance with previous reports that with advanced age more dental expansion as opposed to skeletal expansion occurs during RME (Wertz, 1970).

A systematic review published in 2013 concluded that CBCT imaging is a useful tool for the evaluation of treatment effects produced by RME in all three dimensions namely transverse, vertical and sagittal. It was found that the midpalatal suture opening is around 20%–50% of the total screw expansion. However, there was no congruity on whether the midpalatal suture opened in a parallel or triangular manner (Bazargani *et al*., 2013). This is consistent with reports from a more recent systematic review (Liu *et al.*, 2015).

The triangular manner of expansion is due to the interdigitation of the pyramidal processes of the palatine bone with the pterygoid plates of the sphenoid bone and occurs with increasing age (Wertz, 1970).

Furthermore, it was observed that RME has an effect on the circummaxillary sutures, however, the observed changes were small, between 0.30mm and 0.45mm. The sutures that articulated directly with the maxilla; namely the frontomaxillary and the zygomaticomaxillary showed a greater degree of disarticulation (Bazargani *et al*., 2013).

2.4 Tomographic evaluation of the maturation stage of the midpalatal suture

In light of the studies describing the variability among individuals with regards to the time of sutural obliteration, Angelieri *et al*. (2013) proposed a five-stage classification namely; stages A, B, C, D and E (stages are described in the methodology section of this thesis) to evaluate midpalatal suture morphology using CBCTs. Stages A and B are indicative of an immature suture with no suture ossification, while stage C refers to impending suture ossification. Stages D and E allude to suture approximation. When stage D is observed, ossification of the suture has occurred in the palatine bone whilst in stage E, fusion of the midpalatal suture has also occurred in the maxilla.

The study reported by Angelieri *et al.*(2013) validated the variability that has been reported in the literature regarding chronological age and midpalatal suture maturation (Persson and Thilander, 1977). Stage A was observed in early childhood from 5 to 11 years of age while stage B was frequently noted up to 13 years of age. However, stage B was also observed in the older age groups. Stage C was the predominant stage from age 11 to 18 years but was infrequently noted in younger and older age groups. None of the subjects from 5 to 11 years of age presented with stage D or stage E. However, it was found that from the age of 11 to 14 years, 2.1% and 10.4% of the sample presented with stage D and stage E respectively.

Additionally, in subjects between 14 and 18 years of age, 18.8% showed fusion of the midpalatal suture in stage D and 25.0% presented with stage E. Adults displayed great variability with regards to sutural maturation; 53.0% of the adults were in stage E, 31.0% were in stage D, 12.5% had no fused suture and presented in stage C and 3.0% (1 subject) was found to be in stage B (Table 1).

When the genders were compared, in subjects between 11-14 years of age, stage A was present in 4.2% of males, stage B displayed the highest prevalence in both sexes while 25.0% of females had fusion of the midpalatal suture in the palatine (stage D) or maxillary (stage E) bone (Angelieri *et al*., 2013).

For subjects between 14 to 18 years of age, stage B was observed in 23.0% of males and 15.8% of females. Once again, stage C was most frequently observed in both genders; 57.9% of females presented with stage D or stage E. For the same age group, 23.0% of males were in stage D (Angelieri *et al*., 2013).

In subjects older than 18 years of age; 15.8% females and 7.7% of males were in stage C, 78.9% of females and 92.3% of males demonstrated stages D and E (Table 4).

Age in Years	Stage (%)				
	A	B	C	D	E
5-<11	14.3	78.6	7.1	0.0	0.0
11-<14	3.6	58.3	27.0	2.1	10.4
14-18	0.0	18.8	37.5	18.8	25.0
>18	0.0	3.1	12.5	31.3	53.1

Table 1: Distribution of the maturational stages (Angelieri *et al.*, 2013).

Previous studies have demonstrated that RME undertaken in patients under the age of 12 years (Wertz and Dreskin, 1977) or RME commenced before the pubertal growth peak demonstrated greater and more stable orthopaedic changes (Baccetti *et al.*, 2001). Therefore, Tonello *et al*. (2017) sought to identify the midpalatal suture maturation pattern in children aged 11 to 15 years by using CBCT as a comparison for RME prognosis in older patients.

The authors observed all maturation stages. However, the younger age groups displayed a higher prevalence of stages A, B and C (Table 2). The prevalence of stage D and E increased with advancing age as detected at ages 14 and 15 years.

In the distribution between the genders, stages C, D and E, were more frequently observed in females (77.2%) as compared with males (70.0%). This was followed by stage B that showed a prevalence of 20.5% in females and 30.0% in males. The prevalence's of stages D and E in females was 13.6% and 6.8% respectively; in males the prevalence's were 12.5% and 15%, respectively. Stage A displayed the lowest prevalence of 2.3% and was only observed in females (Tonello *et al.*, 2017) (Table 4).

Age (Y)	Stage (%)				
	A	B	C	D	E
11	7.7	30.8	61.5	0.0	0.0
12	0.0	33.3	51.9	11.1	3.7
13	0.0	41.7	50.0	8.3	0.0
14	0.0	6.7	53.3	20.0	20.0
15	0.0	11.8	35.3	23.5	29.4
11-13	1.9	34.6	53.8	7.7	1.9
14-15	0.0	9.4	43.8	21.9	25.0

Table 2: Distribution of the maturational stages (Tonello *et al.*,2017).

In a follow up study, de Miranda Ladewig *et al.* (2018) evaluated CBCT images of MPSM in subjects aged 16 to 20 years. This sample was selected on the basis that RME in this age group is deemed questionable. Analogous to studies reported by Angelieri *et al*. (2013) and Tonello *et al.* (2017), all maturational stages were observed. Stage C was the most prevalent stage encountered in 44.6% of the sample population. This was followed by stages E (24.1%) and D (23.2%).

A comparison between the age categories (16-18 years vs 19-20-year age group) revealed a higher prevalence of stages D and E in the 19-20-year age group. No subjects in this age category presented with stage A (Table 3).

Age (Y)	Stage (%)				
	A	B	C	D	E
16	4.5	13.6	40.9	18.2	22.7
17	0.0	15.4	50.0	19.2	50.0
18	0.0	0.0	54.2	20.8	25.0
19	0.0	0.0	30.4	34.8	34.8
20	0.0	5.9	47.1	23.5	23.5
16-18	1.4	9.7	48.6	19.4	20.8
19-20	0.0	2.5	37.5	30.0	30.0

Table 3: Distribution of the maturational stages (de Miranda Ladewig *et al.*, 2018).

When the two gender groups were compared, stage C was more frequently observed in both males and females. However, more females displayed maturational stages D and E (53.0%), when compared with the males (38.6%) (Table 4).

Study	Age groups (y)	% MPSM									
		Male					Female				
		A	B	C	D	E	A	B	C	D	E
Angelieri *et al.* (2013)	11-14	4.2	66.7	29.2	0.0	0.0	0.0	50.0	25.0	4.2	20.8
Angelieri *et al.* (2013)	14-18	0.0	23.1	53.8	23.1	0.0	0.0	15.8	26.3	15.8	42.1
Angelieri *et al.* (2013)	>18	0.0	0.0	7.7	23.1	69.2	0.0	5.3	15.8	36.8	42.1
Jang et al. (2016)	6-<12	23.0	12.3	7.0	0.0	0.0	10.5	7.0	28.0	8.7	3.5
Jang et al. (2016)	12-<14	0.0	23.1	15.4	7.6	0.0	0.0	0.0	23.1	15.4	15.4
Jang et al. (2016)	14-<16	0.0	0.0	12.5	12.5	12.5	0.0	0.0	12.5	12.5	37.5
Jang et al. (2016)	>=16	0.0	0.0	0.0	19.0	24.0	0.0	0.0	0.0	14.0	43.0
Tonello *et al.* (2017)	11-15	0.0	30.0	42.5	12.5	15.0	2.3	20.5	56.8	13.6	6.8
de Miranda Ladewig	16-20	2.3	6.8	52.3	25.0	13.6	0.0	7.4	39.7	22.1	30.9

Table 4: Comparison of studies describing the percentage (%) of MPSM by gender.

Baccetti *et al.* (2001) intimated that the timing of RME is of paramount importance. Based on this recommendation, RME undertaken during the early developmental stages namely, stages A and B will show less resistance to expansion compared to stage C, which is suggestive of the impending start of fusion of the palatine portion of the suture. Consequently, stages A and B exhibit considerably more pronounced orthopaedic effects than stage C. Fusion of the midpalatal suture at stage D will prevent sutural opening with RME in the posterior region even though the opening of an anterior diastema is observed clinically. For patients in stages D and E, RME should therefore be undertaken with circumspect as fusion of the midpalatal suture has already occurred in the horizontal process of the palatine bone (Angelieri *et al.*, 2013).

To validate the MPSM classification, Jang *et al.* (2016) compared the maturation pattern of the midpalatal suture as described by Angelieri *et al.* (2013) to contemporary indices of maturation. Based on the premise that skeletal growth has periods of acceleration, maturation and deceleration that are not directly correlated with chronologic age; biologic indicators and radiographic assessment of bone maturation and staging of dental development have been described to evaluate skeletal maturation (Proffit *et al.*, 2013).

The HWR and the CVM are commonly used radiographic methods to ascertain skeletal age (Proffit *et al.*, 2013).

Skeletal maturity based on the HWR has demonstrated a correlation with overall facial vertical and horizontal growth as well as maxillary and mandibular growth (Flores-Mir *et al*., 2004). The HWR uses specific skeletal maturity indicators (SMI) to relate skeletal maturation to peak pubertal growth (Fishman, 1982). Some commonly used indicators are the calcification of the sesamoid, hook of the hamate and the staging of the middle phalanges of the third finger. However, the HWR entails the taking of an additional radiograph (Flores-Mir *et al*., 2004)

The main advantage of the CVM method is that skeletal maturity can be appraised on a single cephalogram; a radiograph that forms a routine part in orthodontic diagnosis and treatment planning. The CVM method has been advocated to assess optimal timing for the treatment of malocclusions in all three planes of space; namely the transverse, sagittal, and vertical planes of space (Baccetti *et al.*, 2005).

However, there are diverging views regarding the reliability of CVM staging. CVM staging has been reported to be a reproducible and reliable skeletal indicator by some investigators (Franchi *et al*. 2000) while others have concluded that CVM staging and appraisal offers no tangible advantage over chronologic age in either assessing skeletal age or predicting the adolescent growth spurt (Beit *et al.*,2013; Mellion *et al*., 2013).

Despite the latter conflicting viewpoints, Jang *et al.* (2016) reported strong associations between the HWR, CVM and MPSM methods, while chronological age and gender displayed relatively weak correlations.

Based on the HWR, MPSM stages D and E were not observed before SMI 6 in both genders. At SMI 10 or 11, stage E was visible.

These results concur with Revelo *et al.* (1994) who used the HWR to determine a positive correlation between skeletal maturity and midpalatal suture fusion as determined on occlusal radiographs. As skeletal maturity progressed through adolescence, both genders demonstrated evidence of midpalatal suture fusion. However, at the termination of general skeletal and facial growth coincident with SMI 11, only fifty percent of midpalatal suture fusion was observed.

CHAPTER 3

3.0 AIM AND OBJECTIVES

3.1 Aim

The aim of this study was to evaluate MPSM in young children(<12 years), older children (12-<15 years and 15-<18 years), young adults(18-<30 years) and older adults(>=30 years) as observed on CBCT images, in a Western Cape South African population attending the Tygerberg Dental facility.

3.2. Objectives

1. To classify the maturational stage of the midpalatal suture in young children (<12 years), older children (12-<15 years and 15-<18 years), young adults (18-<30 years) and older adults (>=30 years) on CBCT images.

2. To determine the inter and intra-rater reliability (reclassification reliability).

3. To determine the relationship between the maturational stage of the midpalatal suture and chronological age.

4. To determine the relationship between the maturational stage of the midpalatal suture and gender.

CHAPTER 4

4.0 MATERIALS AND METHODS

4.1 Study Design

The study was a cross-sectional retrospective study based on CBCT images obtained from the archives of the University of Western Cape spanning the period March 2011 to December 2018. The study design ensured that patients were not exposed to additional radiation.

4.2 Sample size and sampling strategy

The sample size estimation was based on the key research question to be answered, in this case the determination of the relationship between chronological age, gender and the classification of midpalatal suture morphology according to the five stages as described by Angelieri *et al*., (2013).

This required the use of multinomial logistic regression with the estimation of five parameters (one for gender, and four for age category). The rule of thumb given by Peduzzi *et al*., (1996) states that the smallest outcome category (stage) should have at least the number of cases = 10* the number of parameters to be estimated, i.e. 10*5 parameters = 50. Thus, a minimum sample size of 50*5 stages = 250 was required. To ensure adequate representation of all age groups and both genders in the sample, the total sample was divided equally into each age group-gender combination; i.e. 25 scans per group as follows: young children from below the age of 12, young children aged 12 to 15 years, teenagers from age 15 to age 18, younger adults from 18 to 30 years of age and older adults (> 30 years of age). The stratification of our sample population was based on previous studies of MPSM (Korbmacher *et al.*, 2007; Angelieri *et al*., 2013; Tonello *et al.* 2017; de Miranda Ladewig *et al.*, 2018)

The archived scans were examined for eligibility in reverse chronological order beginning from December 2018. The target sample size was two-hundred and fifty, however as the study was a single-centre study (based on the archived CBCT studies selected from UWC); after applying the inclusion and exclusion criteria the actual sample size was two-hundred and twenty-five. This was further reduced to a **final sample size of two-hundred and sixteen as CBCT volumes of patients with facial asymmetry and midline dental impactions made staging and classification difficult and were therefore not included in the study.**

4.3 Inclusion criteria

4.3.1 Patients from age 7 to 78 years,

4.3.2 Good quality CBCT images with no beam hardening or motion artefact.

4.3.3 Volumes that contained the entire midface and associated structures. i.e. full view scans.

4.4 Exclusion criteria

4.4.1 Previous treatment with rapid or slow maxillary expansion,

4.4.2 Previous treatment with orthognathic surgery,

4.4.3 Craniofacial syndromes including cleft lip and palate.

4.5 Image acquisition

A CBCT scanner (Newtom® VGI®, Verona, Italy) was used to obtain full field-of-view (Full mode) scans (15 x 15 cm). The scans were performed at 110 kV and 3-7 mAs. The time/x-ray emission time was 18s/3.6s. The data of each scan was reconstructed with a voxel size of 0.30 mm^3.

The images were converted to Digital Imaging and Communication in Medicine (DICOM) format. DICOM files were reconstructed into a three-dimensional image by multiplanar reformatting (MPR) and volume rendering using imaging software (OnDemand3D® software version1.0 (build 1.0.10.751), Cybermed Inc, South Korea).

The specifications of the computer (Thinkcenter ® M73 Desktop Intel (R) Core ® i5-4590 CPU @ 3.30 Ghz, (4CPU's), 8139 physical RAM). Two monitors were used; the primary monitor was Philips Brilliance MNS 1190T [(aspect ratio: 5:4, screen size: 19inch, display type: LCD – TFT active matrix, native resolution: 1280 x 1024 at 60 Hz, contrast ratio – 800:1/25000:1 (dynamic), colour support: 24 bit (16.7 million colours)]. The secondary monitor was the Philips® UltraClear 4K UHD (BDM435OUC)[(LCD panel type: IPS LCD, aspect ratio: 16:9, optimum resolution: 3840 x 2160 @ 60 Hz, brightness: 300 cd/m^2, contrast ratio (typical) - 1200:1, display colours: colour support – 1.07 billion colours (10 bit)].

4.6 Data Collection

All CBCT studies that met the inclusion criteria were collected from the archived records. The images were initially recorded with the descriptive details of the patient i.e. patient name, gender, date of birth and date at which the CBCT study was taken. This ensured that every CBCT study was recorded only once. Thereafter, every CBCT study was assigned a random numerical identifier. This was captured on a separate data sheet. The descriptive details of the patient were omitted from this data capture sheet. This blinded the examiners to subject as well as time point that the study was captured.

Images for sutural evaluation were obtained in a standardized way. Slice thickness was set at 0.3mm for evaluation and 1mm for identification. The image analysis software cursor was positioned as follows:

- The head was oriented in natural head position in all three planes of space. In the sagittal view, the patient's head was adjusted so that the anteroposterior long axis of the palate was horizontal. The vertical and horizontal cursors were positioned in the centre of the palate in the sagittal, coronal and axial views.

- in the sagittal plane, the horizontal axis of the cursor passed through the centre of the supero-inferior dimension of the hard palate, with the line corresponding to ANS and PNS or a parallel to ANS and PNS
- in the coronal plane, the cursor was positioned over the midpalatal suture and nasal spine
- in the axial slice, the vertical axis passed through the anterior and posterior nasal spine.

Figure 3: Step 1. The head was oriented in natural head position in all three planes of space.

Figure 4: Step 2. In the sagittal plane, the horizontal axis of the cursor was positioned in the middle of the palate.

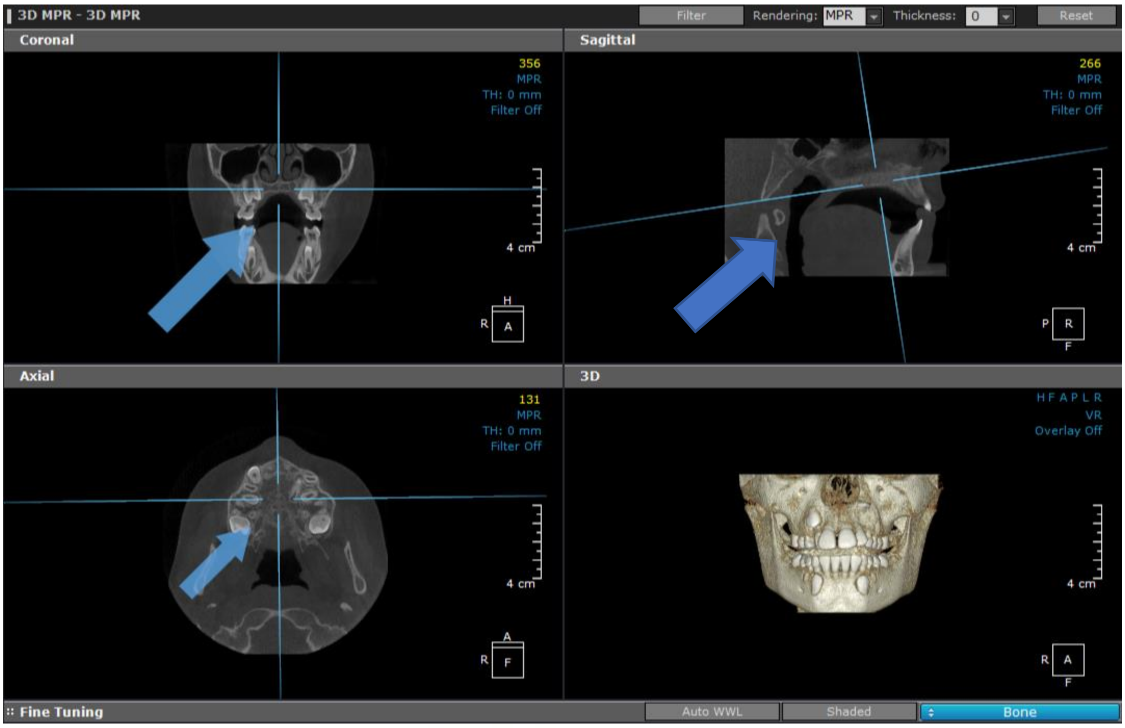

Figure 5: Step 3. **In the sagittal plane** the horizontal axis of the cursor was positioned parallel to points ANS-PNS. **In the coronal plane**; the horizontal axis of the cursor was positioned to parallel the maxilla with the vertical axis of the cursor positioned over the mid maxillary suture and the nasal septum.

Figure 6: Step 4. In the axial plane, the vertical axis of the cursor was positioned to bisect ANS and PNS.

The most central axial cross-sectional slices were used for sutural assessment. To standardize this aspect the most superior slice of the superior aspect of the palate was identified and noted as number of slice. The slice thickness was set at 1mm to get a 1:1 ratio. The most inferior slice corresponding to the inferior aspect of the palate was also identified and noted. The slice numbers were subtracted from each other and the middle slice was selected (see steps 1-3 below) (Figures 7-9).

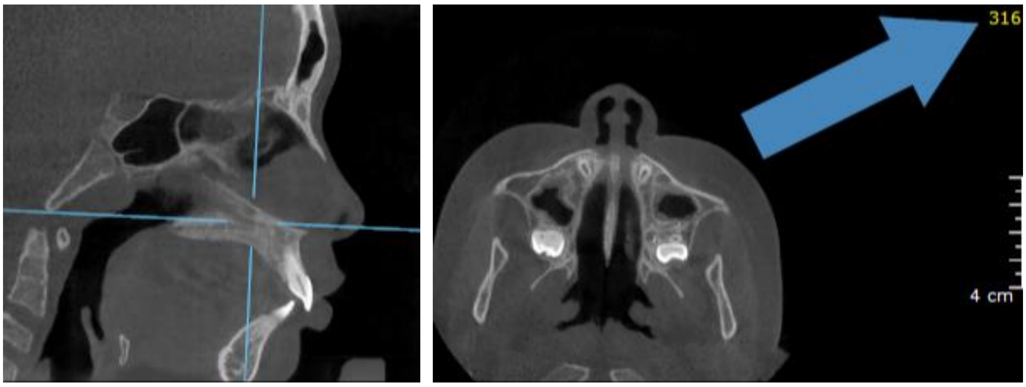

Figure 7: Step one. The horizontal axis of the cursor was positioned on the superior aspect of the palate and the corresponding slice number was noted (slice number 316).

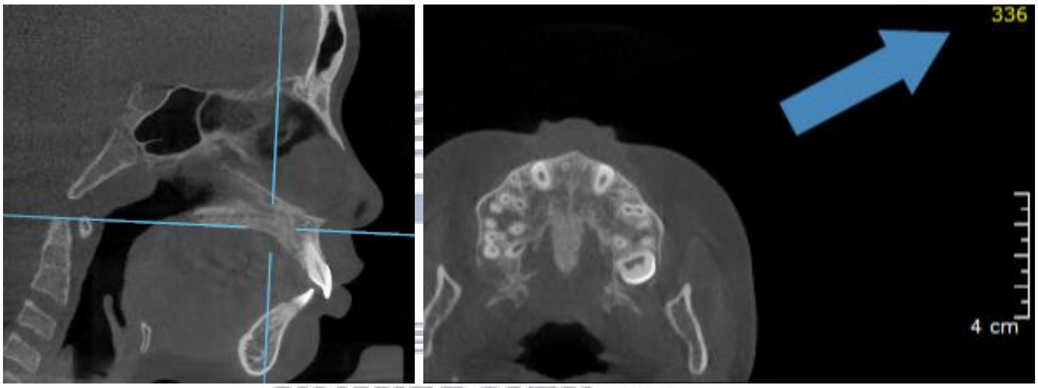

Figure 8: Step two. The horizontal axis of the cursor was positioned on the inferior aspect of the palate and the corresponding slice number was noted (slice number 336).

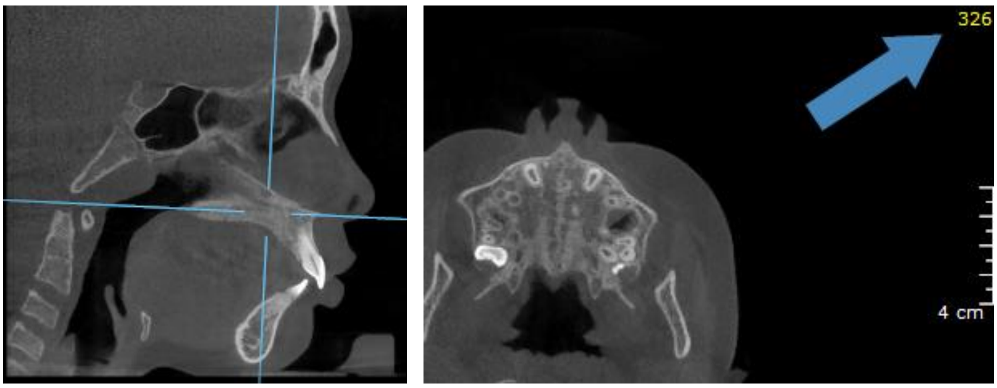

Figure 9: Step three. The superior and inferior slice numbers were subtracted from each other and the middle most slice was selected (slice number 326).

For subjects who exhibited a curved palate, the palate was evaluated in two sagittal slices.

In the first sagittal slice the horizontal axis of the cursor passed through the suture in the most posterior region, and in the second slice, the cursor passed through the most anterior region. The posterior and anterior region of the midpalatal suture were then identified separately but both were used to evaluate the maturation stage.

Prior to staging of suture maturation, the two examiners, one an expert in radiology (SS) and one a registrar in orthodontics (RC), were calibrated. This was done by randomly analysing fifty CBCT images to determine the maturation stage of the midpalatal suture. The randomisation process was done by the receptionist of the Department of Radiology who randomly selected fifty numbers between one and two hundred and twenty-five. These fifty numbers selected were used for the randomisation process. Any disagreements that were encountered during the classification of the midpalatal suture were discussed by two examiners to obtain a final decision. The examiners used the morphologic parameters established by Angelieri *et al.* (2013).

After the calibration process, staging of suture maturation on the CBCT images was performed by both examiners (SS and RC). Each examiner arrived at a diagnosis separately. The diagnoses were then compared to assess the level of concordance. If there was disagreement regarding the suture stage, this was followed by a robust discussion until consensus was reached. The consensus diagnosis formed the "ground truth" for this thesis. To assess the reliability of classifying the maturational stages of the midpalatal suture (stages A-E), staging and reclassification of the midpalatal suture was repeated by both examiners (RC) and (SS) after a two-week period. Randomization for the assessment of the reliability of the suture maturation staging was obtained by selecting every tenth numerical identifier of the sample and reclassifying the midpalatal suture. A total of twenty-two images were reclassified. The same principles were applied whereby staging was reached by consensus following a robust discussion.

The maturational stages of the mid-palatal suture were classified according to Angelieri *et al.* (2013):

1. Stage A: The morphology of the midpalatal suture is characterized by one relatively straight high-density midpalatal suture line with little or no interdigitation.
2. Stage B is observed as one scalloped, high-density line at the midline, or by a scalloped high-density line in some areas and, in other areas, as 2 parallel, scalloped, high-density lines close to each other and separated by small low-density spaces.
3. Stage C is visualized as two parallel, scalloped, high-density lines that are close to each other, separated in some areas by small low-density spaces. The suture can be arranged in either a straight or an irregular pattern
4. Stage D is visualized as two scalloped, high-density lines at the midline on the maxillary portion of the palate, but the midpalatal suture cannot be identified in

palatine bone. The density of the parasutural palatine bone is higher compared with the parasutural maxillary bone.

5. Stage E, sutural fusion has occurred in the maxilla. The midpalatal suture cannot be identified. The parasutural bone density is increased, with the same level as in other regions of the palate.

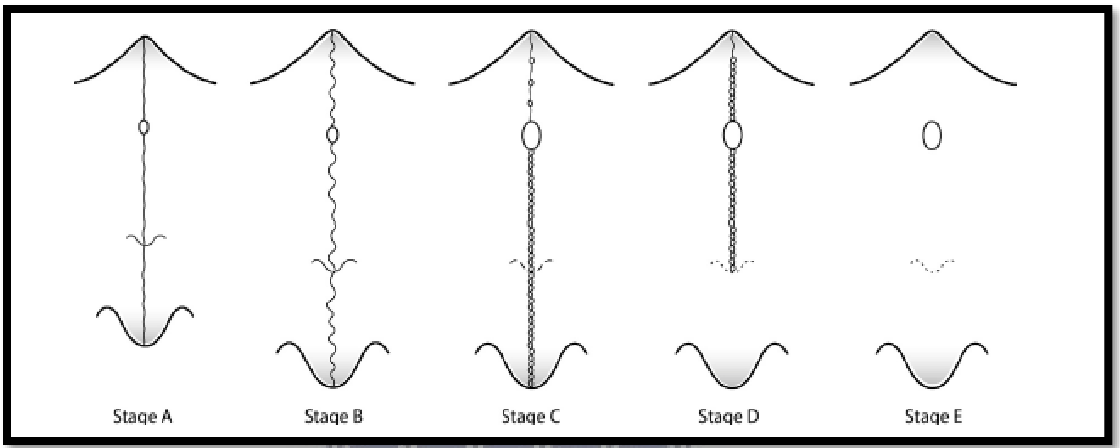

Figure 10: Schematic drawing of the maturational stages of the midpalatal suture (Angelieri *et al.*, 2013).

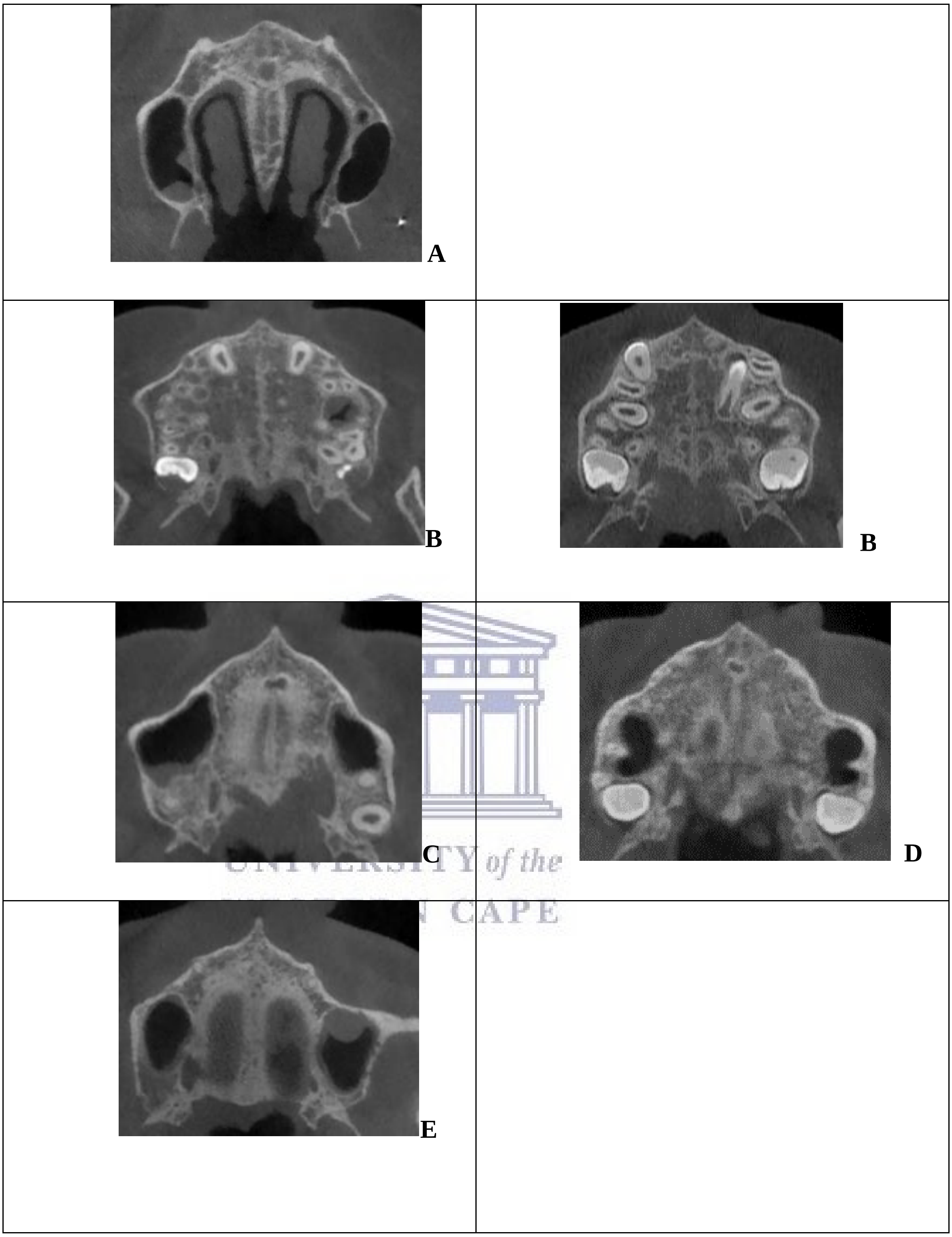

Figure 11: Axial images of MPSM stages A-E.

4.7 Statistical analysis

All recorded data was entered into an Excel® spread sheet. Categorical variables were summarised by frequency and percentage tabulation. Continuous variables were summarised by the mean, standard deviation, median and interquartile range. Interrater and reclassification reliability were quantified by Cohen's weighted kappa and the Stuart-Maxwell test for bias (Shoukri, 2010).

The magnitude of kappa was interpreted according to the classification by Landis and Koch (1977).

< 0.0	no agreement
0.0-0.20	slight agreement
0.21-0.40	fair agreement
0.41-0.60	moderate agreement
0.61-0.80	substantial agreement
0.81-1.00	almost perfect agreement

Table 5: The interpretation of observer agreement for categorical data (Landis and Koch, 1977).

The association between age group and gender, gender and stage, and age group and stage were determined by the chi-squared test. The relationship between chronological age, gender and midpalatal suture maturation stage was determined by ordinal logistic regression with maturation stage as the dependent variable and age group and gender as the independent variables.

Data analysis was carried out in SAS. The 5% significance level was used for all statistical tests.

4.8. Ethical Considerations

Permission to conduct the study was obtained from the Biomedical Research Ethics Committee (BMREC) of the School of Dentistry at the University of the Western Cape (Appendix A). Approval was also obtained from the Dean of the School of Dentistry (UWC) and the Department of Radiology to access archived radiographic records (Appendix B).

The study conducted was a retrospective study. Therefore, no patient was exposed to radiation for the purpose of conducting this research as all the CBCT images examined had already been taken as part of prior clinical examinations.

Patient anonymity was respected, and the identity of the patients was not revealed. Every CBCT study collected was assigned a random number for identification (Appendix C). This was to de-identify the patients and to ensure that patient confidentiality was maintained during the completion of this research. The information was only retained by the main researcher (RC) and stored on a password safe computer.

CHAPTER 5

5.0 RESULTS

The final sample size was two-hundred and sixteen patient CBCT studies.

Descriptive data for the sample is presented in tables 6 and 7. Between the genders, females were overrepresented in the sample and accounted for 57.9% of the final CBCT images.

With regards to the distribution of the data among the different age groups, the <12y and the 15-<18y groups were underrepresented, while the oldest age group (>=30 y) was over-represented (Table 6 and Figure 12).

Overall, the mean age at the time the CBCT images were taken was 24.9 years with a standard deviation (SD) of 16.5 years and an age range of 7.1-77.5 years.

Furthermore, males were under-represented in the 18-<30y age group (p=0.033). Therefore, the cross-tabulation of age group and gender, as shown below, also illustrates that the quota research design for age and gender did not work out.

Gender	Age at time CBCT scan taken (y)					
	<12	12-<15	15-<18	18-<30	>=30	N
F	13	28	13	36	35	125
M	17	22	16	12	24	91
Total	30	50	29	48	59	216
% Male	57	44	55	25	41	42
% Female	43	56	45	75	59	57.9

Table 6: Demographics of the sample group by age and gender.

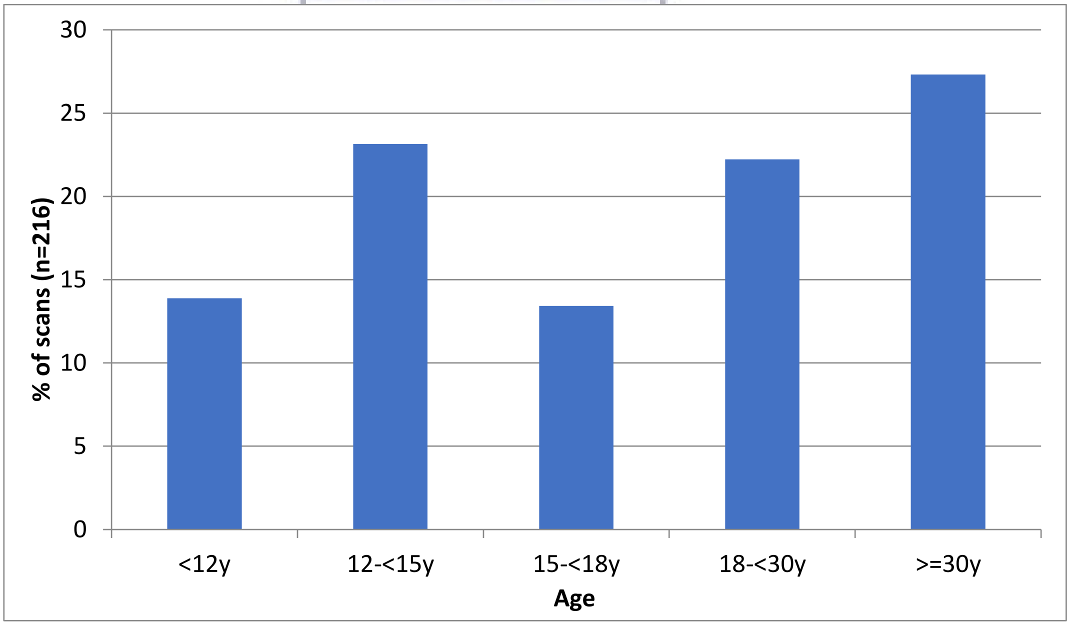

Figure 12: Age distribution of the CBCT images.

The distribution of the maturational stages of the midpalatal suture observed are shown in table 7 and figure 13. MPSM stages B to E were approximately equally represented in the sample, while the prevalence of stage A was very low (6.0%; n=13).

Stage	**Age at time CBCT image was taken**													
	<12y		**12-<15y**		**15-<18y**		**18-<30y**		**>=30y**		**Total**		**N**	**%**
	F	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**		
A	2	1	2	4	0	2	0	0	1	1	5	8	13	**6.0**
B	6	12	8	8	2	5	2	3	3	5	21	33	54	25.0
C	5	2	11	5	7	4	11	6	2	2	36	19	55	25.5
D	0	2	4	4	3	5	11	3	11	5	29	19	48	22.2
E	0	0	3	1	1	0	12	0	18	11	34	12	46	21.3
Total	13	17	28	22	13	16	36	12	35	24	125	91	216	100

Table 7: Distribution of the maturational stages of the midpalatal suture

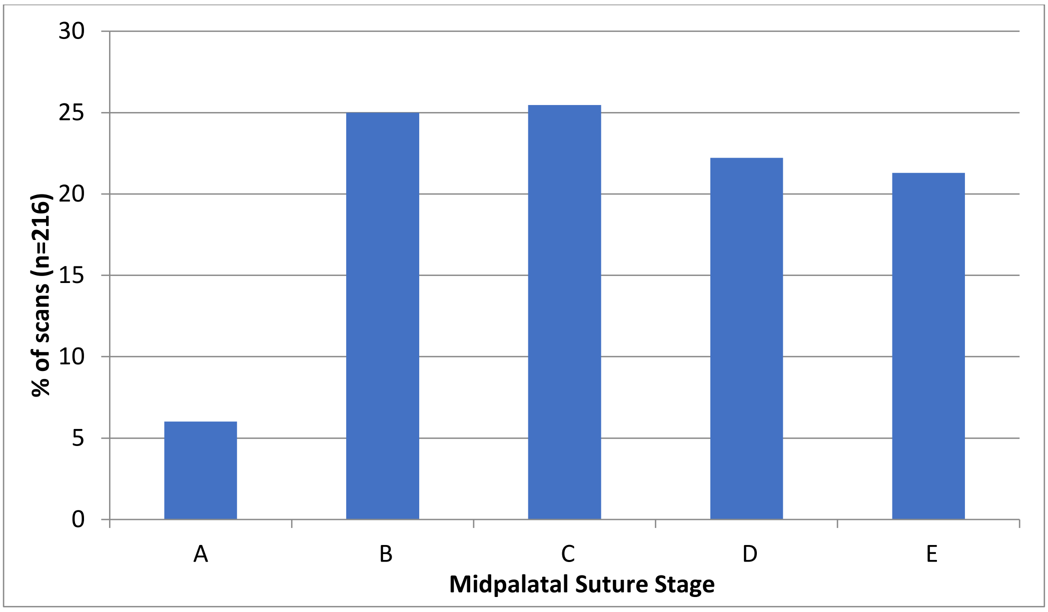

Figure 13: Bar graph demonstrating the distribution of the maturational stages of the midpalatal suture.

5.1 Inter-rater reliability for the assessment of maturation stage

The inter-rater reliability was quantified as Cohen's weighted kappa = 0.94 (95% confidence interval/CI 0.91-0.97) which corresponds to 'almost perfect agreement'. There was no significant intraobserver bias ($p>0.99$). Thus, the interrater reliability was excellent.

Table of T1 (SS) by T1 (RC)							
T1 (SS)	**T1 (RC)**						
	A	**A/B**	**B**	**C**	**D**	**E**	**Total**
A	11	1	4				16
A/B			1				1
B	3	1	46				50
C				54		1	55
D					48		48
E					1	45	46
Total	14	2	51	54	49	46	216

Table 8: The cross-tabulation to assess inter-rater reliability. RC: examiner 1, SS: examiner 2 at T1 (before consensus was reached).

5.2 Intra-rater (reclassification) reliability for the assessment of maturation stage

The reclassification of the CBCT images demonstrated considerable agreement. The reliability was quantified as Cohen's weighted kappa that was equal to 0.92 (95% CI 0.83-1.00). This corresponds to 'almost perfect agreement'. There was no significant intraobserver bias (p>0.99). Thus, the staging categorisation was reliable.

Stage	Reclassification Assessment					
	A	B	C	D	E	Total
A	3					3
B		10				10
C			4	1		5
D				2		2
E				1	1	2
Total	3	10	4	4	1	22

Table 9: The cross-tabulation to assess reclassification.

5.3. Relationship between gender and midpalatal maturation stage

The stage A group was too small (n=13) to be used as an outcome group on its own and was combined with stage B. There was a statistically significant association between gender and stage (p=0.0010, Cramer's V=0.27; small effect size). The proportion of males in stages A/B was higher than in the other stages, while the proportion of females in stage E was higher than in the other stages. Additionally, in 60.4% (29/48) of the female sample and 39.6% (19/48) of the male sample, maturational stage D was observed. Overall, a higher proportion of females displayed the later stages of maturation when compared to males (Figure 14) (Table 7).

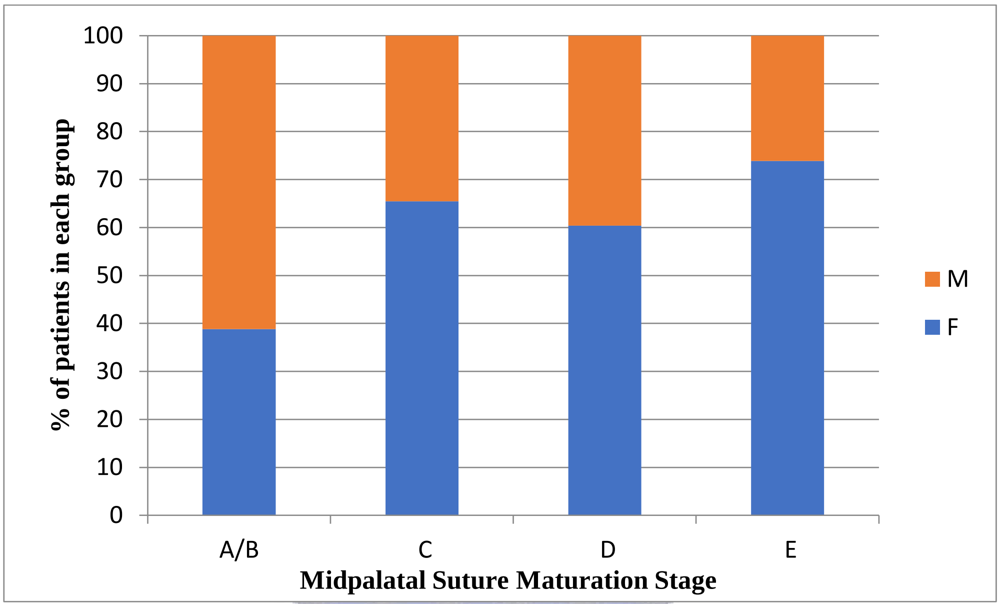

Figure 14: The relationship between gender and MPSM stage.

5.4. Relationship between age and midpalatal suture maturation stage

The association between age group and stage was significant (p<0.0001; Cramer's V=0.36; moderate effect size); however great variability was frequently noted. The proportion of those aged <12y was higher in stage A/B compared to the other stages; the proportion of those aged >=30y was higher in stage E compared to stages A-C; and the proportion of those aged 18-<30y was lower in stages A/B compared to the other stages.

Stage C was the predominant stage from age 12 to 30 years but was also noted in the <12 and >=30 y age groups. No subject younger than 12 years of age presented with stage E; however, stage D was observed in 4.2% of children (2/48) younger than 12 years.

From age 12 to 18 years, 33.4% and 10.9% of the sample presented with stage D and stage E respectively.

For subjects between 18 to 30 years of age, 29.2% showed fusion of the midpalatal suture in stage D, which is only represented in the palatine bone as opposed to the maxillary bone, and 26.1% presented with stage E.

As stated above, a high prevalence of stage E (63%) was observed in older adults (>=30 years). In addition, 14.9% of older adults (>= 30 years) had no fused suture and presented in stage A/B (Figure 15) (Table 10).

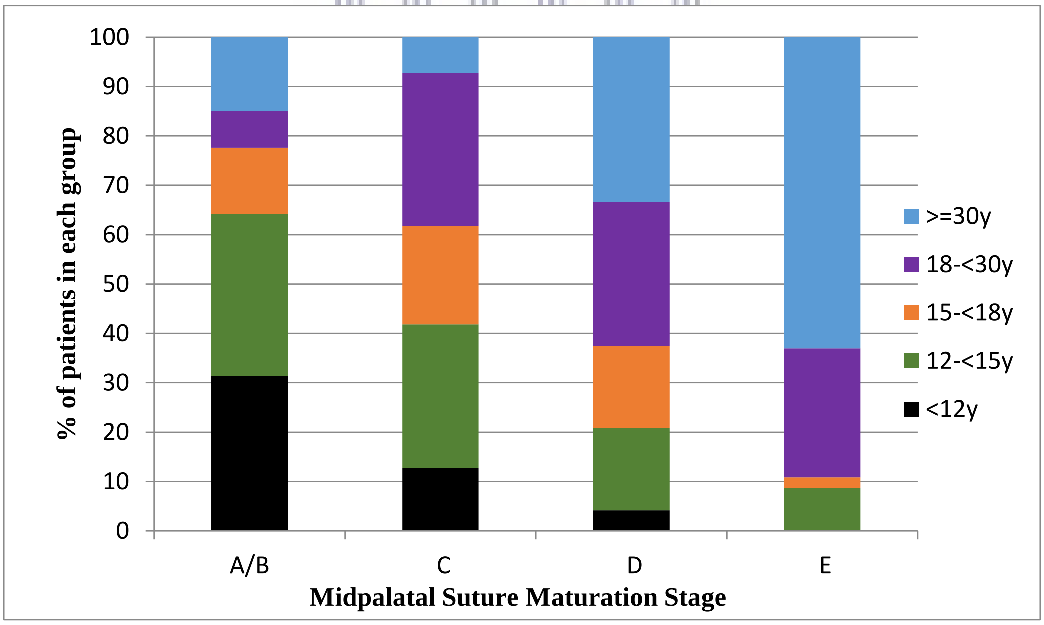

Figure 15: The relationship between age and MPSM stage.

Age	Stage			
	A/B	**C**	**D**	**E**
<12 y	**31.3%**	12.7%	**4.2%**	**0.0%**
12-<15 y	32.8%	29.1%	16.7%	8.7%
15-<18 y	13.4%	20.0%	16.7%	2.2%
18-<30 y	**7.5%**	30.9%	29.2%	26.1%
>=30 y	14.9%	**7.3%**	33.3%	**63.0%**

Table 10: Age distribution per maturational stage.

5.5 Association between age, gender and midpalatal suture maturation stage

The association between maturation stage, age and gender are tabulated below by means of odds ratio (OR) estimates, together with their 95% confidence limits. Odds ratios are significant if the CI does not include 1.0. If the OR>1, it means that the category in question (compared to the reference category) is more prevalent.

5.5.1. Stage C vs A/B

1. Males were less prevalent in stage C compared to stage A/B.
2. Those aged 15-<18y and 18-<30y were more prevalent in stage C compared to stage A/B.
3. Those aged >=30y were less prevalent compared to those aged 18-<30y in stage C compared to stage A/B.
4. Those aged 18-<30y were the most prevalent age group in stage C.

Effect	Point Estimate	Confidence Limits	
Male vs Female	**0.32**	**0.14**	**0.71**
12-<15y vs <12y	2.08	0.69	6.28
15-<18y vs < 12y	**4.12**	**1.15**	**14.84**
18-<30y vs < 12y	**10.43**	**2.68**	**40.62**
>=30y vs <12 y	1.27	0.29	5.62

Table 11: Odds Ratio Estimates of stage C vs A/B.

5.5.2. Stage D vs C

1. Those aged >=30y were more prevalent in stage D compared to stage C.
2. Those aged >=30y were more prevalent compared to those aged 18-<30y in stage D compared to stage C.

Effect	Point Estimate	Confidence Limits	
Male vs Female	1.38	0.58	3.31
12-<15y vs < 12y	1.80	0.30	10.78
15-<18y vs < 12y	2.53	0.41	15.66
18-<30y vs < 12y	3.05	0.54	17.30
>=30y vs < 12y	**14.65**	**2.13**	**100.55**

Table 12: Odds Ratio Estimates of stage D vs C.

5.5.3. Stage E vs D

The two youngest age groups were combined as there were no cases in stage E for the <12y group. If the two youngest age groups had not been combined it would have caused quasi-complete separation of data points that would have made the analysis impossible.

1. Those aged >=30y were more prevalent in stage E compared to stage D.

Effect	Point Estimate	Confidence Limits	
Male vs Female	0.57	0.21	1.52
15-<18y vs <15y	0.32	0.03	3.48
18-<30y vs 15	1.75	0.41	7.38
>=30y vs 15	**4.29**	**1.14**	**16.09**

Table 13: Odds Ratio Estimates of stage E vs D.

CHAPTER 6

6.0 DISCUSSION

There is consensus in the literature that chronological age is not a reliable determinant of skeletal maturation (Revelo *et al*. 1994) because of distinct variations that exist with regard to timing, velocity and duration of growth (Beit *et al*. 2013).

A myriad of imaging/diagnostic tools have been proposed to ascertain the morphology and degree of midpalatal suture synostosis. These methodologies include histological examination of the suture that is the gold standard (Melsen, 1975), followed by the use of occlusal radiographs (Revelo *et al*., 1994) and more recently CT and CBCT imaging of both autopsy material and living human subjects (Korbmacher *et al.,* 2007; Angelieri *et al*., 2013; Tonello *et al*., 2017; Ladewig *et al*., 2018).

In the present study, the morphology of the midpalatal suture as assessed on CBCT images was compared to chronological age and gender to ascertain a relationship between age, gender and MPSM stage.

The CBCT images were staged according to the classification proposed by Angelieri *et al.,* (2013) . The classification is based on the evaluation of the most central cross-sectional axial slice, however, if this slice is not accurately located, the MPSM stage can be misconstrued on the CBCT image. Therefore, in our study, the slice thickness was set to 1mm to allow for a 1:1 ratio. The central most cross-sectional slice was determined by identifying the slice number corresponding to the most superior aspect of the palate; the slice number corresponding to the most inferior aspect of the palate and then subtracting the two. The median of this number was selected as the most central cross-sectional slice.

Based on the rule of thumb given by Peduzzi *et al*. (1996) and the research design, twenty-five images per group were needed. We therefore sought to obtain two-hundred and fifty CBCT images. This sample size would have ensured an equal representation of all age groups and both genders in the sample. However, we were only able to obtain two-hundred and sixteen CBCT studies; **57.9% of the scans were of female patients, the <12y and the 15-<18y groups were underrepresented, while the oldest age group was over-represented. Thus, our analysis may not be adequately powered**.

In retrospect we should have excluded patients who presented with midline dental impactions and facial asymmetry. We observed that in these cases the midpalatal suture in the anterior component or affected side was obscured to a degree and made staging difficult. In cases with an anterior maxillary impaction, the maxillary suture was deviated, and the radiographic features were displaced. In patients who displayed asymmetry, the palate was hypoplastic or hyperplastic on one side and thus the horizontal axis of the cursor had to be altered. This altered the axis of the interpreted slice and thus the features of the suture were blurred.

For this study to be reliable and reproducible there had to be agreement between the examiners. **The examiners selected the consensus method as the "ground truth".** The rationale for using a consensus method was to minimize the probability of diagnostic errors. When evaluating radiographs, the term "ground truth" is more appropriate than "gold standard" as a gold standard will necessitate a histological specimen of the midpalatal suture as a frame of reference (Angelieri et al. 2013).

The interrater reliability was 94% and demonstrated "almost perfect agreement" between examiner 1(RC) and examiner 2(SS). The 6% disagreement between the examiners was resolved by consensus.

The CBCT images were reclassified after a two-week period to determine the intra-rater (reclassification) reliability. **This was quantified at 92% which also corresponds to "almost perfect agreement".** The 8 % disagreement between the examiners was once again resolved by consensus.

The drawbacks that we experienced with the classification proposed by Angelieri *et al.* (2013) were differentiating stage A from stage B where stage A is defined as "relatively straight high density line". Relative is a broad term and is subject to opinion. Stage A should rather have been defined in terms of percentage of straight versus scalloped. Stage A and B infer early suture development, prior to suture ossification, therefore disagreements between examiners regarding stage A and stage B is not critical.

Furthermore, the demarcation between stage D and stage E was also sometimes obscure. Identification of sutural stage D or E is suggestive of ossification of the midpalatal suture.

However, it is only disagreements that occur outside of a single stage that may effect a change in orthodontic treatment.

This study showed that the association between gender and stage was significant; it was observed that the proportion of males in stages A/B was higher than in the other stages whereas MPSM stages C, D and E displayed a greater prevalence in females. **This inferred that maturation between the genders differed, with females maturing earlier than males**. These observations are in concordance with Angelieri et al. (2013) and Jang et al. (2016) as well as the growth studies (Tanner *et al*., 1976; Bambha, 1961; Mellion *et al*.,2013) that have shown that the onset and completion of the pubertal growth spurt occur earlier in females than in males.

However, males were under-represented in the 18-<30y age group (p=0.033) and accounted for only 25% of that age category. Therefore, the cross-tabulation of age group and gender was not achieved and a **definite conclusion regarding chronological age and gender could not be explicated from our study.**

The findings of our study validate previous reports that chronological age is not analogous with MPSM. Ossification of the midpalatal suture increased with chronological age; the proportion of those aged <12y was higher in stage A/B compared to the other stages while the proportion of those aged >=30y was higher in stage E compared to stages A-C. However large variations in the degree of closure of the midpalatal suture among subjects of the same age group were observed. This finding has been reflected in previous studies in which similar aged patients evinced a distinct stage of midpalatal maturation. The results showed that stage A/B was observed in 32.8% of the 12-<15 yr age group. In addition, stage A/B was also observed in 13.4% of those aged 15-<18 yrs, in 7.5% of 18-<30 yr olds and in 14.9% of the >=30 yr age groups. This is in accordance with the study by Korbmacher *et al.*(2007) who reported that subjects aged 14 to 17 years showed no significant relationship between suture ossification and chronological age.

This is important as a fairly sizable proportion of older patients presented with patent sutures at an age where conventional RME is deemed unsuccessful.

The >=30-year-olds had the highest prevalence of both stage D (33.3%) and stage E (63.0%). This observation was predictable as stages D and E are commensurate with ossification of the suture.

A surprise observation was the presence of stage D in 4.2% (2/48) of subjects <12 years of age.

Cohen (1993), postulated that there is no association between the termination of maxillary growth and approximation of the midpalatal suture. Studies have ascribed the patent suture in adults to a decrease in the functional forces from the muscles of mastication. This may be due to the natural processes of aging with the resultant loss of teeth or to the refined, softer diet of western civilizations. Therefore, the maturation and ossification of the midpalatal suture depends on functional forces exerted on the maxillary bone (Katsaros *et al*., 2006). As a result, chronological age alone is not the sole determinant of the developmental stage of the suture. Consideration should therefore be given to the reciprocal effects from functional forces on suture maturation.

Due to the absence of a gold standard to validate the MPSM classification the authors of this study concur with previous reports (Angelieri *et al.* 2013; Tonello *et al*. 2017; de Miranda Ladewig *et al*. 2018) that CBCT is a valid tool to aid in the clinical decision between conventional RME and SARPE in patients whose RME treatment appears equivocal.

CHAPTER 7

7.0. CONCLUSIONS

1. The association between gender and stage was significant. The proportion of males in stages A/B was higher than in the other stages, while the proportion of females in stage E was higher than in the other stages. Overall, a higher proportion of females displayed the later stages of maturation when compared to males.

2. Although the rate of midpalatal suture synostosis increased with chronological age, the large variation in MPSM within the same chronological age group precludes the use of age as a single determinant of the developmental stage of the suture.

3. Factors other than chronological age influence the advancement and extent of ossification of the suture.

4. In a patient whose RME prognosis is doubtful, the classification proposed by Angelieri *et al*. (2013) may assist in determining prospectively which late adolescent or young adult patient can have RME as a less invasive and possible beneficial alternative for skeletal expansion.

5. However, application of this classification depends on the diagnostic ability of the orthodontist to interpret and analyse the CBCT image of the midpalatal suture. A report from a maxillofacial radiologist is mandatory.

CHAPTER 8

8.0. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

There are several limitations to this study.

It was a single centre study; therefore, the ideal sample size was not reached.

Secondly there was no control group. The control group; namely autopsy specimens should have been the gold standard. Future studies could compare the morphology of the midpalatal suture on CBCT images to autopsy specimens, however the likelihood of obtaining the appropriate age for this sample is not available or will take forever to obtain.

The Western Cape consists of a diverse population; however, this study did not evaluate ethnic variations nor did the study evaluate and compare MPSM classification with other skeletal maturity indicators. The study also did not compare the influence of skeletal pattern, namely hypodivergence or hyperdivergence on suture synostosis. The reason for this omission was that these clinical details are not recorded on the patient data base. The implementation of the PACS (Picture archiving and communications system) data capturing system will allow the recording of patient data for future evaluation.

With respect to the resistance that clinicians encounter when transverse force is applied to the midpalatal sutures, it has been suggested that the maturation and ossification of the circummaxillary sutures; namely the zygomaticofrontal and zygomaticomaxillary suture may be as important as the maturation and interdigitation of the midpalatal suture in decreasing the skeletal response to RME (Zimring and Isaacson, 1965). Only the morphology and maturation of the midpalatal suture was considered in our study. Our study also did not evaluate the density or the extent of ossification of the midpalatal suture. It was proposed by Persson and Thilander (1977) that the upper limit for conventional RME is 5% of suture approximation. The low ossification values described by *Knaup et al*. (2004) in patients > 25 years suggest that conventional RME should be successful in this subset of patients. However, clinical evidence is contradictory; there are those researchers and clinician who follow the conventional view that RME in older patients is doubtful, whilst other researchers have shown that RME is possible in older adults (Handelman *et al*., 2000; Stuart and Wiltshire, 2003). Future studies should therefore compare and evaluate the degree of ossification between the midpalatal and circummaxillary sutures to determine if midpalatal suture ossification can be used as a sole determinant of the extent of expected ossification that can be encountered in the circumaxillary sutures. Furthermore, it is tenable that the maturation processes of the midpalatal and circummaxillary sutures mimic one another.

Mellion *et al.* (2013) reported that in growing patients, a patients height may be an even more clinically relevant predictor of skeletal maturation. A further advantage of height is that it can be measured repeatedly without the need for successive radiographs. Hence, further research should be aimed at identifying an association between the onset of peak in stature and the peak in ossification of the midpalatal suture in the different skeletal patterns.

CHAPTER 9

9.0. REFERENCES

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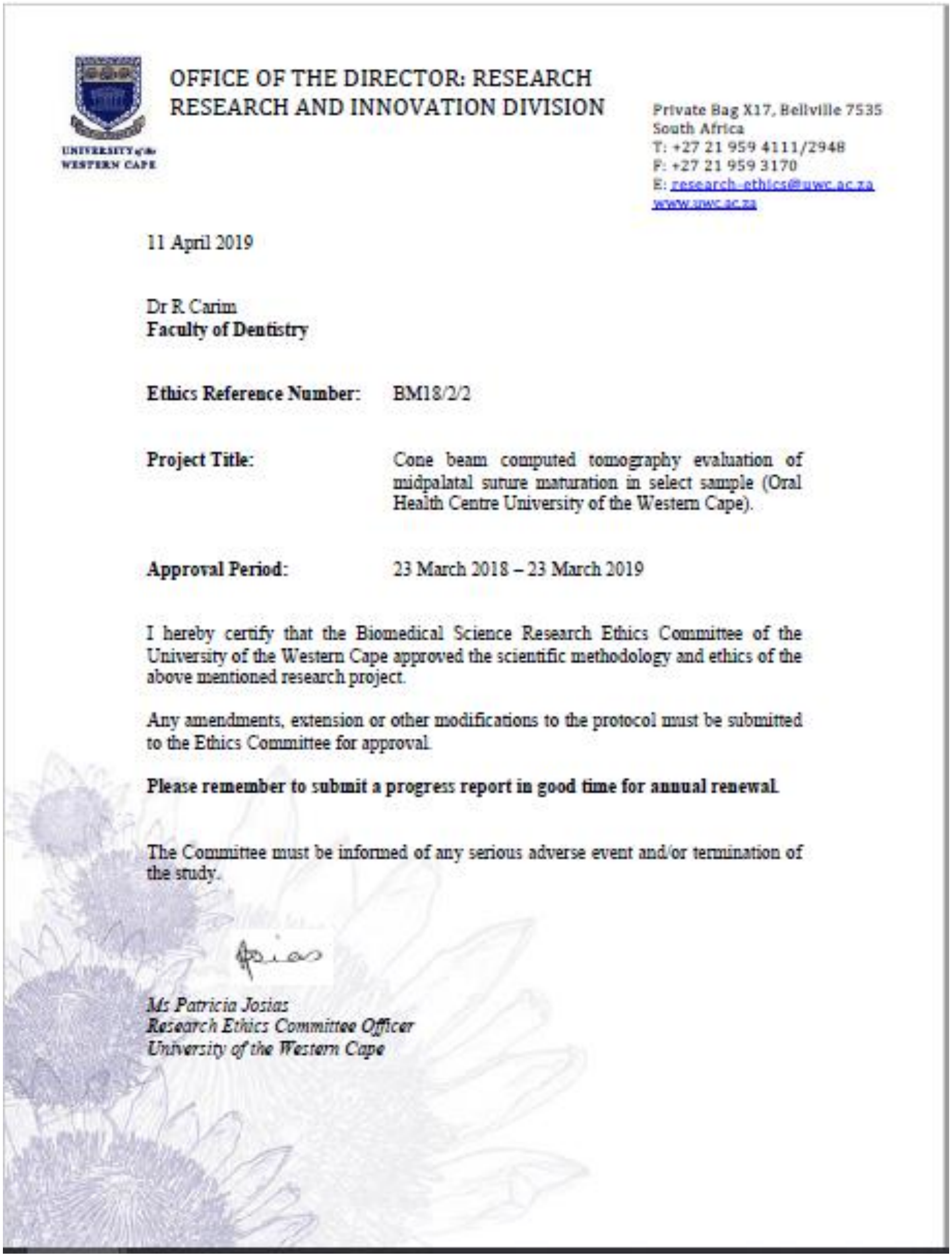
CHAPTER 10

10.0 APPENDIX

10.1 Appendix A: Ethics Clearance



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11 April 2019

Dr R Carim
Faculty of Dentistry

Ethics Reference Number: BM18/2/2

Project Title: Cone beam computed tomography evaluation of midpalatal suture maturation in select sample (Oral Health Centre University of the Western Cape).

Approval Period: 23 March 2018 – 23 March 2019

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report in good time for annual renewal.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

10.2. Appendix B: Letter to the Dean requesting permission to view the CBCT images

UNIVERSITY *of the*
WESTERN CAPE

Letter to the Dean requesting permission to view the CBCT images

Dear Prof Osman

<u>Re: Request for permission to use the CBCT records from the Department of Radiology</u>

I am writing to request the permission of the Deans office to use the records of previously imaged CBCT volumes from the Department of Radiology. The purpose is to complete my research that is in partial fulfillment of my MChD (Orthodontics) degree.

All ethical considerations will be adhered to as set out in my protocol presentation (08/12/2017).

Hope this meets your consideration.

Kind regards.

Approval granted. Please clear this with Prof Parker & Dr Shaikh. Regards. 18/02/2018

Dr Ridwaana Carim

Registrar

Department of Orthodontics

University of Western Cape

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10.3. Appendix C: Raw data for establishing inter-rater reliability

T1: time of initial data capture

RC: examiner 1

SS: examiner 2

No	Sex	Consensus Stage	T1 SS	T1 RC	age at time CBCT taken
0001-	F	b	a	b	10,75
0002-	F	d	d	d	12,58
0003-	M	d	d	d	13,08
0004-	F	b	b	b	10,5
0005-	F	b	b	b	12,83
0006-	F	c	c	c	12,58
0007-	F	b	b	b	12,58
0008-	F	c	c	c	12,08
0009-	F	a	a	a	11,25
0010-	M	b	b	a	12,5
0011-	M	b	b	b	13,75
0012-	F	c	c	c	14,17
0013-	F	c	c	c	11,5
0014-	F	c	c	c	13,5
0015-	M	b	b	b	11,58
0016-	F	b	b	b	11,75
0018-	M	b	b	b	9,83
0019-	F	c	c	e	12,25
0020-	M	d	d	d	12,58
0022-	F	b	b	b	12,5
0023-	F	c	c	c	12,25
0024-	F	a	a	a	12,5
0025-	F	c	c	c	11,17
0026-	M	b	b	b	10,67
0027-	F	c	c	c	10,58
0028-	M	a	a	a	9,25
0029-	M	b	b	b	10,17
0030-	M	b	a	b	9,25
0031-	M	b	b	b	9,17
0032-	M	b	b	b	11,42
0033-	M	b	b	b	7,08
0034-	F	a	a	a	7,92
0035-	F	c	c	c	9,33
0036-	F	b	b	b	8,33

0037-	M	d	d	d	10,42
0038-	M	c	c	c	9,17
0039-	M	b	b	b	10,83
0040-	M	b	b	b	11,67
0041-	M	b	b	a/b	8,67
0042-	F	b	b	b	11,75
0043-	F	c	c	c	11,58
0044-	F	b	b	b	12,67
0045-	M	a	a	a	12,42
0046-	M	e	e	e	12,08
0047-	F	d	d	d	12,25
0048-	F	b	b	b	14,42
0049-	F	d	d	d	14,17
0050-	M	b	b	b	14,25
0051-	F	d	d	d	15,42
0052-	M	d	d	d	15,75
0053-	F	c	c	c	12,0
0054-	M	b	b	b	14,67
0055-	M	a	a	a	14,75
0056-	M	c	c	c	10,92
0057-	M	a	a	a	13,25
0058-	F	a	a	a	13,75
0059-	F	e	e	e	13,0
0060-	F	e	e	e	13,33
0061-	F	d	d	d	13,0
0062-	F	b	b	b	11,17
0063-	M	b	b	b	11,83
0064-	F	c	c	c	13,5
0065-	M	b	b	b	12,58
0066-	M	b	b	b	15,0
0067-	F	b	b	b	14,67
0068-	F	c	c	c	16,5
0069-	M	d	d	d	13,5
0070-	F	b	b	b	12,17
0071-	F	b	b	b	14,17
0072-	M	b	b	b	15,33
0073-	M	a	a	a	13,75
0074-	F	c	c	c	13,67
0075-	M	b	b	b	13,33
0076-	M	c	c	c	14,92
0077-	F	c	c	c	15,75
0078-	M	c	c	c	15,0
0079-	F	e	e	e	15,0
0080-	M	a	a	a	15,33
0081-	M	c	c	c	14,67
0082-	F	c	c	c	14,75

0083-	M	c	c	c	13,5
0084-	M	c	c	c	12,92
0085-	M	b	b	b	14,83
0086-	F	e	e	e	14,0
0087-	M	c	c	c	17,08
0088-	M	b	b	b	15,42
0089-	M	c	c	c	16,33
0090-	F	c	c	c	15,5
0091-	F	d	d	d	18,33
0092-	F	d	d	d	16,67
0093-	M	b	b	b	17,67
0094-	M	c	c	c	13,75
0095-	M	d	d	d	14,0
0097-	M	c	c	c	15,5
0098-	F	d	d	d	19,67
0099-	F	b	b	b	15,83
0100-	M	a	a	b	17,83
0101-	M	d	d	d	19,58
0102-	F	e	e	e	18,83
0103-	F	e	e	e	18,0
0104-	F	c	c	c	16,92
0105-	F	e	e	e	18,75
0106-	M	d	d	d	17,58
0107-	F	e	e	e	18,58
0108-	F	c	c	c	15,5
0109-	M	c	c	c	19,0
0110-	F	c	c	c	22,92
0111-	M	c	c	c	25,83
0112-	F	b	b	b	21,42
0113-	F	e	e	e	26,42
0114-	F	c	c	c	21,33
0115-	M	c	c	c	35,5
0116-	F	c	c	c	25,42
0117-	F	e	e	e	23,0
0118-	F	e	e	e	66,33
0119-	F	d	d	d	15,08
0120-	F	b	a/b	b	22,25
0121-	F	d	d	d	19,33
0122-	F	d	d	d	27,67
0123-	F	c	c	c	13,5
0124-	F	d	d	d	23,33
0125-	F	c	c	c	23,33
0126-	F	d	d	d	37,75
0127-	M	d	d	d	19,92
0128-	M	d	d	d	32,5
0129-	F	d	d	d	24,92

0130-	M	c	c	c	21,67
0131-	M	c	c	c	37,75
0132-	F	d	d	d	45,83
0133-	F	c	c	c	24,67
0134-	F	d	d	d	19,83
0135-	F	c	c	c	21,42
0136-	F	d	d	d	23,58
0137-	M	d	d	d	10,42
0138-	F	b	b	b	15,33
0139-	F	e	e	e	26,17
0140-	F	d	d	d	28,17
0141-	M	d	d	d	15,25
0142-	F	e	e	e	22,42
0143-	M	d	d	d	17,58
0144-	F	c	c	c	28,83
0145-	F	c	c	c	22,0
0146-	M	b	b	b	19,33
0147-	F	d	d	d	64,58
0148-	F	d	d	d	51,92
0149-	F	d	d	d	21,0
0150-	M	b	b	b	57,08
0151-	F	e	e	e	26,42
0152-	M	b	b	b	14,42
0153-	F	c	c	c	16,25
0154-	M	c	c	c	18,17
0155-	M	d	d	d	16,25
0156-	M	c	c	c	29,17
0157-	F	e	e	e	59,08
0158-	M	e	e	e	33,25
0160-	F	c	c	c	22,0
0161-	F	e	e	e	44,5
0162-	M	b	b	b	20,08
0163-	F	d	d	d	30,08
0164-	F	d	d	d	27,33
0165-	M	b	b	b	15,08
0166-	F	e	e	e	69,67
0167-	M	a	a	a/b	43,92
0168-	M	e	e	e	54,92
0169-	F	e	e	e	35,17
0170-	F	c	c	c	29,33
0171-	F	e	e	e	35,08
0172-	M	e	e	e	58,75
0173-	F	c	c	c	17,58
0174-	M	d	d	d	39,58
0175-	F	c	c	c	30,75
0176-	F	e	e	e	30,75

0177-	M	e	e	e	54,0
0178-	M	e	e	e	43,25
0179-	F	d	d	d	33,83
0180-	F	b	b	b	43,33
0181-	M	e	e	e	31,0
0182-	M	b	b	b	23,0
0183-	M	e	e	e	60,75
0184-	M	c	c	c	22,83
0185-	F	d	d	d	44,42
0186-	F	d	d	d	64,0
0187-	M	b	b	b	37,92
0188-	F	e	e	e	71,0
0189-	M	e	e	e	40,83
0191-	F	e	e	e	40,08
0192-	M	b	b	b	36,5
0194-	M	d	d	d	23,17
0195-	F	c	c	c	32,92
0196-	M	b	b	a	45,5
0197-	F	e	e	e	68,75
0198-	F	e	e	e	41,08
0199-	M	d	d	d	41,17
0200-	F	e	e	d	40,92
0201-	F	e	e	e	54,42
0202-	M	e	e	e	74,17
0203-	F	e	e	e	24,17
0204-	F	c	c	c	29,92
0205-	F	e	e	e	57,58
0206-	M	e	e	e	43,92
0207-	F	d	d	d	58,5
0208-	M	b	b	b	44,58
0209-	F	e	e	e	24,58
0210-	F	b	b	a	41,08
0211-	F	e	e	e	26,67
0212-	M	d	d	d	48,67
0213-	F	e	e	e	53,67
0214-	M	d	d	d	76,83
0215-	F	e	e	e	77,5
0216-	F	d	d	d	30,58
0217-	F	d	d	d	32,17
0218-	F	e	e	e	43,08
0219-	M	e	e	e	64,5
0220-	F	a	a	a	72,92
0221-	F	b	a	b	38,42
0222-	F	e	e	e	50,5

10.4. Appendix D: Raw data for establishing intra-rater reliability (reclassification reliability)

No	Sex	T1 SS	T1 RC	Repeatability Assessment	age at time CBCT taken
0010-	M	b	a	b	12,5
0020-	M	d	d	d	12,58
0030-	M	a	b	b	9,25
0040-	M	b	b	b	11,67
0050-	M	b	b	b	14,25
0060-	F	e	e	e	13,33
0070-	F	b	b	b	12,17
0080-	M	a	a	a	15,33
0090-	F	c	c	c	15,5
0100-	M	a	b	a	17,83
0110-	F	c	c	c	22,92
0120-	F	a/b	b	b	22,25
0130-	M	c	c	d	21,67
0140-	F	d	d	d	28,17
0150-	M	b	b	b	57,08
0160-	F	c	c	c	22,0
0170-	F	c	c	c	29,33
0180-	F	b	b	b	43,33
0192-	M	b	b	b	36,5
0200-	F	e	d	d	40,92
0210-	F	b	a	b	41,08
0220-	F	a	a	a	72,92