COMPARISON BETWEEN THE ALPHA ANGLE OF THE MAXILLARY IMPACTED CANINES ON PANORAMIC RADIOGRAPHS AND CONE BEAM COMPUTED TOMOGRAPHY

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KEYWORDS

Alpha angle

As Low As Diagnostically Achievable

Cone-beam computed tomography

Dental pantomograph

Impaction

Maxillary canine

Radiographic predictors

Sectors

ABSTRACT

Introduction

There is a paucity of studies that make use of the alpha angle as a diagnostic tool to assist with the interceptive treatment, prognosis, treatment duration and surgical outcome of possible maxillary canine impaction in orthodontics. While the literature is replete with studies that utilise the sector method, the alpha angle is an alternative approach to assess the possible eruptive outcome of the unerupted canine.

It has been reported that if the alpha angle is greater than 25°, there is the possibility of external root resorption. However, if the alpha angle is more than 31°, the prospect of canine eruption decreases even if the deciduous canine is extracted as an interceptive measure.

The dental pantomograph has historically been used to predict canine eruption or possible impaction. The use of this method, however, is wrought with limitations. These limitations include magnification, distortion and blurred images. The use of cone-beam computed tomography has been advocated as a means to overcome these limitations.

Aim

The aim of the study was to evaluate the difference in the alpha angle when utilising the dental pantomograph or cone-beam computed tomography in clinical orthodontics.

Materials and methods

The sample size consisted of 100 possible maxillary canine impactions on both the dental pantomograph and cone-beam computed tomography images from the same patients. These radiographs were selected from the radiographic archives of four dental centres. The alpha angle was measured on both the dental pantomograph and cone-beam computed tomography images. Inter- and intra-examiner reliability were quantified by intraclass coefficients. Bland-

Altman limits of agreement were used to determine the difference in the alpha angle between the two radiographic methods.

Results

The intra- and inter-examiner reliability was >0.8, indicating good reliability between the examiners. The mean alpha angle as measured on the dental pantomograph was 29.1º (SD 20.9), while the mean alpha angle as measured on cone-beam computed tomography scans was 15.9º (SD 24.4). The mean difference between cone-beam computed tomography and the dental pantomograph in this study was -13.2º. This statistically significant difference ($p<0.0001$) means that on average, cone-beam computed tomography measures 13.2º less than the dental pantomograph method.

Conclusions

Panoramic radiographs overestimate the alpha angle when compared with CBCT images. Therefore, despite the limitations of the dental pantomograph, it is still a valid diagnostic tool that is considered beneficial in determining possible maxillary canine impaction when cone--beam computed tomography is not indicated in treatment planning. This is in keeping with the principle of 'As Low As Diagnostically Achievable'. The corollary that can be drawn from this study is that, in essence the unerupted canine is more upright than it actually appears on the dental pantomograph. Furthermore, based on this study, if cone-beam computed tomography is used, an alpha angle of 16.8º will predicate interceptive intervention.

DECLARATION

I declare that *A Comparison of the Alpha Angle of Maxillary Impacted Canines between Panoramic Radiographs and Cone-Beam Computed Tomography* is my own work, that it has not been submitted before 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: Khaled Alenazi Date: 13 July 2019

Signed

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DEDICATION

This thesis is dedicated to my family who constantly supported me: My father and mother, my siblings and especially, my son **Ahmad** and my daughter, **Dalal**. I thank all of you for the care, love and support that you gave me during this period. You are the light of my life. My appreciation is infinite.

CONTENTS

LIST OF ABBREVIATIONS

ALADA	As Low as Diagnostically Achievable
ALARA	As Low As Reasonably Achievable
ANS	anterior nasal spine
AP	antero-posterior
B&A	Bland-Altman
BDC	buccally displaced canine
BMREC	Biomedical Research Ethics Committee
CBCT	cone-beam computed tomography
DICOM	Digital Imaging and Communications in Medicine
DPT	dental pantomograph
FOV	field of view
ICC	Intraclass correlation coefficient
LoA	Limits of Agreement
MCI	maxillary canine impaction
$\bar{d}$	mean difference
μSv	microsieverts
MPR	multiplanar reformatting
PAN	panoramic radiograph
PDC	palatally displaced canine

PNS	posterior nasal spine
R1	reading one
R2	reading two
SD	standard deviation
UWC	University of the Western Cape

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

"There can be no doubt that in the scheme of occlusion Nature intended the canine to be one of its foremost mainstays. Nevertheless, this keystone of the human denture is found in positional abnormalities of the maxillae more often than any other tooth, and its failure to find its normal position in the arch is a calamity to the occlusal mechanism" (Goldsmith, 1931 as cited in Sajnani & King, 2012) . The impaction of the maxillary canine is one of the most difficult problems that an orthodontist has to deal with in daily practice (Lappin, 1951).

Impaction is defined as a "condition in which the tooth is embedded in the alveolus so that its eruption is prevented" (Kasander, 1994). A canine that is prevented from erupting into its normal functional position by bone, tooth or fibrous tissue is said to be impacted (Proffit, Fields, Larson & Sarver, 2018).

The maxillary canine is the second most commonly impacted tooth after the third molar, with a reported incidence in approximately 2.8% of the population (Bishara, 1992; Chu *et al.*, 2003). The incidence of maxillary canine impaction (MCI) is more than twice that in the mandible (Yavuz, Aras, Buyukkurt & Tozoglu, 2007). Approximately 8% of all patients with MCIs have bilateral impactions. Research has found that MCIs occur more commonly in females (1.17%) than in males (0.51%), with a ratio of 2:1 (Bishara, 1992).

The maxillary canine can be impacted buccally or palatally. However, buccal impactions occur less frequently (4.5%) than palatal impactions (61%) (Stivaros & Mandall, 2000). There are contradicting views regarding side distribution. Harzer *et al.* (2002) as cited in Grande, Stolze, Goldbecher and Kahl-Nieke (2006) found a higher incidence on the left side of the oral cavity, while Stahl and Grabowski (2003) as cited in Grande *et al.* (2006) observed an equal incidence on both sides. In addition, Grande *et al.* (2006) observed that the right side was affected slightly more often than the left side.

There are various aetiologies for MCIs, with some degree of associated uncertainty. The genetic and guidance theories are the main theories postulated for these impactions. In the guidance theory, agenesis of the lateral incisor, peg laterals, spaced maxillary dentitions, unusual eruption rate, abnormal location of the tooth bud and over-retained deciduous canines are considered the causative factors (Bishara, 1992). According to Baccetti (1998), canine impaction is usually associated with dental anomalies, and the genes MSX-1 and PAX9 are directly related to palatally positioned canine impactions. The canine has a long and tortuous path of eruption that increases the potential for impaction. The average length traversed by the maxillary canine for normal eruption between the ages of 5 years and 15 years is 21.99 mm (Coulter & Richardson, 1997).

The canine forms the cornerstone of the mouth and is important for arch development, functional occlusion and smile aesthetics (Rossini, Cavallini, Cassetta, Galluccio & Barbato, 2012). Failure to identify MCIs can result in a short arch length, formation of cysts, ankylosis of the canine and root resorption of adjacent teeth (Alqerban, Jacobs, Souza & Willems, 2009). The most likely tooth to be affected by external root resorption is the lateral incisor. Involvement of the central incisor and premolars has also been reported (Postlethwaite & Hamilton, 1989). The ramification of external root resorption is the reduction in the lifespan of the affected tooth. Therefore, early detection of MCI is of paramount importance because this will decrease orthodontic complications and treatment duration.

Canines can be palpated in the vestibular sulcus about 1.5 years before they erupt into the oral cavity (Kurol, 2006). Therefore, it is suggested that the buccal sulcus in the vicinity of the deciduous canines should be clinically observed in children between the ages of seven and ten years. If the permanent canine appears to be retained, a radiographic examination is mandatory.

The radiographic examination allows the practitioner to localise the impacted teeth and predict treatment duration, treatment difficulties and treatment options. These treatment options include interceptive treatment or observation, surgical exposure and placement of an attachment on the impacted teeth, canine extraction, auto-transplantation and replacement with a dental implant or prosthesis (Stivaros & Mandall, 2000).

Two-dimensional (2D) radiography is routinely used to diagnose an impacted tooth (Botticelli, Verna, Cattaneo, Heidmann & Melsen, 2010). Conventional radiographs provide a 2D screening tool that can aid in the evaluation of the canine impaction. Several 2D radiographic techniques have been advocated. These include the periapical, the dental pantomograph (DPT), occlusal and cephalometric or even a combination of two or more of these approaches. However, these radiographic techniques have their limitations, namely image magnification, superimposition of structures, blurred images, distortion and artefacts (Elefteriadis & Athanasiou, 1996). Furthermore, a DPT is a 2D representation of a three-dimensional (3D) object. These limitations may lead to possible misinterpretations and under-estimations of the labial and palatal features, for example, external root resorption of the teeth adjacent to the impacted canine (Ericson & Kurol, 1988).

To circumvent the limitations associated with conventional radiographs, cone-beam computed tomography (CBCT) is advocated to identify MCIs (Botticelli *et al*., 2010). Cone-beam computed tomography overcomes the drawbacks of 2D radiography since it has the ability to locate impacted canines precisely, to identify pathology and to detect root resorption. The CBCT imaging technique diagnoses up to 50% more cases of root resorption than the DPT

(Alqerban *et al*., 2009). Furthermore, CBCT provides additional information regarding the relationship between the canine and the incisors (Tsolakis *et al*., 2018).

The recommended treatment for the palatally displaced canine (PDC) is extraction of the deciduous canine to improve the chances of spontaneous eruption of the permanent canine into the dental arch (Bazargani, Magnuson & Lennartsson, 2013).

The dilemmas that confront many orthodontists are ascertaining whether or not the displaced maxillary canine will be impacted and determining the appropriate timing for interceptive treatment to prevent MCI. To justify the effectiveness of interceptive extraction of the deciduous canine in the treatment of PDCs, Ericson and Kurol (1987) identified radiographic predictors to evaluate the successful outcome of impacted canines. These include the mesio-distal location of the impacted canine (the sector position), the distance (d) of the impacted canine from the occlusal plane and the alpha angle, which is the angle between the long axis of the maxillary canine and the midline (Ericson & Kurol, 1987).

However, in the study of Stivaros and Mandall (2000), the radiographic decision to expose or extract the impacted canine surgically was determined by the labio-palatal position and the alpha angle. The authors found that as the alpha angle increased (>= 31°), the canine was more likely to be removed (Stivaros & Mandall, 2000).

The literature is replete with studies that use the sector method to predict MCI or to determine the extent of root resorption of the teeth adjacent to the MCI (Ericsson & Kurol 1987; Lindauer, Rubenstein, Hang & Andersen, 1992; Warford, Grandhi & Tira, 2003). The sector method describes the location of the cusp tip of the maxillary canine in relation to the adjacent lateral and central incisors.

There is a dearth of studies that evaluate the alpha angle as a viable predictor. It has been reported that if the alpha angle is greater than 25°, the possibility of external root resorption increases to 50% (Ericson & Kurol, 1988). If the alpha angle is more than 31°, the prospect of the canine erupting normally decreases dramatically, even if the deciduous canine is interceptively extracted (Power & Short, 1993). However, Warford *et al. (*2003) found that the sector location was of greater significance in determining the possibility of MCI than the alpha angle. These authors concluded that the alpha angle was not a useful predictor.

A comparison between the DPT and CBCT in regard to effective dose of radiation showed that CBCT is between two and six times higher than the DPT, depending on the machine and field of view (FOV) (Signorelli, Patcas, Peltomäki & Schätzle, 2016). Therefore, using CBCT as a routine procedure for diagnostic purposes is not recommended (Smith, Park & Cederberg, 2011). Alqerban *et al*. (2013) demonstrated no difference between the two modalities in determining the treatment plan for an impacted canine. In addition, a questionnaire-based study that compared agreement between DPTs and CBCTs for initial orthodontic evaluations of MCIs found moderate agreement between CBCT and the panoramic radiograph (PAN) (Pittayapat, Limchaichana-Bolstad, Willems & Jacobs, 2014). A systematic review concluded that there is insufficient evidence that CBCT is more advantageous than conventional radiography in terms of diagnosis, treatment planning and treatment outcome (Van Vlijmen *et al.*, 2012).

There are few studies that use the alpha angle as a diagnostic aid to evaluate the interceptive treatment, prognosis, treatment duration and surgical outcome of MCIs. While most clinicians prefer the sector method (Lindauer *et al*., 1992; Warford *et al*., 2003), the unresolved question is the accuracy and reliability of using the alpha angle measurement as a predictor on the DPT for MCIs.

The main disadvantages of the DPT are associated with variable magnification and geometric distortions (Yeo *et al.*,2002). The largest angular distortions on a DPT is found in the canine-premolar region due to the curvature of the dental arches. It was found that the DPT projected the anterior teeth more mesially and the posterior teeth more distally (McKee *et al*., 2002). Peck *et al.,(*2007) also found that most of the discrepancy was in the canine area. These findings bring into question the reliability of using any angular measurement for diagnostic purposes especially at the corner of the dental arch.

CBCT images are intrinsically more accurate than conventional radiographs because the beam projection is orthogonal. The radiographic beams are parallel to one another with the object near to the sensor. Therefore, there is little projection effect and no magnification (Mah *et al*., 2004)

CHAPTER 2: LITERATURE REVIEW

2.1 DEFINITION OF CANINE IMPACTION AND SIGNS OF IMPACTION

Many descriptions and interpretations of an impacted tooth are recorded in the literature, and most are related to speculative aetiological factors (Thilander & Jakobsson 1968). An impacted tooth can be defined as the cessation of eruption of a tooth due to a physical obstruction that impedes eruption or the abnormal positioning of the tooth. This is accompanied by clinical and radiographic evidence that there will be no further eruption of the tooth within the normal period of growth. According to Baccetti, Leonardi and Armi (2008), a displaced canine can be defined as impacted if it has not erupted beyond cervical stage 5 (CS5) of cervical vertebral maturation, which occurs on average one year after the end of the adolescent growth spurt.

An impaction should be suspected if the unerupted tooth fails to erupt after complete root development or the contralateral tooth erupted approximately six months previously with complete root formation (Lindauer *et al.*, 1992). Furthermore, Ericson and Kurol (1986) suggested that an impaction should be suspected if there is an absence of the canine bulge after the age of ten years.

2.2 ERUPTION PATHWAY OF THE MAXILLARY CANINE

Tooth eruption is defined as “the axial movement of a tooth from its developmental site within the alveolar bone to its functional position in the dental arch” (Massler & Schour, 1941). This biological process occurs in a localised, bilateral, symmetric and precisely timed way. Eruption of a tooth requires resorption of the alveolar bone and resorption of the roots of the preceding deciduous tooth (Carlson, 1944). The process only starts once mineralisation of the crown has been completed. The mechanism of normal eruption and development of the maxillary anterior teeth was initially described by Broadbent (1941).

Understanding the normal development of the canine is a crucial starting point for understanding abnormal development and subsequent impaction. "No tooth is more interesting from a development point of view than the maxillary canine" (Dewel, 1949). The canine has a long, complex, tortuous path of eruption from its initial development to its final positioning in the oral cavity (Dewel, 1949). The eruption path constitutes a series of events that include movements in three planes, namely posterior, vertical and lateral (Coulter & Richardson, 1997).

The tooth germ of the permanent maxillary canine begins its development at approximately four to five months of age, with the crown mesially and palatally directed. It is positioned high in the anterior wall of the maxillary sinus near the orbital floor (Broadbent, 1941). Calcification of the permanent maxillary canine commences at the age of 12 months between the roots of the first deciduous molar (Broadbent, 1941). With the eruption of the deciduous first molar, the permanent maxillary canine crown is left behind, thereby allowing the first premolar to develop between the roots of the deciduous first molar. With the development of the first premolar, the developing maxillary canines, first premolars and first deciduous molars lie above each other in a vertical row (Nanda, 1983; Duterloo, 1991). The crown of the permanent canine is directed mesially and palatally in relation to the deciduous canine and to the developing first premolar and lies near the mesial root of the first deciduous molar (Broadbent, 1941; Kuftinec & Shapira, 1995). Furthermore, there is a vertical overlap of approximately 3 mm between the permanent maxillary canine and the root of the deciduous maxillary canine (Noyes, 1930).

The 'ugly-duckling stage' occurs from approximately 8 years to 12 years of age. During this stage, the maxillary permanent canine changes from a position palatal to the apex of the deciduous maxillary canine to a buccal position. An increase in the subnasal area causes the canine to traverse downwards, forwards and laterally away from the root of the lateral incisor. Eruption of the canine leads to the uprighting of the lateral incisors and first premolars (Coulter

& Richardson, 1997). Between the dental ages of nine years and ten years, it is possible to palpate the maxillary canine buccal bulge clinically. This bulge is located apical to the root of the deciduous maxillary canine (Nanda, 1983; Shapira & Kuftinec, 1998).

At the dental age of ten years, half the root of the permanent maxillary canine has been formed, and resorption of the deciduous maxillary canines should be clearly discernible in the apical third of the root. The extent of root resorption of the deciduous maxillary canine is dependent on the location of the crown of the permanent maxillary canine (Duterloo, 1991).

Emergence occurs when three-quarters of the root has been formed; root formation is completed two years after eruption of the canine (Nanda, 1983). The permanent maxillary canine is among the last teeth to erupt in the maxilla. The average age of eruption is approximately 12 years and 3 months in girls and 13 years in boys (Hurme, 1949).

Any deviation of the developing permanent maxillary canine from its normal course may lead to an increased risk of abnormal development and impaction (Dewel, 1949).

2.3 AETIOLOGY OF CANINE IMPACTION

The aetiology of impacted canines is multifactorial (Peck, Peck & Kataja, 1994; Becker, Gillis & Shpack, 1999; Sajnani & King, 2012). It is postulated that buccal canine impaction occurs due to an arch-length deficiency (Jacoby, 1983), while 85% of palatal canine impactions are accompanied by sufficient space for eruption (Jacobs, 1996). It is reported that excess space in the upper arch is the causative factor leading to palatal canine impaction by permitting the canine to cross back to the palatal side (Mercuri *et al*., 2013). Similarly, the congenital absence or presence of peg-shaped lateral incisors and late-developing teeth has been associated with palatally impacted canines (Brin, Becker & Shalhav, 1986; Baccetti, 1998; Becker *et al*., 1999;

Leifert & Jonas, 2003). The suture between the maxilla and premaxilla could also be the cause of palatal MCIs (Jacoby, 1983).

Other causes associated with canine impaction include a physical impediment to eruption, an abnormal position of the tooth bud, abnormal tooth morphology, a long and complex path of eruption, early loss of the primary canine, prolonged retention of the primary canine (Lappin, 1951), lack of vertical movement, systemic diseases (Jacoby, 1983; Ericson & Kurol, 1986; Bishara, 1992; Sajnani & King, 2012) and trauma to the face. Trauma can cause the transmission of force to the maxilla with the resultant displacement of the follicle of the unerupted tooth. Trauma can also affect the root development, resulting in a curvature or severe dilaceration of the root (Brin, Solomon & Zilberman, 1993). Furthermore, odontomas and supernumerary teeth can be causative if they occur in the canine area. However, this finding is common in the area of incisors but not in the canine area (Becker, Abramovitz & Chaushu, 2013).

Jacobs (1996) believed that the aetiology of a PDC was mainly genetic in origin, while labial impactions were due to a deficiency in arch length. The author also believed that MCIs could occur before or after the age of ten years. According to Jacobs (1996), an impaction that occurs before the age of ten years is the result of familial history and missing or anomalous lateral incisors.

2.3.1 Theories proposed for maxillary canine impactions

2.3.1.1 The guidance theory

The guidance theory states that the root of the lateral incisor guides the eruption of the maxillary canine in a favourable distal and incisal direction. Therefore, if the root of the lateral incisor is missing or malformed, the canine will be impacted (Becker, 1995; Becker & Chaushu, 2015).

2.3.1.2 The genetic theory

A PDC is genetically determined and is associated with other dental anomalies such as small teeth, aplasia of the second premolar, infra-occlusion of primary molars and enamel hypoplasia (Baccetti, 1998). Palatally displaced canines tend to occur in specific races, with a high percentage occurring in the white population. Maxillary canine impactions also have familial tendencies and are found more in females than males (F:M = 3.2:1.3). Maxillary canine impactions are also found in specific syndromes (cystic fibrosis, Marfan's syndrome and Cleidocranial dysplasia). The association of side is a unilateral to bilateral ratio of 4:1 (Peck *et al*., 1994).

2.3.1.3 The sequential theory

This theory is an amalgamation of the guidance theory and the genetic theory. It provides a sequence in which the above theories may act at different stages during the development of the permanent maxillary canine. The sequential theory hypothesises that both palatally and buccally impacted maxillary canines have a similar aetiopathogenesis. Genetic predetermination may also affect eruption of the canine in the vertical dimension by reducing eruption potential during early canine development. The lateral incisor plays a pivotal role in the later stage of development (Sajnani & King, 2012).

2.4 CLASSIFICATION OF MAXILLARY IMPACTED CANINES

Using a DPT, Yamamoto *et al*. (2003) classified impacted canines according to seven categories (Figure 2.1). The classification was dependent on the angle between the long axis of the canine and the occlusal plane.

1. Type I: The canine is impacted vertically between the lateral incisor and premolar and is perpendicular to the occlusal plane.
2. Type II: The impacted canine lies in a mesial orientation to the occlusal plane.
3. Type III: The impacted canine lies in a distal orientation to the occlusal plane.
4. Types IV: The canine is impacted horizontally with the crown oriented in a mesial direction.
5. Type V: The canine is impacted horizontally with the crown oriented in a distal direction.
6. Type VI: The canine is inverted vertically with the apex directed occlusally.
7. Type VII: Transposed or ectopic impacted canines.

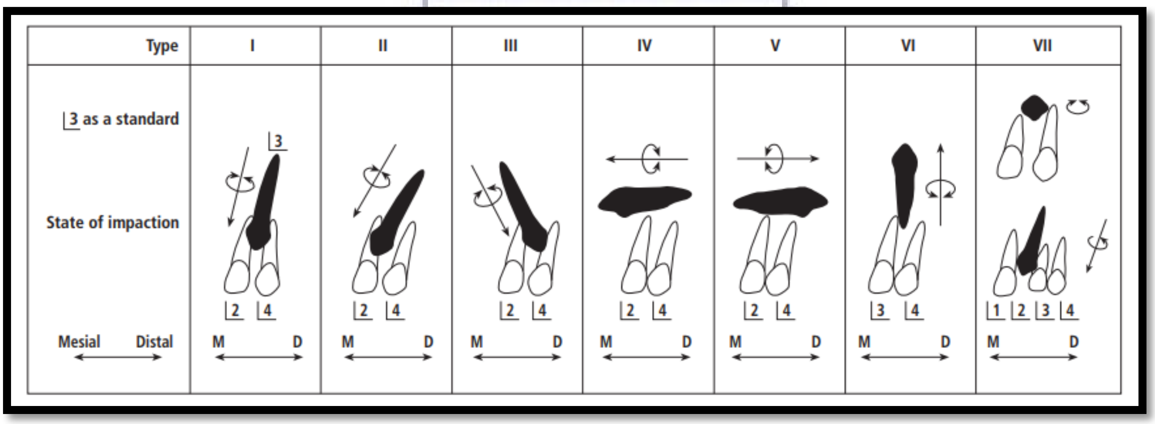


Figure 2.1: Classification of impacted canines

Source: Yamamoto *et al*., 2003

2.5 RADIOGRAPHIC ASSESSMENT OF MAXILLARY CANINE IMPACTION

There has been a shift away from the As Low As Reasonably Achievable (ALARA) principle and towards the principle of As Low As Diagnostically Achievable (ALADA) (Jaju & Jaju, 2015). Radiation should always be in line with ALADA. The principle of ALADA promotes the use of appropriate radiation that benefits the patient and concomitantly provides the orthodontist with accurate diagnostic information. This prevents an unjustified radiation dose to the patient (Björksved Magnuson, Bazargani, Lindsten & Bazargani, 2019).

The DPT is the standard diagnostic radiographic method in orthodontics since it provides an overview of the oral cavity and surrounding structures. Furthermore, the DPT is associated with low radiation exposure (Wriedt, Jaklin, Al-Nawas & Wehrbein, 2012).

Southall and Gravely (1989) reported that in their study, 78% of orthodontists and oral surgeons used more than two 2D radiographs to determine the position of an ectopic or impacted canine and to plan treatment, and 23% used four or more. The rationale for taking multiple radiographs is because the radiographic localisation of MCIs with conventional 2D radiographs can present with inherent limitations due to distortion, superimposition of anatomical structures and imaging artefacts. Conventional radiographs, namely DPT (Ericson & Kurol, 1986) and periapical x-rays using Clark's rule or the buccal-object rule (Clark, 1909; 1910), therefore, contribute diagnostic information regarding the vertical and mesiodistal relationship of the impacted canine with adjacent teeth and anatomical structures.

When radiographs are taken using Clark's rule, the palatal object moves in the same direction as the radiographic beam and the labial object moves in the opposite direction to the radiographic beam. This technique allows for a 92% accuracy in the appraisement of the labio-palatal position of the canine (Ericson & Kurol, 1987).

Panoramic radiographs are based on a principle that is the opposite of Clark's rule since the tube moves from behind the patient, starting from right to left. Thus, the palatally impacted canine will move from the patient's left to right while the labially impacted canine will move in the same direction as the tube head. This is because the palatally impacted canine is farther from the source of radiation in relation to the reference point, which is the anterior part of the maxilla (Turk & Katzenell, 1970).

Furthermore, periapical radiographs and DPTs can misrepresent the space available in the arch for the canine. This can be overcome by the occlusal radiograph that is able to provide supplemental diagnostic information regarding the space requirements.

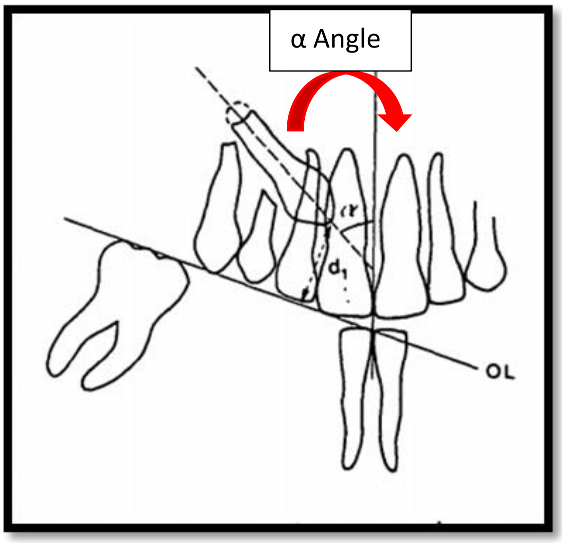
Four types of errors can be produced by the periapical radiograph and the DPT. The DPT and periapical films provide information regarding the mesiodistal dimension but not the labio-palatal dimension of the maxillary bone, thereby conveying an impression of crowding due to the overlap of the impacted canine with the adjacent teeth. However, crowding may not always be present. The image can also be amplified if it is not aligned in the same horizontal plane. If the tooth lies in a different horizontal plane (positioned more labially or palatally), the image will be distorted. The distance between the film and the object determines the amplification ratio. As the distance increases, the magnification increases. Therefore, if a tooth is labially impacted, it will be projected over the adjacent teeth while in the case of a palatally impacted canine, the adjacent teeth will be projected over the canine. Both projections give an appearance of crowding. A periapical image that is positioned laterally and off-centre to the impacted tooth is projected over the adjacent teeth, leading to the appearance of crowding. Slight deviations that occur in repeated DPTs of the same patient can result in different proportions of the jaw dimensions. The roots of the maxillary teeth converge while the roots of the mandibular teeth appear to diverge, thus the maxillary apical base appears crowded (Jacoby, 1983).

2.6 ASSESSMENT OF CANINE IMPACTION ON THE DENTAL PANTOMOGRAPH

A DPT study of MCIs found that 76% of the maxillary canines were palatally impacted and 9% were labially impacted. The palatally impacted canines exhibited a mesio-angular and horizontal inclination, while vertical inclinations were commonly found labially or in the middle of the alveolar ridge. An important observation was that the majority of canines (86%) were inclined mesially. In addition, it was observed that the closer that the crown of canines was to the intermaxillary suture, the more likely the maxillary canines were to be impacted palatally. The canines positioned between the roots of the incisors were most likely to be palatal. If the canine was located above the apex of the incisor, it was most likely to be positioned labially or mid-alveolus. Furthermore, a palatally impacted tooth was magnified on a DPT, while a labially impacted tooth appeared to be reduced in size. These authors concluded from their study that the DPT was not a reliable aid in clinical diagnosis (Wolf & Mattila, 1979).

Ericson and Kurol (1988) developed three methods to predict the eruption of PDCs after extraction of the deciduous canine. The researchers used three planes to determine the position of the canine, namely the sagittal (lateral head film), the frontal (orthopantomogram) and the transverse (vertex projections). Ericson and Kurol (1988) were the first to describe the use of the alpha angle on a PAN as a means to predict the impaction of the maxillary canine.

1. The alpha angle is represented by the angle between the long axis of the impacted maxillary canine and the midline (Figure 2.2).



α Angle: alpha angle

OL: occlusal line

Figure 2.2: The alpha angle and distance of canine cusp tip to occlusal line in the dental pantomograph

Source: Ericson & Kurol, 1988a

2. d_1 represents the distance between the canine cusp tip to the occlusal plane (Figure 2.2).
3. Demonstration of medial crown position in sectors 1–5 (Figure 2.3).

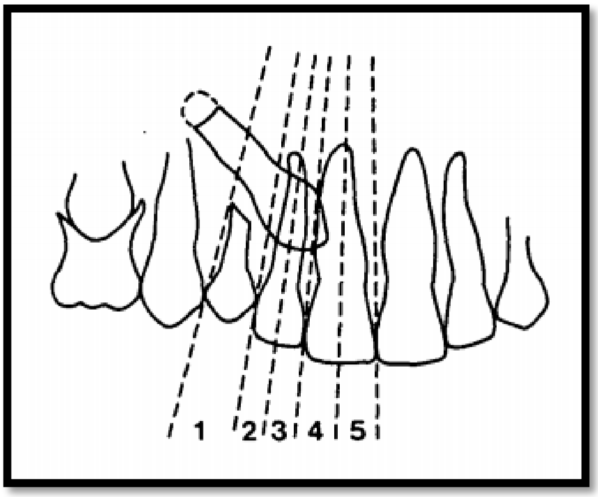


Figure 2.3: Medial position of canine in sectors 1–5 in frontal plane at the beginning of treatment

Source: Ericson & Kurol, 1988

Drawing on the work of Ericson and Kurol (1988), Lindauer *et al*. (1992) developed the method that uses the location of the tip of the canine in relation to the adjacent lateral incisors to expand sectors I to IV (Figure 2.4). Lindauer *et al*. (1992) found that 22% of canines tended to be impacted if the tip of the canine cusp was distal to a line contiguous to the distal half of the root of lateral incisor (sectors I and II), and 78% of canines were destined to be impacted if they were positioned in sectors III and IV. The authors concluded that the DPT was a good predictor of MCI. However, the effects of distortion on the DPT limited its use in establishing the labio-palatal position of unerupted maxillary canines. Lindauer *et al*. (1992) described four sectors as predictors of possible MCI. In Sector I, the canine tip was found in the area distal to the distal margin of the lateral incisor. In Sector II, the canine tip was in the area between the distal surface of the crown and root of the lateral incisor and the midline of the long axis of the lateral incisor. Sector III was described as any position mesial to Sector II, that is, to the mesial surface of the long axis of the lateral incisor. In Sector IV, the impacted canine can be located mesial to Sector III, that is, between the mesial surface of the lateral incisor and the mid-sagittal line.

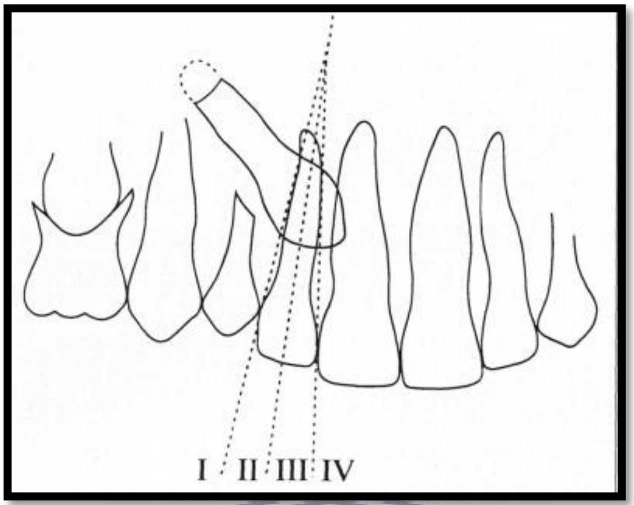


Figure 2.4: Modification of the sectors
Source: Adapted from Ericson & Kurol, 1988 by Lindauer *et al*., 1992

A study by Power and Short (1993) was conducted to determine the outcome of early extraction of the deciduous canine on the successful eruption of MCI and to establish the factors that contribute to successful canine eruption. The study found that 62% of the canines erupted spontaneously while 19% improved in their path of eruption. A favourable outcome for eruption of the permanent canine after extraction of the deciduous canine depended on the extent of horizontal overlap of the permanent canine to the adjacent incisors. If the canine exceeded half the width of the incisor root, normal eruption was considered unlikely. Crowding was also found to be a factor that would adversely affect the eruption of permanent canines. An alpha angle greater than 31° impeded spontaneous eruption (Power & Short, 1993).

A comparison between the DPT and vertex occlusal view (gold standard) to localise the position of the MCI either buccally or palatally was carried out. Of the five cases, four were correctly predicted using the DPT by employing differential magnification (i.e. the palatally impacted tooth is larger than the buccally impacted tooth), while one of the five cases was either not detected or falsely predicted. The PAN cannot detect the position of the root of an impacted canine. The kappa value between the DPT and the vertex occlusal view was 0.54, which equated to a moderate level of agreement (Fox, Fletcher & Horner, 1995).

Conversely, Chaushu, Chaushu and Becker (1999) considered the PAN to be the reliable method to determine the position of a displaced maxillary canine. The authors reported the canine incisor index for the buccally displaced canine (BDC) in the coronal and middle zones to be 0.78–1.11 and indicated an index of 1.15–1.7 for the PDC. Thus, the cut-off point to determine palatal displacement of canines is 1.15. In the apical zone, the canine incisor index for the BDC is 0.94–1.45 and for the PDC, it is 1.15–1.29 (Chaushu *et al*., 1999). This indicates overlapping, making the decision difficult to confirm the displaced canine without using other radiographic modalities.

Stivaros and Mandall (2000) evaluated the following parameters of the impacted canine on a panoramic image; angulation of the MCI to the midline (Figure 2.5); antero-posterior (AP) position of the root apex (Figure 2.6); vertical height (Figure 2.7); extent of overlap of the MCI with the adjacent incisor (Figure 2.8); and root resorption of adjacent lateral incisor. The information was obtained from DPTs. The study concluded that the treatment options of either exposing the impacted canine or extracting the impacted canine are determined by the angulation of the MCI to the midline and the labio-palatal crown position (Stivaros & Mandall, 2000).

As the alpha angle increased, there was an increased likelihood of the surgical removal of the canine. Similarly, if the canine was palatally positioned, there was an increased likelihood of surgical exposure, while canines that were in a labial position or positioned in the line of the arch tended to be extracted. The rationale for this extraction protocol was the difficulty experienced in the management of the attached gingiva with buccal flaps compared with palatal flaps (Stivaros & Mandall, 2000).

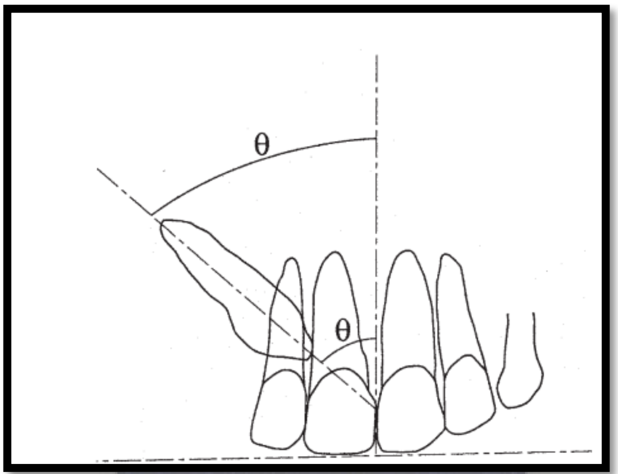


Figure 2.5: Alpha angle formed by intersection of the long axis of the canine to the midline
Source: Stivaros & Mandall, 2000

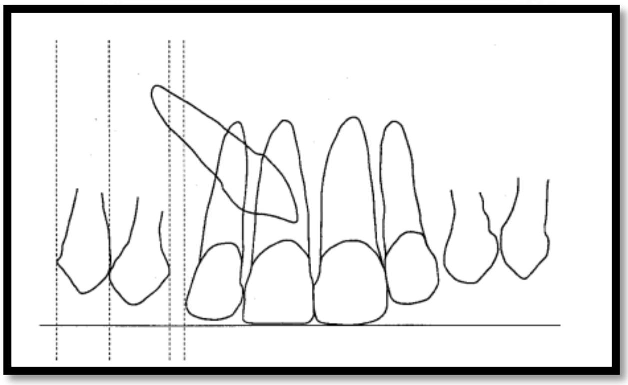


Figure 2.6: Antero-posterior position of the canine root apex
Source: Stivaros & Mandall, 2000

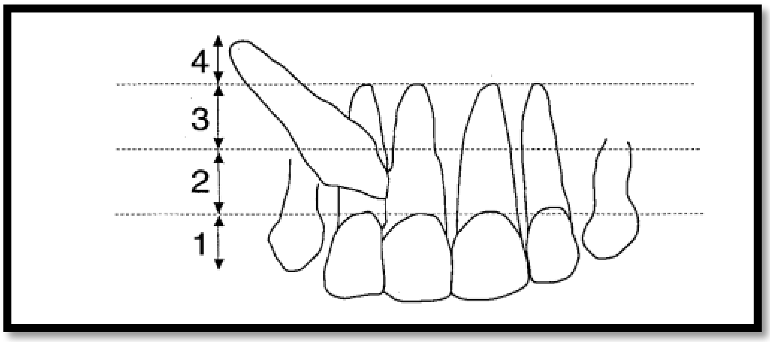


Figure 2.7: Vertical position of the canine

Source: Stivaros & Mandall, 2000

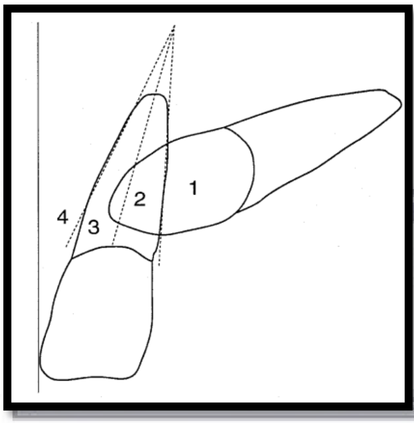


Figure 2.8: Overlap of canine with adjacent incisor

Source: Stivaros & Mandall, 2000

Smailiene (2002) reported that if the alpha angle is more than 20°, the spontaneous eruption of the permanent canine is unlikely to happen. For every 1° increase above 20°, the spontaneous eruption decreases by 4.9%, and if the d-distance is greater than 12 mm, every 1 mm increase in d-distance decreases the spontaneous eruption by 6.8% (Smailiene, 2002).

The sector method was evaluated using orthopantomograms for a more accurate predictive value (Warford *et al.*, 2003). It was concluded that compared with angulation, the sectors had a greater predictive value regarding MCI. However, the authors conceded that these results were only suggestive of possible impaction. They recommended that a larger sample was needed to confirm their results. Warford *et al.* (2003) found that in Sector I, the canine had a greater chance of not being impacted and thus, there was a greater possibility of erupting in the normal position. However, sectors III and IV showed a greater chance that the canine would become impacted. Angulation only provided a potentially significant value in the prediction of MCIs in Sector II (Warford *et al.*, 2003).

To evaluate the practicality of radiographic indicators in assessing displaced and impacted canines, Crescini, Nieri, Buti, Baccetti and Pini Prato (2007) used a modification of the radiographic predictors indicated by Ericson and Kurol (1987) (Figure 2.9). The modification was made in regard to the following sectors. Sector 1 (S1) comprised the area between the midline and the long axis of the central incisor in which the canine cusp was found. Sector 2 (S2) was located between the long axis of the central incisor and the long axis of the lateral incisor. Sector 3 (S3) represented the area between the long axis of the lateral incisor and the long axis of the first premolar.

Crescini *et al.* (2007) found an association between pre-treatment radiographic variables on DPTs and the duration of active orthodontic traction. It was reported that for every 1 mm increase in d-distance of the cusp of the MCI from the occlusal plane, an additional week of traction was required. Similarly, every 5° increase in the alpha angle required an additional week of traction. Furthermore, an MCI in Sector 1 required approximately six additional weeks of active orthodontic traction compared with an MCI in Sector 3 (Crescini *et al.*, 2007).

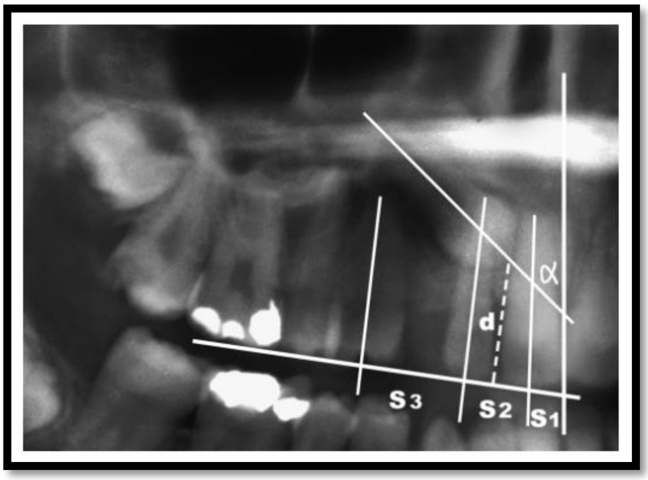


Figure 2.9: Modified radiographic predictors

Source: Crescini *et al*., 2007

Early prediction of MCI from the alpha angle on the DPT showed a highly statistically significant difference between the control group (impacted canine) and its antimere (erupted canine) at the age of nine years. At age nine, the impacted canine showed a mesial inclination with an alpha angle of approximately 30°, while the erupted canine displayed a vertical inclination with a mean alpha angle of approximately 11°. With advancing age, the impacted canine showed a tendency to tilt mesially, thus increasing the alpha angle. In contrast, the antimere canine erupted in the oral cavity (Sajnani & King, 2012).

2.7 DISTORTIONS OF IMAGES ON THE PANORAMIC RADIOGRAPH

The disadvantages associated with the PAN are variable magnification and geometric distortion occurring during image generation. The accuracy of the PAN is dependent on the image layer (or focal trough), the projection angle, patient positioning and horizontal and vertical magnification. The inaccuracies associated with the PAN questions its reliability in determining the mesiodistal angulations of the teeth (Mckee *et al*., 2001, 2002; Yeo, Freer & Brockhurst, 2002).

The PAN displays a great deal of overlap in the premolar area (Scarfe, Nummikoski, McDavid, Welander & Tronje, 1993). The beam projection angle that is needed to allow for open contacts between the teeth changes along the dental arch. Significant inconsistency has been observed in the projection angles of the different PAN units when compared with the interproximal contact angulations. The commonly used DPTs magnify and distort the resulting images. The resulting magnification that occurs in the horizontal and vertical dimensions differ with respect to position along the object and object depth (Tronje, Welander, McDavid & Morris, 1985).

Variables such as patient positioning errors and intrinsic machine factors can lead to inaccuracies that result in a false representation of the patient (Harrell, Hatcher & Bolt, 2002). Incorrect patient head positioning can compound the intrinsic distortion that is generally present in the DPT. It has been observed by McKee *et al*. (2001) that the axial inclination of teeth in the maxilla and the mandible is influenced by a change in the head position. A 5° superior tilt of the head will result in the maxillary teeth roots being tipped mesially, while a 5° inferior tilt of the head will result in the maxillary teeth roots being tipped distally. In addition, the posterior teeth are affected more than the anterior teeth. These errors are common to all types of panoramic machines when assessing the mesiodistal axial inclination of teeth. In contrast, mandibular anterior teeth are more susceptible to changes in horizontal head position

(5° left/right rotation). Therefore, the clinician should apply discretion during radiographic evaluation of mesiodistal tooth angulation (McKee *et al*., 2001).

It has been suggested that horizontal head rotation leads to alterations in the object-to-film and source-to-object distances (McKee *et al*., 2001). This can result in different degrees of horizontal and vertical magnification and, therefore, angle distortion. The largest angular distortion on a DPT was found in the canine-premolar region, and it corresponded to the curve of the dental arches. Rotation of the head in the horizontal plane also alters the beam projection angle. Since the focal trough is narrowest in the anterior dental region, the mandibular anterior teeth are more sensitive to horizontal rotation (McKee *et al*., 2001; Yeo *et al*., 2002).

If an impacted tooth lies in front of the focal trough, the angle between the long axis of the impacted tooth and the horizontal plane will be increased, whereas if the impacted tooth lies behind the focal trough, the angle between the long axis of the impacted tooth and the horizontal plane will be decreased (sämfors & Welander, 1974).

Mckee *et al.* (2002) used four different types of panoramic units and a skull to simulate a patient in order to evaluate the true mesiodistal angulations of teeth. It was concluded that the DPT altered the perception of mesiodistal root angulations on the skull-testing device. The DPT projected the anterior roots more mesially and the posterior roots more distally. This amplified the root divergence between the canine and the first premolar. Similarly, in the mandible, the DPT projected almost all roots more mesially. The canine and the first premolar showed more divergence than in the actual situation. It was noted that root parallelism is projected as root convergence (Mckee *et al*., 2002). The validity of the radiographs from the panoramic units was further evaluated by Peck *et al.* (2007) who used CBCT on patients as the gold standard method for comparison to confirm the study of McKee *et al*. (2002). It was found that most of the discrepancy was in the canine and premolar area.

The advent of CBCT allowed for the reconstruction of panoramic-like images. It has been observed that on the panoramic-like image, the maxillary roots (excluding the first molars) are projected with greater distal angulations while the mandibular roots (excluding the premolars and molars) are projected with greater mesial angulations. In contrast to previous studies on the accuracy of DPTs, the mesiodistal angular projection of teeth on the reconstructed DPT is closer to the true mesiodistal angulation. Therefore, the panoramic-like image can be beneficial in evaluating mesiodistal root angulations (Van Elslande, Heo, Flores-Mir, Carey & Major, 2010).

It has also been established that the digital panoramic image on the computer monitor in the original acquisition mode is more accurate than the printed copy (Guerrant, Moore & Murchison, 2001). In addition, glossy paper with the use of inkjet prints provides the best quality image; using regular paper decreases the quality of the images (Gijbels, Sanderink, Pauwels & Jacobs, 2004).

To overcome the drawbacks associated with 2D imaging, the use of 3D imaging such as CBCT has been suggested. Cone-beam computed tomography enables a more accurate determination of the relationship with the adjacent teeth and structures. However, CBCT is limited to specific indications because this imaging technique is associated with increased costs and high radiation exposure (Abdelkarim & Jerrold, 2018).

2.8 CONE-BEAM COMPUTED TOMOGRAPHY

Cone-beam computed tomography is a contemporary imaging acquisition technique that has revolutionised the medical and dental fields. In April 2001, the Food and Drug Administration (FDA) officially recognised the first CBCT system in the market for oral and maxillofacial imaging (Abramovitch & Rice, 2014). This CBCT system was the NEWTOM® (Quantitative Radiology, Verona, Italy).

Cone-beam computed tomography uses a 2D panel or detector with a single rotation of the gantry around the object to give a complete image of the object. A series of algorithms reconstruct the original data to form a 3D dataset in the x-, y- and z-axis. This provides the axial, coronal and sagittal planes that allow for appraisal of the study volume. The x-ray beam is used more efficiently because there is a decrease in the electronic energy and a reduction of scattered radiation (Halazonetis, 2005).

Radiography should always be commensurate with the principle of ALADA (Jaju & Jaju, 2015) and the guidelines presented by SEDENTEXCT, *Safety and Efficacy of a New and Emerging Dental X-Ray Modality*. These guidelines aim to prevent the stochastic effects associated with increased radiation exposure (SEDENTEXCT project consortium, 2012). Furthermore, the benefits of CBCT should transcend the biologic and financial costs that are incurred by the patient.

Cone-beam computed tomography is only warranted if conventional radiographs do not provide adequate information and if there is a possibility that CBCT will alter the diagnosis and treatment plan (Abdelkarim & Jerrold, 2018). Cone-beam computed tomography delivers an effective radiation dose between 20 μSv and 100 μSv. This is approximately 20% of the total radiation dose of a computed tomography and equal to a full-mouth series of periapical radiographs (Mah, Danforth, Bumann & Hatcher, 2003). Cone-beam computed tomography systems differ in their radiation output. These differences are dependent on the CBCT imaging machine used, FOV, scan time, milliamp and kilovolt output of the CBCT system, voxel size and sensor sensitivity (Silva *et al.*, 2008).

Cone-beam computed tomography images are intrinsically more accurate than conventional radiographs because the beam projection is orthogonal. The radiographic beams are parallel to one another, with the object near to the sensor. Therefore, there is little projection effect and no magnification. Additionally, any projection effect is addressed by the computer software. This results in an undistorted 1:1 measurement that is in contrast to conventional radiographs that always have a degree of projection error because the anatomic regions of interest are at varying distances from the film. Another advantage of the CBCT scan is that additional views are available from the original acquisition data (Mah *et al*., 2004). The disadvantages of CBCT are poor soft tissue contrast and inherent and induced artefacts (Suomalainen, Esmaeili & Robinson, 2015).

Table 2.1 tabulates the average effective doses of the different imaging modalities. Some of the current CBCT machines have a larger FOV with a lower resolution. This limits and reduces the effective dosage to the region.

Table 2.1: Effective dose of different dental imaging techniques

Types of x-ray methods	Effective dose (µSv)
Intraoral radiographs	<1.5
PANs	2.7–24.3
Cephalometric radiographs	<6
Dentoalveolar CBCT (FOV height <10 cm)	11–674
Craniofacial CBCT (FOV >10 cm)	30–1073
MSCT maxilla-mandibular	280–1410

PAN: panoramic radiograph; CBCT: cone-beam computed tomography; FOV: field of view; MCST: multislice computed tomography

Source: Suomalainen *et al*., 2015

2.9 CONE-BEAM COMPUTED TOMOGRAPHY ASSESSMENT OF MAXILLARY CANINE IMPACTION

A number of studies evaluated MCIs using CBCT (Haney, Gansky, Lee, Johnson, Maki & Miller, 2010; Alqerban, Jacobs, Fieuws & Willems, 2011; Botticelli *et al*., 2011; Wriedt *et al.*, 2012). The majority of CBCT studies regarding MCI commented on three aspects of canine impaction, namely localisation, presence of resorption and predictors for treatment. Studies that compared the diagnosis of MCIs based on 2D and 3D images reported a difference between the two techniques (Alqerban *et al*., 2009; Alqerban *et al*., 2011). Using CBCT, the crown of the canine was diagnosed as being in a more occlusal position than in the 2D images. Cone-beam computed tomography allows for the accurate and definite assessment of the mesiodistal and bucco-palatal position of the apex (Botticelli *et al.*, 2010).

Furthermore, it has been reported that the exposure from CBCT is within the same range as conventional 2D imaging. The authors based this reasoning on the fact that a combination of conventional dental radiographs may be warranted for adequate diagnosis, thereby justifying the efficacy of CBCT imaging (Southall & Gravely, 1989; Mah *et al.*, 2003).

Liu *et al. (*2008) used CBCT to assess the position of the impacted canine and the presence of root resorption quantitatively. The results of the study revealed that there are a variety of possibilities that the MCI can present regarding location. Incisor resorption was observed in 27.2% of lateral incisors and 23.4% of central incisors. The majority of cases (94.3%) of resorption were detected when the canine was in close contact with the incisors (Liu *et al*., 2008).

Justification to perform a CBCT examination could also be based on the position of the MCI in the sectors observed on the PAN. Jung *et al*. (2012) compared the labio-palatal position of the maxillary canine on CBCT with the mesiodistal position of the canine on a DPT. The authors found that on CBCT, labially impacted canines were more frequently located in sectors I, II and III. In addition, mid-alveolus impactions were more frequently located in Sector IV and palatally impacted canines were more likely to occur in Sector V. External root resorption of the lateral incisor was more likely to be observed in sectors III, IV and V. It was concluded that the occurrence of an MCI in sectors III, IV and V on a DPT warrants CBCT investigation (Jung *et al*., 2012).

In studies that investigate predictors for treatment, it is important to consider the outcomes where measurements could guide the practitioner in decision-making. Decisions that determine the cut-off point for whether interceptive treatment for eruption of PDCs is necessary or not could thus be made easier.

A study that utilised a modified methodology of Ericson and Kurol(1988), compared canine position between the DPT and CBCT and found that there was 64% concordance between canine positions assessed on the DPT and CBCT (Wriedt *et al*., 2012). However, in more than

25% of canine impactions, the canine apices were imperceptible on the DPT. Furthermore, information garnered from CBCT imaging led to a recant of the decision to extract teeth. It was concluded that a small-volume CBCT may be justified as an extra modality to the DPT in the following cases: the inclination of the canine is greater than 30° to the midline; there is a suspicion of root resorption of adjacent teeth; and the apical third of canine root is not easily recognised on the DPT (Wriedt *et al*., 2012).

A randomised control study used CBCT to determine the cut-off points for predictors in ascertaining the necessity of interceptive extraction for the eruption of PDCs (Naoumova, Kürol & Kjellberg, 2015). The researchers studied four predictors, namely mesio-angular angle (103°), distance from cusp tip to dental arch plane (2.5 mm), distance from cusp tip to midline (11 mm) and patient age (10–11 years). The authors considered the canine cusp tip to midline as the determinant predictor for the success of interceptive treatment for PDCs (Naoumova *et al.,* 2015).

The conventional PAN will always be the initial screening imaging modality. However, certain cases will provide the necessary justification for further CBCT examination. A systematic review concluded that CBCT may be more efficacious in complex cases; however, there is still insufficient evidence that CBCT imaging will improve treatment outcomes (Eslami, Barkhordar, Abramovitch, Kim & Masoud, 2017).

2.10 CONE-BEAM COMPUTED TOMOGRAPHY ASSESSMENT OF THE ALPHA ANGLE ON IMPACTED CANINES

A study comparing conventional DPT with two different CBCT machines evaluated the following parameters: width of canine crown; follicle width; location and angulation of the canine; resorption of primary canines; contact between canine and incisors; and severity of resorption of incisors (Alqerban *et al*., 2011). A significant difference was reported for all parameters between conventional radiographs and CBCT. Of interest was the observation that the results varied between the DPT and the different CBCT machines. The mean alpha angle on the DPT was 24.07°, on the Scanora® scans, it was 14.5° and on the Accuitomo® scans, it was 25.45° (Alqerban *et al*., 2011) (Table 2.2).

Björksved, Magnuson, Bazargani, Lindsten and Bazargani (2019*)* observed higher alpha angle values and PDC sectors in both the DPT and CBCT scans. Most PDCs were reported in sector III on the CBCT, and in sector IV on the DPT. The average alpha angle on the DPT was 34.8° and 27.9 degrees on the CBCT scans, demonstrating a mean difference of 6.9° between the DPT and the CBCT. It was suggested that DPTs overestimate the alpha angle when compared with CBCT scans (Björksved *et al.*, 2019*)* (Table 2.2).

It was hypothesised by Björksved, Magnuson, Bazargani, Lindsten and Bazargani (2019) that the differences observed in the mean angles between the various studies was a reflection of the population differences and the location of the MCI (buccal or palatal). Alqerban *et al*. (2011) did not differentiate between BDCs and PDCs, while Björksved *et al.* (2019) specifically evaluated PDCs.

Table 2.2: Comparisons of the mean alpha angle between CBCT machines and panoramic machines

Study	Machine	Mean Angle (Degrees)	Mean Diff. (Angle)	Field of View (FOV)
Alqerban *et al.*, 2011	Accuitomo®	25.45	1.38	3 * 4 cm
	Scanora®	14.52	-9.55	7.5 * 10 cm
	DPT®	24.07		
Björksved *et al.*, 2019	Accuimoto®	27.5	-7.5	6 * 6 cm
	DPT	35.0		
	ICAT®	29.0	-5.3	16 *3.8 cm
	DPT	34.3		
	Mean CBCT	34.8	-6.9	
	Mean DPT	27.9		

The current study was undertaken to determine if there was a difference between the DPT and CBCT regarding the alpha angle. The analysis of agreement between the DPT and CBCT regarding the alpha angle of the MCI can guide dentists and orthodontic practitioners to be prudent in their application of routine CBCT for early interceptive treatment. This will preclude the exposure of patients to increased radiation from CBCT scans.

CHAPTER 3: AIM AND OBJECTIVES

3.1 AIM

The aim of this study was to evaluate the difference in the alpha angle when utilising the dental pantomograph or cone-beam computed tomography in clinical orthodontics.

3.2 OBJECTIVES

The objectives of this study were as follows:

Objective 1: To measure the alpha angles on panoramic radiographs and CBCT scans

Objective 2: To determine the intra- and inter-examiner reliability

Objective 3: To compare the difference of the alpha angle between the panoramic radiographs and CBCT, which is regarded as the gold standard for radiographic imaging

CHAPTER 4: MATERIALS AND METHODS

4.1 STUDY DESIGN

The study was a cross-sectional, retrospective study based on the use of PANs that were printed and CBCT images that were obtained from the databases of four sources. These sources comprised the facilities of the University of the Western Cape (UWC) at Tygerberg Hospital and Mitchells Plain and the databases of two private orthodontists practising in Cape Town. The data collection spanned the period May 2008 to December 2018. Since the study was a retrospective study, no new CBCT images were specifically taken for the research and no patient was exposed to unnecessary radiation to fulfil the sample size requirements relating to the study.

4.2 SAMPLE SIZE

The study sample comprised both DPT and CBCT images of 100 possible MCIs. Calculation of the required sample size was based on the aim of the research, in this case, the method agreement analysis. This analysis requires at least 60 (preferably 100) samples; thus, the sample size of 100 MCIs was adequate (Bland & Altman, 1986).

4.3 SAMPLING STRATEGY

The archived radiographic material used in this study was evaluated from the period spanning May 2008 to December 2018 until the sample size of 101 was reached. If there were bilateral impactions on a CBCT and the corresponding PAN, the impacted canine was counted twice. The sample size collected from the four sources was 132. However, after applying the inclusion and exclusion criteria as indicated below, the final sample size was reduced to 101 MCIs.

Notable from this group was the presence of one outlier. The alpha angle of the outlier measured 112° on the DPT and was therefore excluded from the statistical analysis. This further reduced the sample size to 100 MCIs.

4.4 INCLUSION CRITERIA

The inclusion criteria were as follows:

- Panoramic radiographs and CBCT scans that were taken no more than four weeks apart
- Patients with a unilateral or a bilateral impacted maxillary canine
- Patients aged nine years and older
- Good quality images demonstrating adequate diagnostic capability

4.5 EXCLUSION CRITERIA

Patients demonstrating the following were excluded:

- Missing central or lateral incisors
- Craniofacial deformities
- Previous or current orthodontic treatment
- History of trauma or odontogenic pathology associated with the anterior maxilla as detected on the DPT or CBCT scan

4.6 DATA COLLECTION

All CBCT and DPT images that met the inclusion and exclusion criteria were collected from the archived records of the four designated sources. The images were initially recorded with the descriptive details of the patient, namely patient name, gender, date that the CBCT and panoramic images were taken, position of the impacted canine (buccal or palatal), and location (right side or left side).

Recording of the descriptive data in this way ensured that the images were recorded only once. Thereafter, both the CBCT images and the DPT images that were obtained were assigned random numerical identifiers to ensure patient confidentiality.

4.7 IMAGE ACQUISITION

4.7.1 Panoramic radiograph image acquisition [reading one (R1)]

The records of four radiological sources were evaluated for the occurrence of MCIs with corresponding PAN and CBCT volumes. Four panoramic machines were, therefore, used to obtain this sample. The technical specifications of importance were as follows: total voltage range = 60–90 kV, tube current = 3–16 mA, voltage = 240 V (50–60 Hz), exposure time = 12−16 seconds, and radiation time range = 9–13 seconds.

The printed versions of all DPTs were used. This was done to maintain consistency of the evaluations since there were some digital copies of the archived radiographic material. The images were printed using a laser printer and 80-micron A4 size paper. Minor enhancement was applied to the image quality prior to printing. All prints were evaluated in a room with a desk lamp and a low ambient temperature. The globe for the desk lamp was a 7-watt LED type in cool white.

4.7.1.1 Construction of the alpha angle on the dental pantomograph (R1)

A line (Line A) was drawn on the midsagittal plane corresponding to the anterior nasal spine (ANS),the middle of the central incisors, and the mandibular symphysis (Figure 4.2). If there were a midline deviation of the two maxillary central incisors, the ANS, the mandibular central incisors and the midline symphysis of the mandible was used to denote the midsagittal plane.

A second line (Line B) was drawn through the long axis of the maxillary canine (Figure 4.2). In the event of any form of dilacerations, the overall inclination of the tooth was used with the reference line bisecting the entirety of the tooth from the cusp tip to the start of the dilacerations in its most linear plane. The angle formed between the two lines was measured using a protractor. If the canine cusp tip was directed towards the midsagittal plane, a positive value was assigned to the alpha angle. If the canine cusp tip was directed away from the midsagittal plane, a negative value was assigned to the alpha angle.

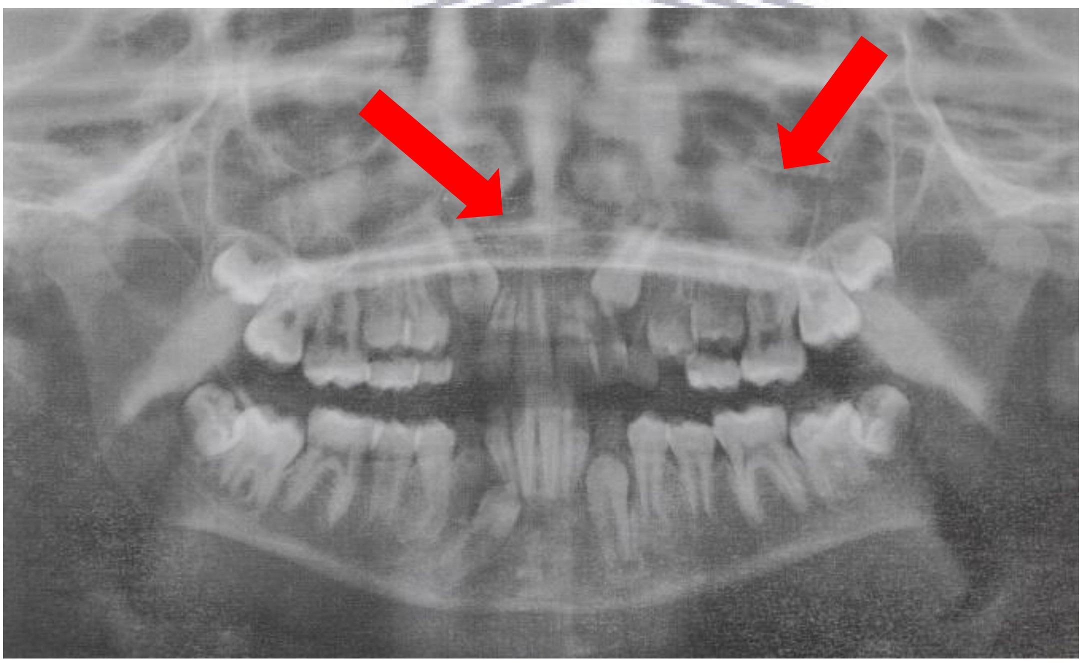


Figure 4.1: Dental pantomograph with arrows denoting maxillary canine impactions

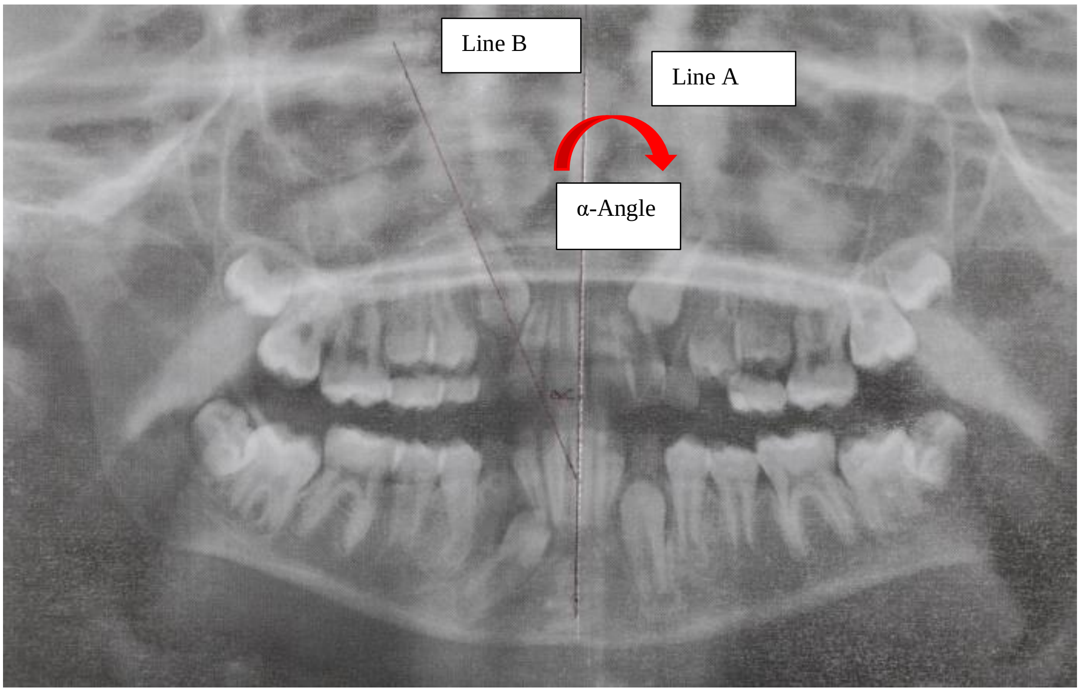


Figure 4.2: Construction of alpha angle on dental pantomograph with arrow denoting a positive alpha angle

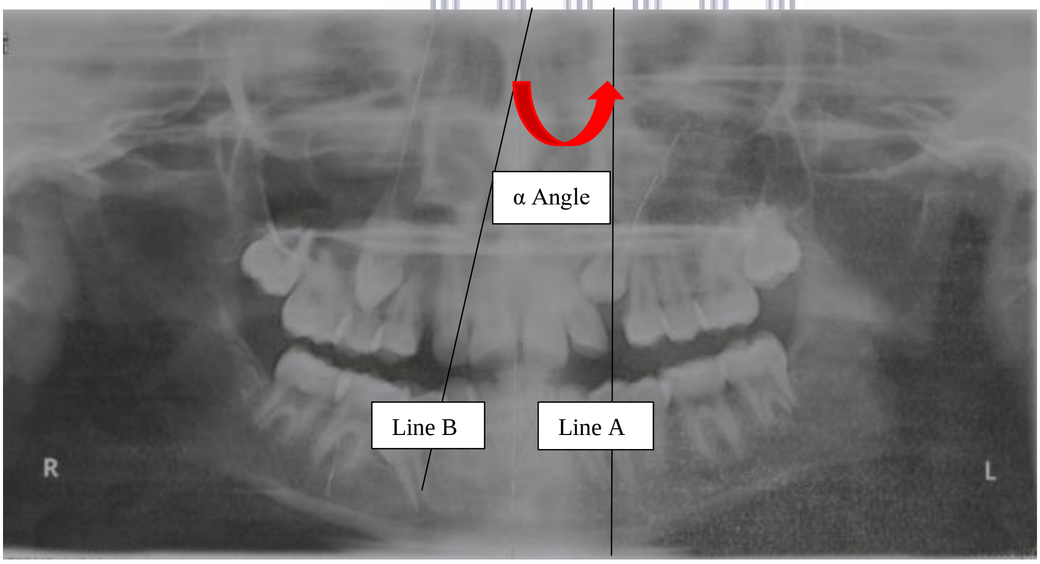


Figure 4.3: Construction of alpha angle on dental pantomograph with arrow denoting negative alpha angle

4.7.2 Construction of the alpha angle on cone-beam computed tomography [reading two (R2)]

Construction of the alpha angle for reading two was made on CBCT slices that corresponded to the DPTs that provided reading one.

The Newtom® (VGI®, Verona, Italy) CBCT machine was used to obtain 15 x 15 cm FOV scans. The scans were performed at 110 kV and 3–7 mAs. The data from each scan was then reconstructed with a voxel size of 0.30 mm^3.

The DICOM files of the initial acquisition were transferred to the PC via the secured portable hard drive. The settings on the OnDemand3D® software was set to open all new studies at 0.3 mm slice thickness (Figure 4.4). The 3D function was selected to provide a multiplanar reformatting (MPR) window that was used to assess the canine in the three planes, namely axial, coronal and sagittal.

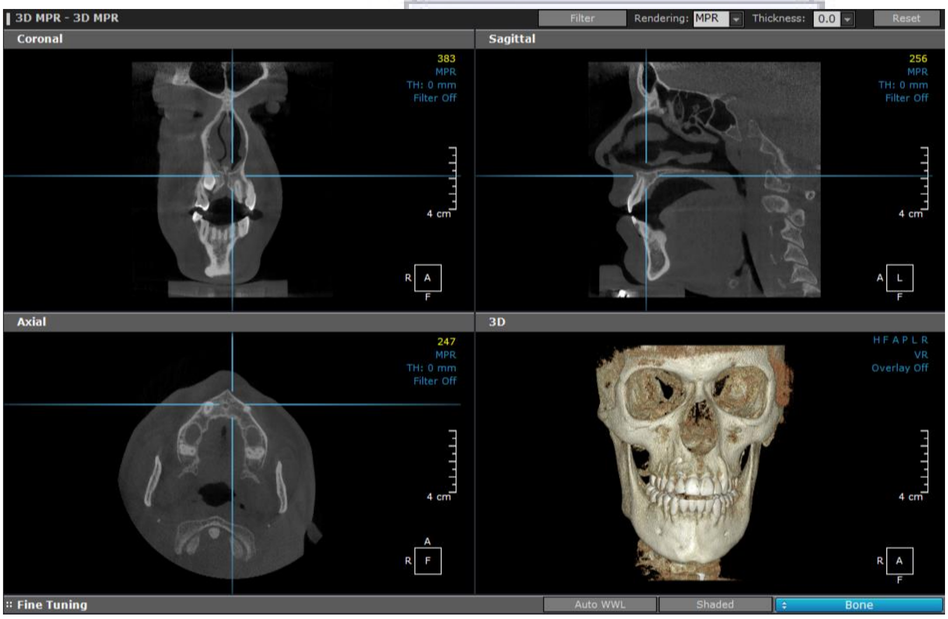
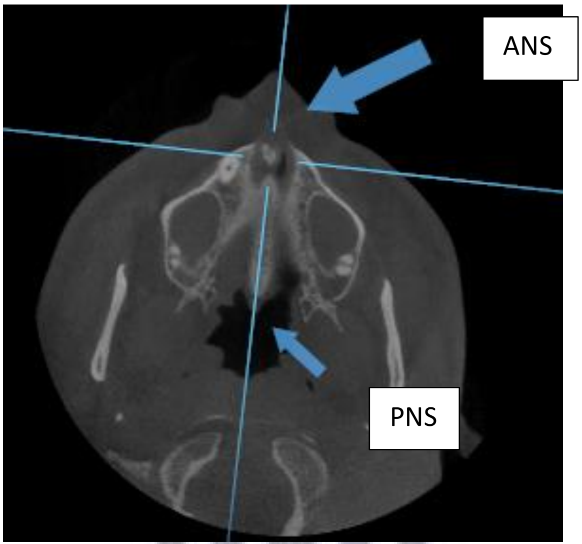


Figure 4.4: Selection of the DICOM image

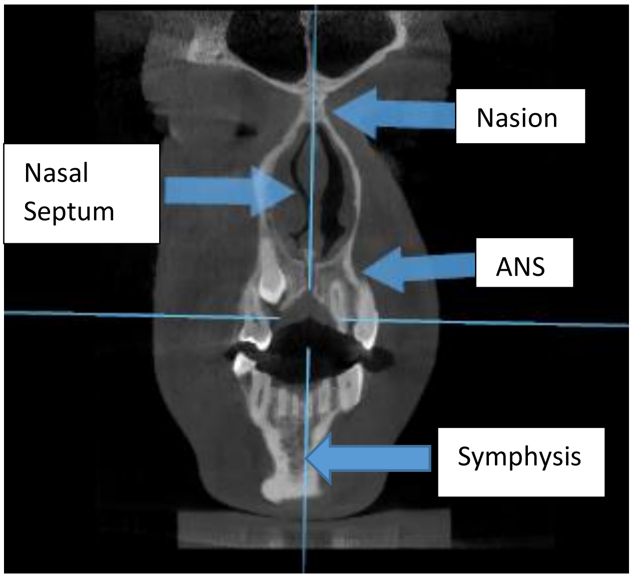
The axial slice was corrected to make the coronal cut through the maxilla by aligning the slice through the ANS and the PNS (Figure 4.5).



ANS: anterior nasal spine; PNS: posterior nasal spine

Figure 4.5: Axial slice indicating positioning of the horizontal and vertical axis of the image cursor guides

On the coronal slice, the image analysis software cursor (blue lines on the images in figures 4.4, 4.5 and 4.6) was positioned through the nasion, the nasal septum, the ANS and the mandibular symphysis (Figure 4.6). This denoted the midsagittal plane.



ANS: anterior nasal spine

Figure 4.6: Positioning of the midline in the coronal slice

The long axis of the canine was thereafter located on the coronal slice, and a line was drawn through it (Figure 4.7).

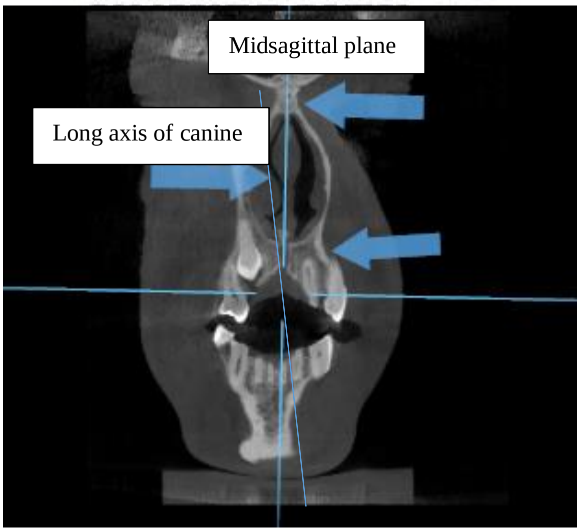


Figure 4.7: Positioning of the midline in the coronal slice

Three points were selected to measure the alpha angle (Figure 4.8). Point 1 denoted the mandibular symphysis, Point 2 was drawn through the nasion, the nasal septum, the ANS, the maxillary suture and where possible, the maxillary centrals. Point 3 denoted the long axis of the canine. The alpha angle is the angle formed between points 1, 2 and 3 (Figure 4.9).

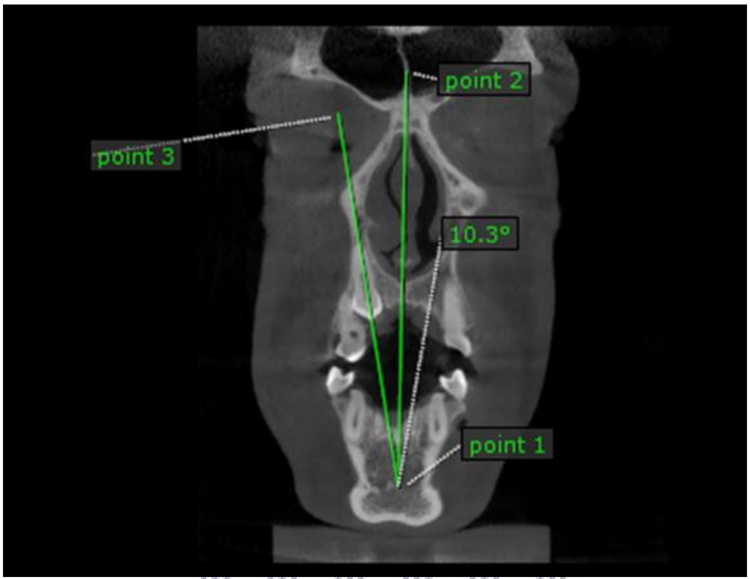


Figure 4.8: Coronal slice indicating construction of points 1, 2 and 3 to measure alpha angle

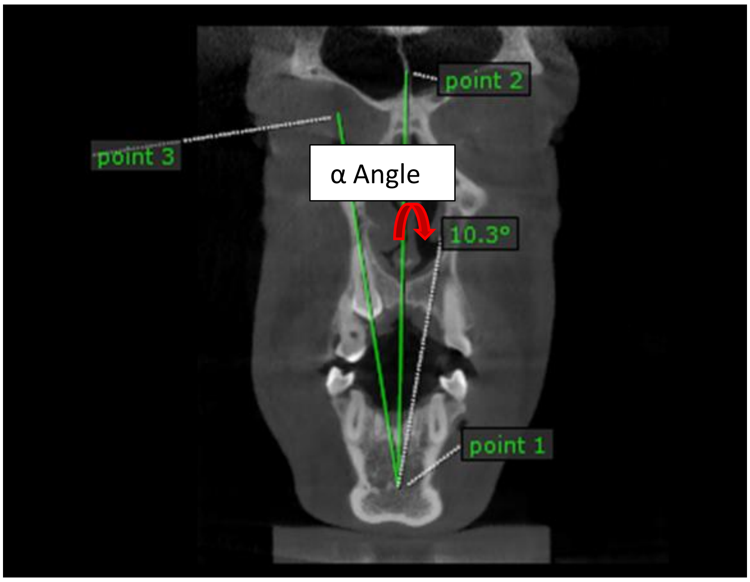


Figure 4.9: Coronal slice indicating alpha angle

In some instances, the position of the impacted canine did not allow for optimum visualisation of the tooth in a 0.3 mm slice. In these cases, the slice thickness was increased to 20 mm to allow for enhanced visualisation of the long axis of the MCI. The measured alpha angle was thereafter recorded on the Xcel® data-capturing sheet.

Readings one and two comprised a total of 100 values each. Intra-examiner reliability was obtained by evaluation of every tenth sample to obtain a set of reading one and reading two at a time interval of one month denoted as T1.

This sample group (T1) was re-evaluated after two weeks to provide another set of values at time interval two (denoted as T2). To obtain inter-examiner reliability, the same selected sample (T2) was evaluated by a senior member of the maxillofacial radiology department(SS). The sample was identified as inter-examiner SSR1 and SSR2.

These three sets of measurements for reading one and reading two were captured on a separate data-capturing sheet. Data was captured on an Excel® spreadsheet (appendices C–E).

4.8 STATISTICAL ANALYSIS

Descriptive analysis of the data was carried out as follows. Categorical variables were summarised by frequency and percentage tabulation. Continuous variables were summarised by the mean, standard deviation (SD), median and interquartile range, and their distribution was illustrated by histograms.

Intra- and inter-examiner agreement were determined using the intraclass correlation coefficient (ICC) (Table 4.1).

Table 4.1

Table 3: Interpretation of intraclass correlation coefficient

Below 0.50	Poor
Between 0.50 and 0.75	Moderate
Between 0.75 and 0.90	Very Good
Above 0.90	Excellent

Source: Koo & Li, 2016

Method comparison was carried out using Bland-Altman (B&A) methodology (Bland & Altman, 1986). The effect of gender on the bias between the methods was determined by regressing the bias on gender. The effect of canine side (left or right) was determined in the same manner.

Data analysis was carried out using SAS (version 9.4 for Windows®). The 5% significance level was used.

4.9 ETHICAL CONSIDERATIONS

Archived records from four radiological sources were used in the current study. These included the UWC facilities at Tygerberg Hospital and Mitchells Plain and the private practices of two orthodontists in the Western Cape.

Ethical clearance to conduct this study was obtained from the UWC Biomedical Research Ethics Committee (BMREC, Ethics reference number - BM18/1/11) (Appendix A). Permission to access the patient records from UWC was also obtained from the Dean of Dentistry

(Appendix B1) and from the two private orthodontic practitioners (Appendix B2 and Appendix B3).

The retrospective nature of the study design ensured that no new radiographs were necessary and only existing radiographic records were analysed.

Patient information was assigned a numerical identifier. No personal information was divulged, transferred or displayed. The researcher was the only person with access to the patients' personal details. These details were secured on a password-locked computer. This ensured that patient confidentiality was always respected.

CHAPTER 5: RESULTS

5.1 DESCRIPTIVE DATA

Descriptive data for the sample is presented in Table 5.1. The majority of the cases were female (65%); 35% of the cases were male. With regard to the location of the MCI, there was an even distribution of MCIs between the left and right sides.

Table 5.1

Table 4: Demographics of the sample group by gender and side

Variable	Category	n	%
Gender	F	65	65
	M	35	35
Side	L	49	49
	R	51	51

Furthermore, 2% of the MCIs on the DPT had crowns that were oriented away from the midline. This is in contrast to the CBCT scans where it was observed that 23% of the impacted crowns were oriented away from the midline and 77% of the impacted canine crowns were directed towards the midline (Table 5.2). The canine that was oriented towards the midline had a positive value as opposed to the canine oriented away from the midline that had a negative value.

Table 5.2

Table 5.2: Distribution according to canine crown orientation

	Category	n	%
PAN_R1	<0	2	2.0
	>=0	98	98.0
CBCT_R2	<0	23	23
	>=0	77	77

<0 denotes MCIs with crown tip directed away from the midline

>=0 denotes MCIs directed towards the midline

PAN_R1: panoramic radiograph reading 1

CBCT_R2: cone-beam computed tomography reading 2

The mean alpha angle as measured on the PAN was 29.1º (SD 20.9º), while the mean alpha angle as measured on the CBCT was 15.9º (SD 24.4º). The distribution of the measurements is shown in Table 5.3 below.

Table 5.3:

Table 6: Descriptive statistics for continuous data

	Variable	**n**	**Mean**	**SD**	**Median**	**IQ Range**		**Min**	**Max**
All Data	PAN_ R1	100	29.1	20.9	24.0	13.5	44.5	-7	90
	CBCT_ R2	100	15.9	24.4	11.5	0.0	35.8	-43.3	79.5

A comparison of the means between the two imaging techniques revealed notable differences. The mean and SD of the intra- and inter-examiner data are depicted in Table 5.4.

Table 5.4:

Table 7: Mean and standard deviation of intra- and inter-examiner data

	Variable	n	Mean	SD	Median	IQ range		Min	Max
Intra- and inter-examiner data	PAN_R1	11	33.2	16.0	36.0	17.0	51.0	9.0	54.0
	PAN_T1	11	34.3	17.0	38.0	19.0	53.0	8.0	55.0
	PAN_T2	11	33.5	16.5	34.0	19.0	52.0	7.0	54.0
	PAN_SSR1	11	31.6	17.2	36.0	16.0	47.0	7.0	54.0
	CBCT_R2	11	20.9	28.0	26.7	6.7	45.1	-43.3	52.3
	CBCT_T1	11	22.0	29.7	28.0	7.3	46.3	-46.0	54.0
	CBCT_T2	11	22.2	29.5	27.8	7.8	47.0	-44.8	55.0
	CBCT_SSR2	11	20.6	17.5	18.4	13.0	39.1	-12.0	47.8

R1 denotes panoramic reading 1

R2 denotes CBCT reading 2

T1 denotes a time interval of one month

T2 denotes a time interval of two weeks

SS refers to senior member of the maxillofacial radiology department

5.2 INTRA- AND INTER-EXAMINER ASSESSMENT

Intra- and inter-examiner reliability was calculated using the ICC. The ICC for both the PAN and CBCT was >0.8, indicating very good intra- and inter-examiner reliability. This allowed the B&A method comparison to proceed.

5.3 BLAND-ALTMAN METHOD COMPARISON

To determine the agreement between the MCI angular measurements in the PANs and the CBCT scans, the B&A method was used. This statistical method quantifies agreement between two quantitative measurements by constructing the LoA that are represented in a scatterplot (Figure 5.1).

In the scatterplot XY, the Y-axis shows the difference between the two paired measurements, and the X-axis represents the average of these measures.

In this study, the bias, that is, the average of the differences between the CBCT method and the PAN method was **-13.2º** (difference = CBCT measurement – PAN measurement) and was statistically different from zero ($p<0.0001$). **This means that on average, the CBCT method measured 13.2º less than the PAN method.** The differences were compared with the mean of the two paired values. The B&A plot (Figure 5.1) is simply a plot of the differences between the PAN and CBCT methods that were plotted against the mean of the two measurements. The green line shows the bias of **-13.2º.**

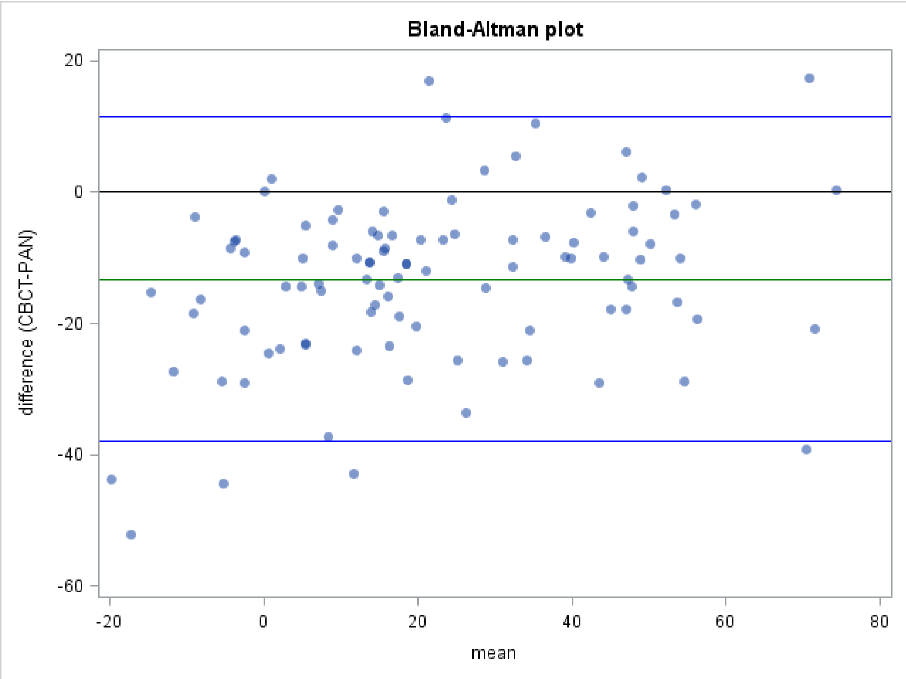


Figure 5.1: Scatterplot indicating differences between the panoramic radiograph and cone-beam computed tomography methods

The bias increases with an increasing mean alpha angle, as determined by a regression of the differences on the means (p=0.0036). A 1-unit increase in the mean alpha angle corresponds to an estimate of 0.17-unit increase in the between-method difference (the difference becomes more positive). The normality of the distribution of the differences in the pairs of measurements is verified by the histogram (Figure 5.2)

We can summarize the lack of agreement of the alpha angle between the DPT and CBCT by calculating the bias. The bias is estimated by the mean difference ($\bar{d}$) and the standard deviation of the differences (SD). We would expect most of the differences are expected to lie between $\bar{d}$-2 SD and $\bar{d}$+2 SD, or more precisely, 95% of the differences will be between $\bar{d}$-1.96 SD and $\bar{d}$+1.96 SD, if the differences are normally distributed; these are the Limits of Agreement (LoA).

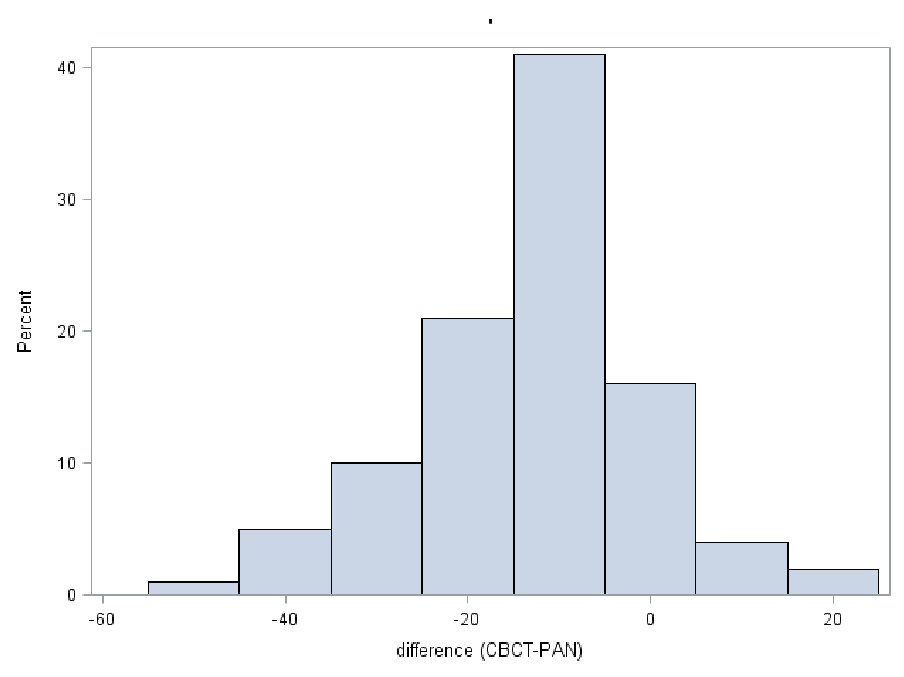


Figure 5.2: Normality of the distribution of the differences in the pairs of measurements

The green line (Figure 5.1) shows the bias of -13.2º, and the blue lines show the LoA of -37.9 and 11.5 at 95% confidence. Therefore, the LoA are [-37.9; +11.5] degrees. Hence, results measured by the PAN method may be 11.5º below or 37.9º above the CBCT method.

However, the bias increases with an increase in the mean alpha angle, as determined by a regression of the differences on the means (p=0.0036). A 1-unit increase in the mean alpha angle corresponds to an estimated 0.17-unit increase in the between-method difference (the difference becomes more positive). As illustrated in Figure 5.3, if the bias is not dependent on the mean alpha angle, then the bias is shown as a horizontal line that is parallel to the X-axis (the green line with LoA as blue lines). However, if the bias increases with an increase of the mean angle (i.e. the bias becomes more positive), the bias line will slope upwards from left to right. This is illustrated by the three red lines (the middle line is bias and the two outer lines are LoA).

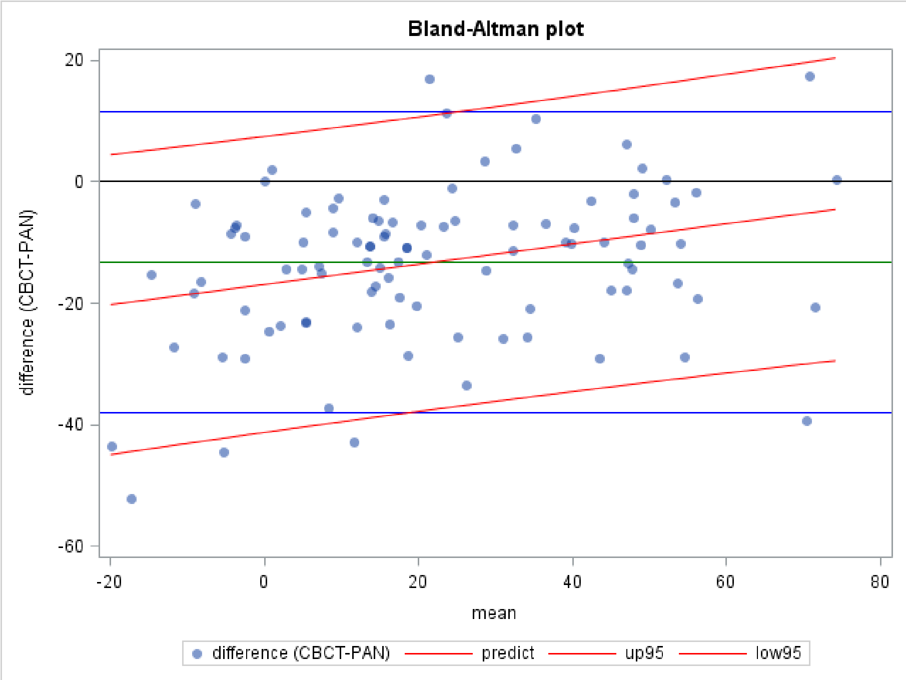


Figure 5.3: Bland-Altman plot indicating the LoA for change in the bias with an increasing mean alpha angle

The B&A analysis only quantifies the bias and a range of agreement, within which 95% of the differences between one measurement and the other are included. It does say if the agreement is sufficient. We know that the bias is significant, but only analytical, biological or clinical goals could define whether the agreement interval is too wide or sufficiently narrow for the purpose of the methods. The best way to use the Bland and Altman plot system would be to define *a priori* the limits of maximum acceptable differences (limits of agreement expected), based on biologically and analytically relevant criteria, and then to obtain the statistics to see if these limits are exceeded, or not.

The effect of gender (p=0.84) and the effect of side on the bias were not significant (p=0.46).

CHAPTER 6: DISCUSSION

There is a paucity of studies in the literature that compare the alpha angle in PANs with the alpha angle in CBCT images. The reported studies have compared the sectors in CBCT scans with the sectors in the PANs to predict the presence of root resorption on lateral incisors, the location of impacted canines (buccal or palatal) and the prognosis for the impacted canine and periodontal health (Alqerban *et al.*, 2014; Ngo, Fishman, Rossouw, Wang & Said, 2018).

The aim of this study was to evaluate the difference in the alpha angle when utilising the DPT and CBCT in clinical orthodontics. The 3D CBCT is regarded as the gold standard when compared with 2D radiographs because it is intrinsically more accurate than conventional radiography. Cone-beam computed tomography overcomes the limitations of the 2D DPT, namely magnification, superimposition of structures, blurred images, distortion and artefacts (Elefteriadis & Athanasiou, 1996).

In the current study, the sample size was reduced to 100 MCIs to exclude the outlier, which limited the extreme variations in the alpha angle in the original sample.

The intra- and inter-examiner reliability was >0.8 for both the PAN and CBCT. This showed very good agreement between the two examiners and consistency of the repeated measurements.

The high SD of this study meant that the sample covered a broad range of alpha angles, which was useful when conducting the method comparison analysis. It is noteworthy that whilst some of the MCIs had a negative value on the DPT, the same MCI had when viewed on the CBCT showed a positive value.

This study did not evaluate the predictive capability of the alpha angle regarding complications of MCIs, namely root resorption, ankyloses, short arch length, etc. Only the difference in the mean alpha angle for MCI between CBCT and the DPT was investigated. Furthermore the calibration to predict CBCT from PAN was not the objective of the present study. The LoAs are so wide that it is not possible to statistically determine a corrector factor between PAN and CBCT.

The results of this study showed that the alpha angle had higher mean angular values in the PANs than in the CBCT images. The mean alpha angle measured on the DPT was 29.1° while the mean alpha angle measured by CBCT was 15.9°. This difference between the mean alpha angles is in agreement with the measured values of Alqerban *et al*. (2011) who reported a mean angle of 24° on the DPT and a mean angle of 14.5° on the Scanora® CBCT scans. However, no difference was reported between the DPT and the Accuitomo® CBCT scans that had a mean angle of 25° (Alqerban *et al*., 2011). Björksved *et al.* (2019) reported an average alpha angle of 35° in the DPT and 28° in the CBCT scans. The authors hypothesised that the differences observed in the mean angles between the various studies were a reflection of the population differences and the location of the MCI (buccal or palatal) (Björksved *et al.*, 2019).

The mean alpha angle in the current study resembled that of Alqerban *et al.* (2011). This could be the result of similar samples in the two studies. Both this study and the study of Alqerban *et al*. (2011) evaluated the alpha angle in displaced canines both buccally and palatally. The studies did not differentiate between buccal and palatal displaced canine.

Alqerban *et al*. (2011) also intimated that the higher mean alpha angle observed in the Accuitomo® scans may be the consequence of the smaller FOV (3 * 4 cm) in the Accuitomo® system. This is in contrast to the smaller mean alpha angle that was observed on the Scanora® that had a larger FOV (7.5 * 10). Björksved *et al.* (2019) reported high mean alpha angles with both smaller (6 * 6 cm) and larger (16 * 3.8 cm) FOVs. The FOV in the present study was 15

* 15 cm. There may be an associated between the FOV and the mean alpha angle value measured on the CBCT. However, that was not the objective of the present study.

A gender disparity was observed in this study; 64.4% of the MCIs were from female patients while the remaining 35.6% MCIs were from male patients. This was analogous to previous studies (Fastlicht, 1954; Johnston, 1969; Ericson & Kurol, 1987; Ngo *et al.*, 2018). In accordance with Stahl and Grabowski (2003), the incidence of MCIs observed on the left and the right side was almost the same.

However, gender bias did not influence the outcome of this study (p=0.84). It was observed that the mean difference (bias) between the alpha angles on the CBCT images was 13.2° less than the alpha angles on the PAN. Furthermore, the mean alpha angle difference changed as the mean alpha angle increased. In this study an outlier was observed. The alpha angle of the outlier was measured as 112° while on CBCT, the angle was 0°. The alpha angle was located parallel to the midsagittal plane on the CBCT image. The outlier was an extreme alpha angle that was measured on the DPT and presented as a palatally impacted canine that was inverted with the apex angulated disto-occlusally.

In retrospect, these extremes in angulation of impacted canines should have been excluded, and there should have been differentiation between buccal and palatal impactions and between canine crown inclinations (mesial or distal). The 22.8% of negative angles measured on CBCT compared with the 2.0% that was measured on the DPT is an important justification for the use of CBCT evaluation. This also highlights the possible inaccuracies in using the DPT.

The mean alpha angle difference of 13.2° observed in the current study was higher than the values observed by both Alqerban *et al*. (2011) and Björksved *et al*. (2019). The former authors reported a mean alpha angle difference of -9.5°. The latter authors observed a preponderance of PDCs in a more mesial sector position, with a mean alpha angle difference of -6.9° (Björksved *et al.*, 2019).

The mesiodistal location and the alpha angle are considered as two possible predictors of successful treatment. If the alpha angle on the DPT increases more than 25°, the possibility for root resorption increases up to 50% (Ericson & Kurol, 1988). However, if the angle is more than 31°, the chance of canine eruption decreases noticeably, even if the deciduous canine has been extracted (Power & Short, 1993).

In concordance with the former studies of Alqerban *et al*. (2011) and Björksved *et al*. (2019), the PAN in the current study over-estimated the alpha angle. Therefore, the CBCT should not be taken routinely for early interceptive orthodontic treatment to determine possible MCI.

This study included CBCT scans and panoramic images from four different sources. To standardise the panoramic images from the four sources, printed copies instead of digital copies were used, with the images being printed on regular paper. Gijbels *et al*. (2004) observed that direct thermal prints provided a better image quality than inkjet prints. Glossy paper provided the highest image quality in inkjet prints, while regular paper demonstrated the lowest.

It has also been established that the digital PAN is more accurate than the printed copy (Guerrant *et al*., 2001). The regular paper that was used in the current study could have affected the results, either increasing or decreasing the alpha angle.

Van Elslande *et al*. (2010) determined that compared with conventional PANs, the mesiodistal angular projection of teeth on the reconstructed PAN (PAN reconstructed from a CBCT volume) is closer to the true mesiodistal angulation. Therefore, this study should have used a reconstructed PAN instead of a conventional PAN printed on regular paper. This may have provided a lower bias.

Because the study was dependent on the radiographic archives from four sources, the images were taken by different operators. Patient position during DPT image acquisition could have influenced the results of this study since all images were not acquired by the same operator and thus, the maintenance of a standardised patient position was questionable.

The implication of head position and change in angulation was expressed in a study by McKee *et al.* (2002). The authors stated that if the PAN and CBCT are not taken with exactly the same head position, angular measurements will be subject to inconsistency. Alteration of the head position of a patient could change the angle of the long axis of teeth, especially in the canine-premolar region in the maxilla (McKee *et al.*, 2002).

Furthermore, alterations in the head position of a patient during a panoramic procedure can affect the inclination of the teeth. Hence, the variation in alpha angle between panoramic readings could be exaggerated as a result of alterations or a superiorly or inferiorly tipped head position (McKee *et al*., 2001).

The PAN has a focal trough of between 20 mm and 50 mm, depending on the machine used, and this allows for a broad range of image clarity or definition of objects in focus (White & Pharoah, 2014). The contrary applies to a CBCT slice that was initially evaluated at 0.3 mm in this study. In instances where the canine was not clearly visible in the 0.3 mm slice, the thickness was changed to 20 mm to allow the long axis to be identified and measurements to be taken. This was done in cases where the canine was dilacerated, or the angulation was so severe that the crown was visible in some slices and the root was not visible.

Despite the limitations of a dental pantomograph, it is still a valid diagnostic tool that can be considered beneficial for determining possible maxillary canine impaction, when a cone-beam computed tomography is not indicated for treatment planning. This is in keeping with the "As Low As Diagnostically Achievable" (ALADA) principle. The corollary that can be drawn from this study is that, in essence the unerupted canine is more upright than it actually appears on the DPT. Therefore, any increase in the alpha angle will more likely result in impaction of the canine, which concurs with the findings of Ericsson and Kurol (1988). Further, based on this study, if a CBCT is used then an alpha angle of 16.8° will predicate interceptive intervention. The 16.8° was determined by subtracting the mean difference of the alpha angle (13.2°) found in this study from the 30° alpha angle that was reported by Ericson and Kurol (1988) in their study. These findings need to be validated in future studies using a larger sample size as well as adopting a standardized protocol in obtaining radiographic images.

CHAPTER 7: CONCLUSIONS

1. The results of this study found that the alpha angle was over-estimated on the DPT. There was a mean difference of 13.2º in the measurement of the alpha angle between the panoramic radiograph when compared to the CBCT.

2. It is proposed from the findings of this study that if a CBCT is used, then an alpha angle of 16.8º will predicate interceptive intervention, namely the removal of the deciduous canine.

3. Despite the limitations of the DPT, it is a valid diagnostic tool that can be considered beneficial for determining MCI position in early interceptive treatment.

CHAPTER 8: LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study primarily looked at the use of the alpha angle as a means to predict MCIs. During the gathering of the sample for this dissertation, the alpha angle of the MCI was not specifically sorted by site location. A future study should therefore endeavour to separate buccal from palatal impactions, which should increase the accuracy and reliability of the alpha angle as a means to predict MCIs.

The other limitation of this study is that the sector method described by Kurol and Ericson (1988) was not considered for this study. Finding a correlation between the alpha angle and the corresponding sectors should also further increase the reliability in using the PAN as a means to predict MCIs.

A future retrospective longitudinal study should make use of three different groups, which should include varying ranges of the alpha angle on the DPT; namely 30-34 degrees, 35-39 degrees and 40-44 degrees. The age range of the patient sample should be 9-13 years. The aim of this investigation would be to observe at which alpha angle value the maxillary canine erupts spontaneously.

Long-term follow up of the patients was not included in the study, and therefore the treatment outcomes could not be evaluated.

To determine the predictive capability of the mean alpha angle difference between the DPT and CBCT, a prospective study design that follows young patients from early dental developmental age is mandatory. However, ethical constraints linked to undesired radiation will be an impediment.

Because of the disparate readings of the alpha angle between the DPT and the CBCT the need does exist for a fuller and more extensive investigation into these findings, which could then pre-empt a recalibration of earlier values for the alpha angle.

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APPENDICES

Appendix A: Ethics Clearance

UNIVERSITY of the WESTERN CAPE

OFFICE OF THE DIRECTOR: RESEARCH
RESEARCH AND INNOVATION DIVISION

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12 April 2018

Dr K Alenazi
Faculty of Dentistry

Ethics Reference Number: BM18/1/11

Project Title: Comparison between the alpha angle of maxillary impacted canines on panoramic radiographs and cone bean computer tomography.

Approval Period: 09 April 2018 – 09 April 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

PROVISIONAL REC NUMBER -130416-050

Appendix B1: Letter to the Dean requesting permission to view CBCT images

Dear Dean of Dentistry -UWC

Prof Y Osman

RE: Request for permission to use the records of the radiology department.

Good day to you prof. I hope this finds you in good health.

I am writing to humbly request the permission of the Deans office to use the records of previous exposed CBCT volumes and panoramic radiographs in the department of radiology. The purpose of this request if to fulfil a masters study in orthodontics. All ethical considerations will be adhered to as set out in my protocol presentation (8/12/2017).

Hope this meets your consideration.

Kind regards

Dr K Alenazi

student number: 3504908

Supported from the Deans office.
Please clear it with the Department.
(Prof Parker & Dr Shaikh)

16/01/2018.

Appendix B2: Letter to Professor A Shaikh requesting permission to view the CBCT images from her private orthodontic practice

RESPICE PROSPICE

UNIVERSITY *of the*
WESTERN CAPE

Letter to request permission to view the Patient Panoramic and CBCT images from private orthodontic practices

To whom it may concern

Re: Request for permission to use the Panoramic and CBCT records from your practice

I am writing to request the permission to use the panoramic radiographs and CBCT volumes from your archived patient records. The purpose is to complete my research that is in partial fulfillment of my MChD (Orthodontic) degree.

All ethical considerations will be adhered to as set out in my protocol presentation at the University of Western Cape on the 8th of December 2017.

Hope this meets your consideration.

Kind regards.

....
Dr Khaled Alenazi

Registrar
Department of Orthodontics
University of Western Cape

....
Specialist Orthodontist
University of Western Cape

....
(Signature)

Appendix B3: Letter to Dr A de Villiers requesting permission to view the CBCT images from his private orthodontic practice

RESPICE PROSPICE

UNIVERSITY *of the*
WESTERN CAPE

Letter to request permission to view the Patient Panoramic and CBCT images from private orthodontic practices

Dear Dr De Villiers

<u>Re: Request for permission to use the Panoramic and CBCT records from your practice</u>

I am writing to request the permission to use the records of previously imaged panoramic radiographs and CBCT volumes from your practice. 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 at the University of Western Cape on the 08th of December 2017.

Hope this meets your consideration.

Kind regards.

Dr Khaled Alenazi

Registrar

Department of Orthodontics

University of Western Cape

Appendix C: Raw data for readings one and two

				PANORAMIC	CBCT
ID	Number	**Gender**	**Side**	**Reading 1**	**Reading 2**
1	001-	F	R	27	19,7
2	002-	M	R	55	51,6
3	003-	F	L	24	10,9
4	004-	M	R	12	-2,4
5	005-	M	L	10	-4,3
6	006-	F	R	55	40,6
7	007-	F	R	62	45,3
8	008-	M	L	58	29
9	009-	F	L	25	23,9
10	0010-	F	L	51	45,1
11	0011-	M	L	112	0
12	0012-	M	R	17	-6,2
13	0013-	F	L	40	33,1
14	0014-	F	R	17	7
15	0015-	F	L	13	-11,6
16	0016-	M	L	8	-13,1
17	0017-	F	R	82	61,2
18	0018-	F	R	22	7,9
19	0019-	F	L	17	11
20	0020-	F	R	20	6,7
21	0021-	F	L	33	4,4
22	0022-	F	R	19	8,3
23	0023-	F	L	14	0
24	0024-	F	L	36	21,5
25	0025-	F	L	24	16,8
26	0026-	F	R	44	34,1
27	0027-	F	L	10	0
28	0028-	M	L	2	-7,1
29	0029-	M	R	11	6,7
30	0030-	F	R	44	50,1
31	0031-	M	R	27	30,4
32	0032-	F	R	0	-18,4
33	0033-	F	R	11	8,4
34	0034-	F	R	8	3
35	0035-	F	L	0	-7,2
36	0036-	F	R	-7	-10,7
37	0037-	M	L	2	-41,7
38	0038-	M	R	0	2,1
39	0039-	F	L	90	50,7
40	0040-	F	L	52	52,3

41	0041-	F	R	-7	-22,2
42	0042-	M	L	15	0
43	0043-	M	R	2	-25,3
44	0044-	F	R	30	9,6
45	0045-	M	L	0	-16,4
46	0046-	M	L	48	50,2
47	0047-	M	L	45	34,9
48	0048-	F	R	56	38,2
49	0049-	F	L	0	0
50	0050-	F	R	38	26,7
51	0051-	F	L	27	-10,3
52	0052-	F	R	20	11,4
53	0053-	F	L	69	40,2
54	0054-	F	R	24	13,1
55	0055-	F	L	74	74,4
56	0056-	M	L	20	13,3
57	0057-	F	R	20	11,1
58	0058-	F	R	54	40,6
59	0059-	F	L	59	48,9
60	0060-	F	R	36	28,8
61	0061-	F	L	49	47
62	0062-	F	L	38	12,3
63	0063-	F	L	54	46,2
64	0064-	M	R	66	46,6
65	0065-	M	L	23	5,8
66	0066-	F	R	30	35,4
67	0067-	F	L	33	-9,8
68	0068-	M	R	23	4,8
69	0069-	F	R	28	21,6
70	0070-	F	L	54	36,1
71	0071-	M	L	24	13,1
72	0072-	M	R	24	0
73	0073-	M	L	62	79,5
74	0074-	F	L	13	4,8
75	0075-	F	R	27	8
76	0076-	M	R	54	43,7
77	0077-	M	L	19	8,4
78	0078-	F	R	43	9,4
79	0079-	M	R	44	36,4
80	0080-	M	L	9	-43,3
81	0081-	M	R	12	-17,1
82	0082-	F	R	47	21,4
83	0083-	F	R	0	-8,6
84	0084-	F	L	0	-7,5
85	0085-	M	R	24	8,2

86	0086-	F	L	28	4,6
87	0087-	F	R	18	11,5
88	0088-	M	L	57	55,2
89	0089-	F	R	27	15
90	0090-	F	L	17	14,1
91	0091-	F	L	49	39,1
92	0092-	F	R	17	-27,5
93	0093-	M	R	44	40,9
94	0094-	M	L	44	18,2
95	0095-	M	R	45	24
96	0096-	M	R	18	29,4
97	0097-	M	L	13	30
98	0098-	F	R	30	40,4
99	0099-	F	L	14	-9,8
100	00100-	F	L	17	-6,1
101	00101-	F	R	9	-19,9

Appendix D: Raw data for establishing intra-rater reliability

		PANORAMIC (t1)	CBCT (t1)	PANORAMIC(t2)	CBCT (t2)
ID	Number	**INTRA Rater group 1 (R1)**	**INTRA Rater group 1 (R2)**	**INTRA Rater group 2 (R1)**	**INTRA Rater group 2 (R2)**
1	001-	26	21,2	27	20,1
2	002-				
3	003-				
4	004-				
5	005-				
6	006-				
7	007-				
8	008-				
9	009-				
10	0010-	53	46,3	52	47
11	0011-				
12	0012-				
13	0013-				
14	0014-				
15	0015-				
16	0016-				
17	0017-				
18	0018-				
19	0019-				
20	0020-	22	7,3	21	7,8
21	0021-				
22	0022-				
23	0023-				
24	0024-				
25	0025-				
26	0026-				
27	0027-				
28	0028-				
29	0029-				
30	0030-	47	53	45	52,7
31	0031-				
32	0032-				
33	0033-				
34	0034-				
35	0035-				
36	0036-				

37	0037-				
38	0038-				
39	0039-				
40	0040-	54	54	53	55
41	0041-				
42	0042-				
43	0043-				
44	0044-				
45	0045-				
46	0046-				
47	0047-				
48	0048-				
49	0049-				
50	0050-	40	28	40	27,8
51	0051-				
52	0052-				
53	0053-				
54	0054-				
55	0055-				
56	0056-				
57	0057-				
58	0058-				
59	0059-				
60	0060-	38	31	34	32
61	0061-				
62	0062-				
63	0063-				
64	0064-				
65	0065-				
66	0066-				
67	0067-				
68	0068-				
69	0069-				
70	0070-	55	39	54	38
71	0071-				
72	0072-				
73	0073-				
74	0074-				
75	0075-				
76	0076-				
77	0077-				
78	0078-				
79	0079-				
80	0080-	8	-46	7	-44,8
81	0081-				

82	0082-				
83	0083-				
84	0084-				
85	0085-				
86	0086-				
87	0087-				
88	0088-				
89	0089-				
90	0090-	19	17	19	17,2
91	0091-				
92	0092-				
93	0093-				
94	0094-				
95	0095-				
96	0096-				
97	0097-				
98	0098-				
99	0099-				
100	00100-	15	-9	16	-8,7
101	00101-				

Appendix E: Raw data for establishing inter-examiner reliability

		panoramic	CBCT
ID	Number	**inter-rater (R1)**	**inter-rater (R2)**
1	001-	26	23,1
2	002-		
3	003-		
4	004-		
5	005-		
6	006-		
7	007-		
8	008-		
9	009-		
10	0010-	52	41,1
11	0011-		
12	0012-		
13	0013-		
14	0014-		
15	0015-		
16	0016-		
17	0017-		
18	0018-		
19	0019-		
20	0020-	21	13
21	0021-		
22	0022-		
23	0023-		
24	0024-		
25	0025-		
26	0026-		
27	0027-		
28	0028-		
29	0029-		
30	0030-	44	47,8
31	0031-		
32	0032-		
33	0033-		
34	0034-		
35	0035-		
36	0036-		
37	0037-		
38	0038-		
39	0039-		

40	0040-	54	39,1
41	0041-		
42	0042-		
43	0043-		
44	0044-		
45	0045-		
46	0046-		
47	0047-		
48	0048-		
49	0049-		
50	0050-	38	18,4
51	0051-		
52	0052-		
53	0053-		
54	0054-		
55	0055-		
56	0056-		
57	0057-		
58	0058-		
59	0059-		
60	0060-	36	14,3
61	0061-		
62	0062-		
63	0063-		
64	0064-		
65	0065-		
66	0066-		
67	0067-		
68	0068-		
69	0069-		
70	0070-	47	25,2
71	0071-		
72	0072-		
73	0073-		
74	0074-		
75	0075-		
76	0076-		
77	0077-		
78	0078-		
79	0079-		
80	0080-	7	-12
81	0081-		
82	0082-		
83	0083-		
84	0084-		

85	0085-		
86	0086-		
87	0087-		
88	0088-		
89	0089-		
90	0090-	16	13,8
91	0091-		
92	0092-		
93	0093-		
94	0094-		
95	0095-		
96	0096-		
97	0097-		
98	0098-		
99	0099-		
100	00100-	7	2,5
101	00101-		

Appendix F: Hardware and Software:

Personal Computer (PC):

Thinkcenter® M73 Desktop Intel (R) Core® i5-4590 CPU @ 3.30 Ghz, (4CPU's), 8139 physical RAM.

Monitor one (primary) – 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)

Monitor Two (secondary) – Philips® UltraClear 4K UHD (BDM435OUC)

LCD panel type: IPS LCD

Aspect Ratio: 16:9

Optimum Resolution: 3840 x 2160 @ 60 Hz

Brightness: 300 cd/m2

Contrast Ratio (typical) - 1200:1

Display colours: colour support – 1.07 billion colours (10 bit)

Software:

The images were converted to Digital Imaging and Communication in Medicine (DICOM) format. DICOM files were then reconstructed into a 3D image by multiplanar reformatting (MPR) and volume rendering using the OnDemand3D® software [version 1.0 (build 1.0.10.751), Cybermed Inc, South Korea].