Table of contents

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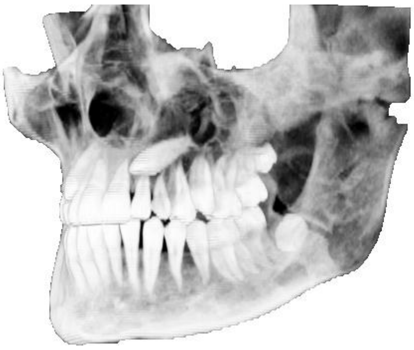

Chapter 1

General introduction

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Root resorption of the maxillary lateral incisor caused by impacted canine: a literature review

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Abstract

Root resorption of maxillary lateral incisors caused by erupting canines is well-known and not uncommon. There is, however, much debate and conflicting evidence on the actual resorption trigger and potential etiological factors, so there are no obvious clinical indications concerning prevention and diagnosis or for the subsequent treatment decisions. Cone beam computer tomography (CBCT) has recently shed new and much more documented light on the diagnostic and therapeutic strategies. However, it has yet to be determined if this new information will result in better diagnosis and improved treatment outcomes. Therefore, the present chapter will summarize the evidence provided by two-dimensional (2D) and three-dimensional (3D) images and link the radiological observations to further preventive, diagnostic and/or therapeutic measures. The detection thresholds, accuracy, and reliability of impacted canine localization and neighboring root-resorption risks will also be considered. This chapter demonstrates how adding a third dimension to the radiographic information may well alter perception of the prevalence of root resorption and the descriptions of this prevalence. In any case, further investigation is needed to determine resorption-detection thresholds with various two-dimensional and three-dimensional imaging techniques as well as to determine the therapeutic thresholds and criteria for strategic tooth extraction based on radiographically manifest and unmanageable resorption lesions.

Introduction

Root resorption is defined as a dental complication associated with either a physiological or pathological activity of the tooth resorbing cells that results in loss of cementum and/or dentine.[145] It is very difficult to treat and usually requires extraction of the affected tooth. Impaction is the failure of tooth eruption at its appropriate site in the dental arch within the normal period of growth and is determined on the basis of clinical and radiographic assessment.[143] Permanent maxillary canines are the second most frequently impacted teeth after the third molars.[143]

Maxillary canines are important esthetically and functionally.[57] An impacted canine, which is usually diagnosed by routine examination, can cause additional problems during the development and eruption of the impacted tooth and the neighboring teeth. The process of permanent tooth eruption and movement into the final functional position is complicated and comprises a series of events. The maxillary canines develop relatively late and emerge into the oral cavity after the neighboring incisors have erupted. The germ of the canine is situated high in the maxilla of three-year-old children, and the crown is mesially and palatally directed.[44] When the canine migrates down and forward toward the occlusal plane, the tooth gradually becomes more upright until it reaches the distal aspect of the lateral incisor root and the mesial aspect of the root apex of deciduous canine.[36, 44] If this process does not follow such a trajectory, the canine becomes impacted. Unfortunately, the potential occurrence of impacted maxillary cuspids affects the neighboring structures, and its prevention and treatment approach remain a matter of debate. The present review addresses these issues and provides a state-of-the-art report on the potential role of cone beam computed tomography (CBCT) imaging, which is as an improved approach to determining canine impaction-associated root resorption of adjacent teeth.

Etiology of the ectopic canine

The precise etiology of impacted maxillary cuspids is unknown, but two theories may explain the phenomenon of the palatally impacted canine: the guidance theory and the genetic theory. The "guidance theory of palatal canine displacement" suggests that this anomaly is due to local predisposing factors such as congenitally missing lateral incisors, supernumerary teeth, odontomas, tooth transposition, and other mechanical determinants, all of which interfere with the eruption path of the canine.[27, 66, 144]

The second theory for canine impaction is "the genetic theory". In addition, there are some factors that are thought to cause canine impaction such as obstruction, an abnormal position of the tooth bud, a lack of guidance along the root of the lateral incisor, dental crowding, a long and complicated eruption path, late eruption, early loss of deciduous canine, prolonged retention of the deciduous teeth, and systemic disease.[20, 29, 45, 50, 70] Palatally impacted maxillary cuspids are often present along with dental abnormalities such as tooth size, shape, number, and structure, which are hereditary.[23] These factors are associated with such anomalies as hypoplastic enamel, infra-occluded primary molars, and aplastic second bicuspids.[12] An inadequate arch space and a vertical developmental position are often associated with buccal canine impactions.[122]

Incidence of canine impaction

The incidence of impacted maxillary canines varies from 1% to 3%.[41, 144] The incidence of palatally displaced canines in the Caucasian population is approximately 2%[118] and 1.2% in African-Americans.[80] Canine impactions are most frequently bucally located in the Asian populations.[93, 111] The reported percentage of palatally impacted canines also varies widely among the studies. For instance, in a study of 44 patients, Stivaros and Mandall[137] reported canine impaction with a palatal location in 61% of the patients and a labial location in 5% with the remaining 34% being located in line with the arch. Rimes et al.[123] reported 26 patients with 32 impacted canines of which 14 were located palatally, 12 buccally, and 6 in line with the arch. Szarmach et al.[141] found 102 impacted canines (*n* = 82 patients) with distributions of 67%, 20%, and 13%, respectively. Ericson and Kurol[47] reported that 20% of the impacted canines were buccally placed, and 80% were either palatal or distal to the lateral incisors, with an estimated 8% of these being bilateral impactions. In a CT study, Bjerklin and Ericson[22] found even more buccally placed canines, the respective rates being 42% (palatal), 40% (buccal), and 18% (in line with the arch) for 113 impacted canines.

The incidence of detecting impaction may increase through the use of three-dimensional imaging techniques such as CBCT for dentomaxillofacial applications but give similar percentages as those indicated during CT studies. Indeed, with CBCT, Liu et al.[93] found that the impacted canines were located palatally in 41%, labially in 45%, and midalveolus in 14% of 210 patients. A CBCT study by Walker et al.[147] found that 25 of 27 impactions (*n* = 19 patient) were located palatally, and two were located labially *(Table 1.1)*. The detectability and diagnostic

Table 1.1: Relative position of impaction canines in maxilla according to various studies

Authors reporting impacted canines	Palatally %	Buccally %	In line with the arch %
Stivaros & Mandall [137]	61	5	34
Rimes et al.[123]	44	38	19
Szarmach [141]	67	20	13
Ericson & Kurol [47]	80	20	-
Bjerklin & Ericson [22]	42	40	18
Liu et al.[93]	41	45	14
Walker et al. [147]	93	7	-

methods used, gender, biological group and skeletal jaw may influence the incidence of impactions. These data demonstrate that randomized controlled trials using CBCT imaging are necessary to evaluate the true effect of these variables and, therefore, are capable of controlling for those variables during prognosis in a specific patient population.

Sequelae of maxillary canine impaction

Untreated partially erupted or impacted canines may lead to several complications like displacement of the adjacent incisors, shortening of the dental arch, formation of follicular cysts, canine ankylosis, recurrent infections, recurrent pain, internal resorption, external resorption of the canine and the adjacent teeth, and combinations of the them. The external resorption of the adjacent teeth is a major concern, and the most common sequelae of impacted canines can result in tooth loss. Proper diagnosis and early intervention may surely influence any further treatment strategy or final outcome. This process often remains asymptomatic. Furthermore, once root resorption is clinically diagnosed, the process may already be at an advanced stage that is not treatable.[149] The etiology of the resorption is unclear and involves a complex biological process that is not well understood. The reasons behind the resorption of some incisor roots due to the pressure of erupting and the lack of this effect in other incisors are unknown.[29] Several possible etiological factors for root resorption have been identified, such as genetic, trauma, and particular habits, but no clear causal relationship has yet been established.[51, 77] Most studies have focused on root resorption caused by palatal canines, although buccal canines can also cause incisor resorption *(Figs. 1.1-3)*.[77, 93, 123] Nevertheless, one also should bear in mind that canine teeth can cause root resorption of neighboring maxillary premolars.[36, 147]

Fig 1.1: Clinical intraoral photographs of a 20 years-old female patient showing an impacted upper left canine: A. Frontal view, B. Sagittal view, C. Occlusal view.

Diagnosis of canine impaction

The diagnostic methods that may allow for the early detection and prevention of canine impaction could reduce the time and complexity of the treatment, complications, and costs. This method should include family history, visual inspection, and tactile clinical examinations by the age of 9-10 year old.[45] Patients with deep bite, missing lateral incisors, prolonged retention of a deciduous canine, or peg-shaped upper lateral incisors need further investigation.[70] Palatally erupting canines have been found to frequently correct themselves with early removal of the primary canines, which has been recommended as the treatment of choice in appropriate patients.[46]

Radiographic examination is an essential part of the diagnostic process for impacted canine. Until recently, 2D radiological imaging was the standard method of choice due to the relatively low radiation dose and the availability of this procedure in the standard dental office. Several 2D radiographic techniques have been used for the differential diagnosis of root resorption, including periapical, occlusal, panoramic, and cephalometric radiographs or a combination of these approaches.[101, 102] In 2D images, many structures overlap as complex 3D structures are projected onto plain film.

The panoramic radiograph is user-friendly and non-invasive, and it provides helpful information regarding the dental age, symmetry, number of

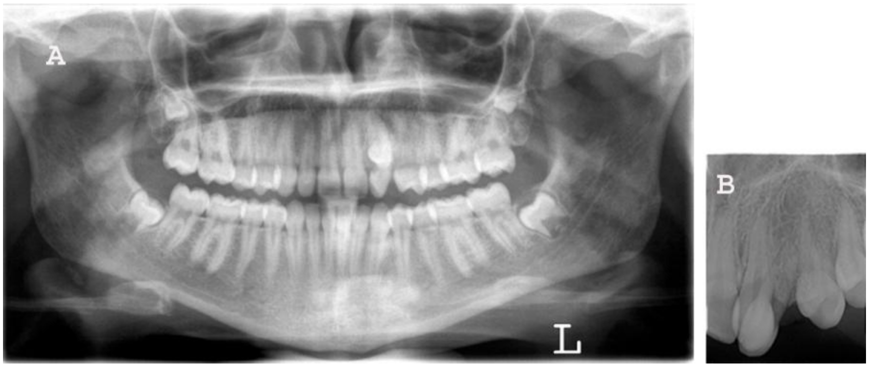


Fig. 1.2: A series of 2D images taken as a routine procedure for orthodontic treatment reveals an impacted upper left canine with no sign of resorption in lateral incisor tooth #22. A. Panoramic image confirming the impacted canine position, B. Intraoral periapical film showing the relative position of the impacted canine with intact root contour and no resorption visible in tooth #22.

teeth present, sequence of dental eruption, and presence of pathology as well as variations with respect to the norm and treatment results. It might also be useful in detecting the intra-alveolar location of malpositioned and unerupted canines. For instance, the canine occasionally becomes palatally impacted when the canine cusp tip is located mesial to the long axis of the erupted lateral incisor or the canine occasionally becomes palatally impacted when the canine cusp tip overlays the distal half of the lateral incisor root.[92] Moreover, structures closer to the X-ray source appear more magnified than those closer to the detector.[57] Tooth distortion and superimposition should be taken into consideration as factors that reduce the diagnostic accuracy of panoramic radiograph. In addition, using panoramic radiography for the detection of root resorption has limited diagnostic value because the accuracy of assessing palatal or buccal root resorption of the lateral incisor is limited, particularly in cases of early or mild resorption.[44, 53, 64, 121] Furthermore, conventional radiological imaging techniques, such as panoramic imaging, have been found to be inadequate for the diagnosis of root resorption in the maxillary incisors with impacted canines (*Figs. 1.1* and *1.2*).[57]

Assessing root resorption and changes in the root surface typically requires 3D information. Therefore, three-dimensional images have been suggested, especially when the root of the canine is suspected of becoming ankylosed or when the lateral incisor root is likely to exhibit resorption lesions.[48] 3D imaging such as obtained with MSCT can detect the position of the impacted canine as well as the extent and exact location of the lateral incisor root resorption, which cannot be detected by classic radiography.[50] Three-dimensional high resolution scans are indicated whenever one suspects that the roots could be moderately to severely resorbed.[125] While MSCT was typically developed for medical indications, CBCT is available for dentomaxillofacial applications, which an advantage of the fact that a compact readily available machine in dental practice.

CBCT offers a promising alternative for three-dimensional imaging in oral health care because it is low-cost, compact and particularly designed for detailed visualization of the maxillofacial structures. More than 70 different CBCT units are available worldwide. Cone beam machines all emit a conical-(or half conical)-shaped X-ray beam.[128] CBCT makes it possible to reconstruct the area of interest in 3 dimensions. Furthermore, the data provided by digital imaging and communication in medicine (DICOM) can be exported to dedicated software for advanced analysis and even preoperative treatment planning. Unlike conventional 2D images, CBCT images provide useful diagnostic information about dental structures that are overlap-free in the sagittal, axial, and coronal planes. If one considers the huge variation amongst CBCT machines, it can be stated that particular low dose and high resolution CBCT machines provides invaluable information regarding initiation or potential resorption of tooth roots adjacent to impacted canines *(Fig 1.3)*.[79, 128, 147]

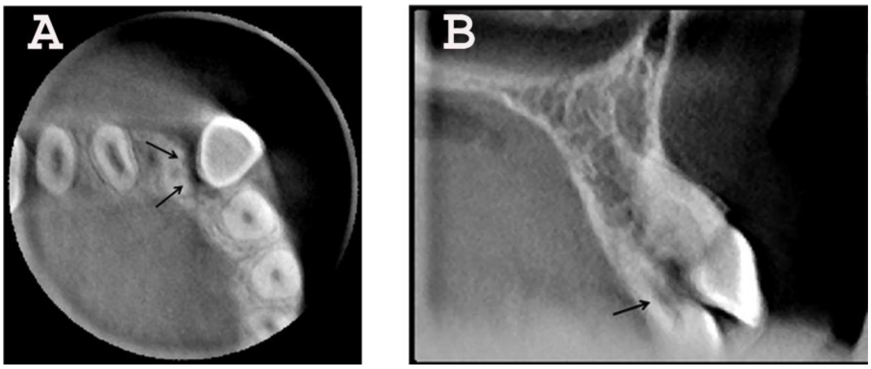


Fig. 1.3: A CBCT image shows an impacted upper left canine and severe resorption in the cervical third of the lateral incisor tooth #22 (arrows) in 3D Radiographs (CBCT Accuitomo 3D, Morita, Kyoto, Japan). A. Axial view, B. Cross-sectional view at the level of the vestibular root resorption lesion.

Radiation exposure

The radiation dose is always a matter of concern when using X-rays. Radiation exposure should be minimized as much as possible and should be balanced against patient benefit and the specific diagnostic information needed. The potentially harmful effects of ionizing radiation should not be neglected and should be taken into account when X-rays are involved. The short-term effects resulting from low-level radiation are cumulative over time and include both deterministic and stochastic effects. The deterministic effects cause death of cells from high doses that reach the threshold over short periods of time, such as radiation-induced oral mucositis. The stochastic effect causes irreversible damage to, or mutation of, cellular DNA, which increases the risk of cancer, depending on the radiation dose. Further, the long-term risk associated with diagnostic radiographic imaging is radiation-induced carcinogenesis.[7] The cancer risk may increase for young patients because most orthodontic patients are growing children, who are assumed to carry the incurred radiation burden for a longer period of time and since the developing organs of children are more sensitive to radiation effects than adults.[64, 128] CBCT requires lower radiation doses and shorter acquisition scan times. Most studies have focused on CBCT itself and its comparisons with spiral CT or conventional tomography. Meanwhile, the remarkable progress of CT technology has produced commercially available devices with more detectors, allowing for faster scanning times and low dose exposures compared with conventional CT.

The radiation effective dose of CBCT is ranging from 11 to 252 μSv for small, from 28 to 652 μSv for medium, and from 52 to 1,073 μSv for large field of view (FOV).[25] In a pilot study, the highest effective dose was measured for the Accuitomo CBCT system at 44 mSv in the maxilla for the canine and premolar regions and 26.6 mSv for the Scanora system using the medium field of view and high-resolution mode. The radiation dose of CBCT is 2–4 times the effective dose of the panoramic radiograph, which is between 4.7 and 14.9 mSv.[60] On the other hand, a higher effective dose for children has been found related to CBCT than to panoramic and lateral cephalometry.[132] The effective radiation dose varies between studies and is strongly dependent on FOV, kV, mA and exposure time.[116] The radiation dose of a CBCT scan has been reported in the range of 87–206 mSv for a full craniofacial scan[132] or, for the large FOV, 68–368 mSv[116]and 50–1024 mSv, compared with that of a panoramic radiograph (14.2–24.3 mSv) and a lateral cephalogram (10.4 mSv).[124]

The role of the dental follicle of impacted canines

Many studies indicate no association between enlarged canine follicles and resorption.[47, 67] Ericson and Kurol[47] reported an incidence of enlarged follicle in 23% of their cases. They also compared the resorption group to a control group with ectopically positioned canines that did not develop incisor root resorption and found that the incidence of follicular enlargement did not differ significantly from that of the resorption group, so they concluded that follicular enlargement was not a factor in the etiology.[46]

Indeed, such follicles may prevent direct tooth contact between the canine enamel and the incisor root cementum. Morphological and histological studies have shown that the dental follicle of the canine will often expose the root of the adjacent incisor during eruption without resorbing any of the hard tissues of the root provided that eruption proceeds normally.[46-48] A CT study by Ericson and Bjerklin [44] (*n* = 107 children) confirmed that the dental follicle of an ectopically erupting canine does not cause resorption of the adjacent permanent incisor and that the resorption seemed unrelated to follicular width and shape. In the same study, the follicle seemed to cause resorption of the periodontal contour of the lateral incisor during eruption and resorption of the root of the adjacent deciduous canine.[44] However, the retaining or resorption of the deciduous canine could not be linked to incisor root resorption.[46] However, once direct tooth contact is present, the risk of root resorption may be increased.

Incidence of lateral incisors root resorption

In the past, 2D imaging techniques, such as the combination of panoramic and occlusal images, were most often used to study impacted canines and potentially related tooth impaction. Many studies have found incisor resorption to be more common in females, with the female/male ratio varying between 2:1[22, 28, 51, 123], 3:1[50], 4:1[46, 147] and 10:1.[10] No gender differences have been found in either the severity or the location of root resorption.[46] The maxillary lateral incisor root is the area most commonly affected by ectopic eruption of the canine, with several reasons for this association 1) the root is conical; 2) it demonstrates the highest rate of abnormal root shapes; 3) it has developmental anomalies like dens invaginatus; 4) the roots are more susceptible to resorption during their developing stage; 5) the apex is deeply located in the palate, where impacted canines often develop; and 6) the canine is the third most commonly missing tooth after third molars and lower second premolars.[10, 125] Brin et al.[28] found that, if there was a deviation in the canine eruption path, then the tooth would be more likely to hit and resorb incisors with normal tooth size than would a small peg shape or small mesiodistal width tooth. Moreover, Kook et al.[78] found that the pattern of external root resorption for peg-shaped lateral incisors and small lateral incisors was not at great risk with orthodontic treatment. Even so, several authors have shown that roots with an abnormal shape have a higher susceptibility of apical root resorption during orthodontic movement.[110] Sameshima and Sinclair [125] reported that dilacerated lateral incisor and pointed teeth have greater root resorption in 860 cases. One report found that small roots resorbed during orthodontic treatment almost twice as much as did all the other root forms.[110] However, many studies found no differences between adults and children for external apical root resorption during orthodontic treatment.[8, 110, 125]

The central incisors can also be affected by the impacted canine.[77, 123] Resorption can be unilateral or bilateral and can affect all upper incisors. In a group of 11 patients, Sasakura[127] had only one with three incisors resorbed and none with all four incisors resorbed. Ericson and Kurol [46] had no cases with resorption of all four incisors. Only three children had bilateral resorption of the lateral incisors in their study of 41 patients. Rimes et al.[123] studied 26 patients with root resorption of 26 lateral incisors and nine central

Table 1.2: Incidence of resorption of lateral and central incisors caused by maxillary impacted canine

Authors reporting incidence of resorption of lateral and central incisors	Lateral Incisor %	Central Incisor %
Ericson & Kurol in CT study [53]	38	9
Liu et al.[93]	27	23
Walker et al. [147]	67	11

incisors of which eight were affected bilaterally. None of the patients had all four incisors resorbed. However, Szarmach et al.[141] found only five patients with lateral incisor resorption in 82 with impacted canines, four bilaterally, and one unilaterally. Tomography was deemed to diagnose resorption reliably.[52] Even using CT, Ericson and Kurol [53] found that only seven out of 156 canines caused resorption of both the central and the lateral incisors. In a study of consecutive cases of unerupted maxillary canines, resorptions were not found before a patient was 10 years of age, so canine positions should be evaluated at no later than when the child is 10 to 11 years old.[46] According to Ericson and Kurol,[47] radiographic investigation of the upper canines is generally unnecessary before 10 years old. This study determined that 8% of children over 10 years old require a supplementary radiographic investigation to reveal the exact position of the canine. After such an investigation, 1.5% of canines were shown to be impacted. The complication of incisor root resorption due to impacted maxillary canines has been underestimated because of the difficulty in identifying the affected teeth. The reported prevalence of root resorptions of the maxillary incisors clearly depended on the diagnostic procedure and the imaging technique. Superimposition of the incisor roots and the crown of an impacted canine on intraoral radiographs obscured the root morphology in 45% of cases.[47] Resorption was consistently found in patients in whom the cusp of the maxillary canine was positioned medially to the midline of the lateral incisor in panoramic and periapical films.[50]

Cross-sectional and three-dimensional imaging may overcome this problem by enabling more accurate diagnosis of root resorption. With tomography and intraoral radiographs, incisor root resorption was found to be associated with 12.5% of the impacted canines.[47] This is twice the frequency detected when only intraoral radiographs were used. Computed tomography (CT) provides highly detailed images of impacted canine location and root resorption.[48, 51] Using stepwise radiographs, Ericson and Kurol[46, 47] found that lateral incisor root resorption occurred in approximately 12% of the impacted maxillary canine population. Later on, with CT of the maxilla, they found resorption occurring in 38% of the maxillary lateral incisors and 9% of the central incisor roots in a population of 107 children with ectopically erupting canines.[53] Ericson and Kurol [51] found a high correlation in the diagnosis of root resorption between the CT and the clinical findings of extracted teeth. They found resorptions were similar in depth and pulpal involvement of the extracted teeth. Resorption was associated with approximately 48% of impacted maxillary canines.[51] In another study, Bjerklin and Ericson[22] found that 49% of the patients exhibited root resorption in a group of 80 patients. CBCT in 210 ectopically impacted maxillary canines showed incisor root resorption in 27% of the lateral incisors and 23% of the central incisors.[93] Walker et al.[147] reviewed 27 cases of impacted canines with CBCT and found lateral incisor root resorption and central incisor root resorption in 18 and 3 of those cases, respectively. *(Table 1.2) (Fig 1.4)*. Compared with conventional radiographic methods such as intraoral and panoramic radiographs, the amount of resorption detected by CT scanning was approximately 50% higher.[47, 50, 53]

Degree of root resorption

Various clinically applicable scoring methods have been developed to determine the degree or severity of the resorption lesion. Malmgren et al.[100] established a method based on the degree of root resorption on the mesial and distal aspect as follows: the first degree of resorption is an irregular root contour; the second degree of resorption involves less than 2 mm of the assessed original root length; the third degree of resorption involves between 2 mm and one third of the assessed original root length; and the fourth degree of root resorption exceeds one third of the assessed

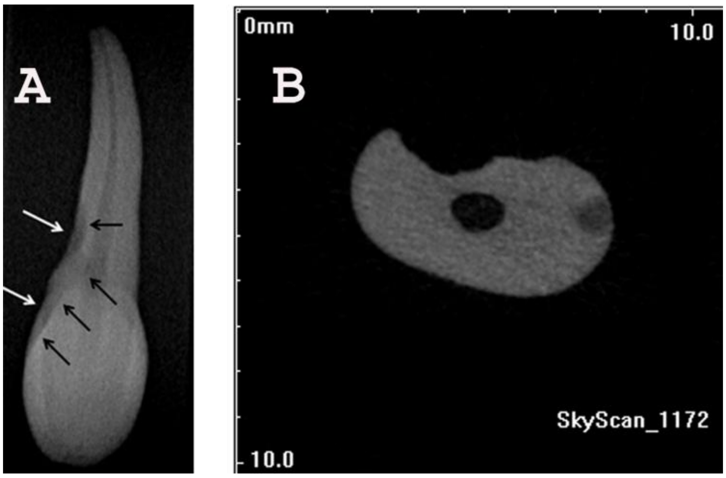


Fig. 1.4: a Peri-apical film showing the extent of resorption in cervical third of the upper left lateral incisor after extraction (arrows). b A Cross-sectional view of a Micro CT image shows the upper left lateral incisor after extraction with severe resorption in cervical third of the root (Skyscan 1172 high resolution Micro CT, Kontich, Belgium).

original root length. Peene et al.[119] defined three degrees of root resorption that can be determined with CT: "degree=0" is defined as having close contact to the roots of adjacent teeth with normal appearance of cross-sectional outline; "degree 1" has root resorption without involvement of the pulpal canal; and "degree=2" describes resorption reaching the pulpal canal with complete breakdown of the cementodentine line. However, many studies use the classification of root resorption severity devised by Ericson and Kurol,[51, 53] who graded resorption into four categories: 1) no resorption, intact root surfaces and the cementum layer may be lost; 2) slight resorption, resorption up to half of the dentine thickness to the pulp; 3) moderate resorption, resorption midway to the pulp or more, the pulp lining being unbroken; and 4) severe resorption, the pulp is exposed by the resorption.

Location of lateral incisor root resorption

The apical and middle thirds of the incisor roots are the most commonly resorbed. Ericson and Kurol[46] found that 82% of the laterals were resorbed in the middle third and 13% apically with the remainder being cervically resorbed. Half of the resorbed lateral incisors and one out of the six resorbed central incisors showed resorption reaching the pulp. In this study, 33% of the lateral incisors with root resorption appeared normal on conventional dental periapical radiographs. Medial inclination of the ectopically erupting canine overlapping more than 50% of the lateral incisor and the impacted canines with well-developed roots presented the greatest risks of leading to resorption of the lateral incisors.[47] Rimes et al.[123] found that 60% were resorbed in the apical and middle thirds, 31% were apically resorbed, and 9% were resorbed in the cervical third with or without the middle third. It is noteworthy that 30 of the 35 resorbed incisors used in this study had resorption into the pulp.[123] Brin et al.[28] found that lateral incisors were resorbed up to at least one-third of the original root length in 60% of their cases. Most interestingly, even with pulpal involvement, lateral incisors with root resorption had no clinical symptoms. Using CT, Ericson and Kurol[53] reported that maxillary incisor resorption occurred most commonly in the middle third of the roots on the labial or the lingual surfaces with 60% of the resorbed lateral incisors and 43% of the resorbed central incisors having pulpal involvement (Table 1.3).

Table 1.3: Location of the root resorption of the lateral incisors

Authors describing impacted canine related resorption	Apical tip %	Apical third %	Middle third %	Cervical third %
Rimes et al.[123]	-	31	60	9
Ericson & Kurol [51]	-	13	82	5
Ericson & Kurol in CT [53]	31	43	21	5

Treatment strategies

Orthodontists typically use different approaches to treat impacted canines. The primary issue when setting up the treatment plan is ruling out the presence of root resorption on the adjacent teeth and, if so, establishing the severity of the resorption. Lateral incisor root resorption requires modification of the treatment plan. In cases of severe root resorption, the tooth may be lost during or after the treatment. In patients who lack space, extraction of severely resorbed lateral incisor may be better than removing intact premolars.[22]

Bjerklin and Ericson[22] compared treatment plans of 80 children with impacted maxillary canines before and after information was gained from a CT examination. The information obtained from the CT images modified the treatment plans for 44% of the 80 children, and 54% of those children showed incisor root resorption. Consequently, with conventional radiography, 11 patients with undiagnosed severe incisor root resorption would have received a treatment plan with premolar removal rather than extraction of the affected incisors. Hence, CT imaging brought new and valuable information about the location of the impacted canines and the resorption of adjacent incisors.[22]

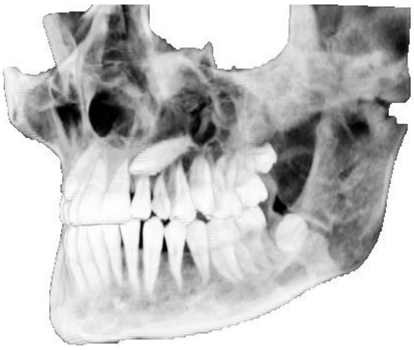
A recent study on the clinical management of ectopic canines by Bjerklin and Bondemark [21] found that orthodontists modified their approach to treatment when supplementary CT information was available about the extent of root resorption present on the maxillary lateral incisors, especially when resorption was diagnosed half-way between external dentin surface and pulp or more. In these cases, the treatment plan changed drastically: instead of keeping the lateral incisor in the arch, this tooth was now extracted in function of the amount of root resorption visualized.

CBCT may add useful information about the condition of the adjacent root and is valuable in the detection of root resorption associated with impacted canines.[93, 147] It is impossible for a routine panoramic radiograph to show such detailed information because of the 2D limitations: inherent deformation and low resolution. Another advantage of the CBCT information gain is that it indicates the exact 3D position of the impacted canine and allows one to define its possible eruption path. This positional information enables the surgeon to expose more accurately the impacted canine in a minimally invasive procedure when the treatment plan incorporates the open or closed eruption technique. The closed eruption technique is usually used for buccally impacted canines. The canine crown is surgically exposed and an attachment is bonded to the crown. The mucosal flap is reposition and sutured, leaving a twisted ligature wire or gold chain passing through the mucosa into the oral cavity.The open technique involves surgically removing the soft tissue and bone covering the crown of a palatally impacted canine thus creating a window. A dressing is usually used to cover the exposed area. The canine is allowed to erupt normally. Once the canine has erupted sufficiently, an orthodontic attachment is bonded to bring it into normal position. Moreover, complete 3D morphological information on the canine enables one to identify apical deformations that could retard guided or open eruption techniques.

Preventive measures could also be taken with an early diagnosis of an impacted canine when 3D information predicts an unfavorable eruption pathway for the canine. As CBCT imaging data can locate the canine and its eruption path, one can predict the potential direct contact between the canine enamel and the lateral incisor's root cementum, which would create a risk for incisor root resorption. Rather than opting to start opening a space for canine eruption by an orthodontic correction with fixed appliances, one would consider the premature removal of the deciduous canine, which would allow for partial or full normalization of the canine eruption.

Conclusion

Incisor resorption is very difficult to diagnose. Early diagnosis of impacted canine and root resorption might reduce complications during treatment, and the presence or absence of root resorption will determine the treatment plan. The risk of root resorption in children with displaced canines must not be neglected. If there is no evidence of primary canine root resorption, a displaced or impacted maxillary canine should be suspected. Every dentist should palpate the maxillary permanent canines by 9 to 10 years of age or earlier and take radiographs as needed. The severity of lateral incisor root resorption cannot be accurately determined from two-dimensional radiographs alone. Two-dimensional radiographs are easy to use, and provide useful information even though they fail to detect the exact localization of the canines or any potential root resorption, especially with early or mild root resorption. Moreover, CBCT has less radiation dose than does CT and overcomes the limitations of conventional radiography. Indeed, CBCT is useful for diagnosing the position, inclination, distance from adjacent structures, complications of impacted canines and detection of lateral incisors root resorption. Thus, this method can well have a significant impact on the diagnosis and the therapeutic interventions.



Chapter 2

Objectives of the research

GENERAL RESEARCH AIM

The main objective of this research is to develop an improved diagnostic methodology for the early diagnosis (Hypothesis A), treatment (Hypothesis B), and prediction (Hypothesis C) of canine impaction as well as associated lateral incisor root resorption. Therefore, the following hypotheses were formulated:

Research Hypothesis A

Early contemporary radiographic diagnosis alters the detection of canine impaction and associated lateral incisors root resorption. Therefore, *in vitro* and *in vivo* investigations were conducted:

- A comparison of the radiographic diagnostic accuracy of the conventional 2D radiographs versus CBCT for canine localization and the detection of root resorption *in vitro*.

  This study is intended to provide an understanding of the differences between CBCT and conventional panoramic images for identifying the root damage and spatial position of impacted canines. A cadaver skull of a child with an impacted left maxillary canine in the early mixed dentition was used. Panoramic and CBCT radiographs of the skull were taken with specific conditions in an experimental setup. The diagnostic accuracy for the detection of simulated canine-induced external root resorption lesions in maxillary lateral incisors was compared with conventional radiographic procedures using 2D panoramic radiographs and using 3D CBCT imaging systems.

- An evaluation of the image quality and diagnostic accuracy of different CBCT systems for the detection of lateral incisor root resorption *in vitro*.

  High quality radiographic images are essential for the assessment of root resorption caused by impacted canines. The high image quality displays early resorption in optimal conditions and reduces misinterpretation due to image noise and artefacts. Moreover, the performance of CBCT may depend a great deal on the parameter settings as well as on the machines used. Therefore, the subjective image quality and radiographic diagnostic accuracy for the detection of root resorption lesions in maxillary lateral incisors was compared between different CBCT systems *in vitro*. CBCT radiographs taken by different devices of a child cadaver skull with early mixed dentition were taken in specific experimental setups.

- A comparison of the radiographic diagnostic accuracy of conventional 2D radiographs versus CBCT for canine localization and detection of root resorption *in vivo*.

  The use of CBCT and the potential influence of 3D information *in vivo* for diagnostic and preventive measures needs to be ascertained and requires validation by means of comparison with conventional methods. Therefore, the clinical records of 60 consecutive patients were studied to test the findings of previous *in vitro* study. Patients (37 females and 23 males, mean age 13, SD: 4 years) with impacted maxillary canines were included. For each patient, two sets of radiographic information were compiled. One hundred and twenty sets of images were reviewed and analyzed by 11 examiners in order to link the radiological observations to the potential diagnostic effects, therapeutic measures, detection thresholds, accuracy, and reliability regarding impacted canine localization and root resorption of neighboring incisors.

Research Hypothesis B

The treatment planning of impacted maxillary canines is significantly different if a CBCT image is available. The following investigations were performed in order to respond to this research hypothesis:

- The effect of using 2D versus 3D radiographs on the surgical treatment planning of impacted maxillary canine cases.

  Using CBCT images to assess the impacted canine location in a three-dimensional representation had a clear diagnostic benefit. The advantages of using CBCT in canine localization may have an impact on the surgical management. The aim of present study was to compare the impact of using 2D panoramic radiographs vs 3D CBCT for the surgical treatment planning of impacted maxillary canines. This prospective study consisted of 32 subjects (19 females, 13 males, mean age 25, SD 14 years). In total, 39 maxillary impacted canines were referred for surgical intervention.
- A comparison of orthodontic treatment planning carried out on the basis of conventional and of CBCT information.

  Conventional treatment records have served the orthodontist well over many years. With respect to the reliability of CBCT in the diagnosis of impacted canines, it is essential to verify the effect of CBCT on orthodontic treatment planning. Therefore, this study compared the orthodontic treatment planning of 40 patients (26 females and 14 males, mean age 12, and SD 3 years) with impacted maxillary canines based on conventional treatment records with treatment planning based on a single CBCT image.

- The influence of CBCT on the treatment methods used and treatment outcomes achieved for orthodontically treated patients with impacted maxillary canines.

  CBCT images have proven in the previous studies to be reliable diagnostic tools for canine impaction. The treatment method and treatment outcome of 118 orthodontically treated patients with impacted maxillary canines were investigated. The patients were divided into two groups: Group A (*n* = 60) consisted of those who had conventional treatment records consisting of panoramic and cephalometric radiographs, intra- and extra-oral photographs, and dental casts. Group B (*n* = 58) consisted of those who had similar conventional treatment records along with CBCT images as extra diagnostic information.

Research Hypothesis C

Early prediction and prevention of canine impaction and root resorption is possible with early radiological investigations. Being able to predict canine impaction at an early stage of dental development and prevent the occurrence of lateral incisor root resorption could reduce the risk of complications. Therefore, the following studies were performed:

- The prediction of lateral incisor root resorption based on conventional 2D radiographic criteria validated by CBCT.

This study set out to establish prediction criteria for the presence of root resorption on 2D radiographs and to validate this method with a control group. 306 patients who had both 2D and 3D images were divided into two groups in function of the presence or absence of lateral incisor root resorption with CBCT images being used as the gold standard (base line). The radiographic measurements and specific radiographic features on 2D images were correlated to the presence of incisor root resorption detected on CBCT.

- Radiographic predictors of canine impaction by means of CBCT images for canine impaction.

The aim of this study is to compare the radiographic parameters obtained from CBCT images of 65 patients with unilateral impacted maxillary canine. The diagnosis of impacted canines was made from the patients' dental records to be a failure of the canine to erupt on one side at its appropriate site in the dental arch in comparison with the contralateral side. Radiographic follow-up assessment was conducted for a year in order to identify unilateral impaction. The parameters related to the impaction were also correlated on the basis of CBCT information in order to predict the possibility of an impacted canine developing.

Chapter 3

Comparison of the radiographic diagnostic accuracy of conventional 2D radiographs versus CBCT for canine localization and detection of root resorption *in vitro*

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

In-vitro comparison of 2 cone-beam computed tomography systems and panoramic imaging for detecting simulated canine impaction-induced external root resorption in maxillary lateral incisors.

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Abstract

The introduction of cone-beam computed tomography (CBCT) in dentomaxillofacial radiology has created new diagnostic challenges along with opportunities for evaluating impacted teeth. The diagnostic accuracy for the detection of simulated canine-induced external root resorption lesions in maxillary lateral incisors was compared with conventional 2-dimensional panoramic radiographic imaging and two 3-dimensional CBCT systems. A child cadaver skull with early mixed dentition was obtained from the Department of Anatomy, Hasselt University, Diepenbeek, Belgium, with ethical approval. This skull had an impacted maxillary left canine and allowed reliable simulation. Simulated root resorption cavities were created in 8 extracted maxillary left lateral incisors by the sequential use of 0.16 mm diameter round burs in the distopalatal root surface. Cavities of varying depths were drilled in the middle or apical thirds of each tooth root according to 3 setups: slight (0.15, 0.20, and 0.30 mm), moderate (0.60 and 1.00 mm), and severe (1.50, 2.00, and 3.00 mm). The lateral incisors, including 2 intact teeth, were repositioned individually in the alveolus of the pediatric skull with approximal contacts to the impacted maxillary left canine. Three sets of radiographic images were obtained with panoramic Cranex Tome (Soredex, Helsinki, Finland), Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan), and Scanora 3D CBCT (Soredex, Tuusula, Finland) for each tooth setup. Eight observers examined the three sets of ten radiographs for resorption cavities. The differences in the correct detection of simulated root resorption for all cavity sizes were significantly different (P >0.05) between the panoramic and both CBCT systems. CBCT imaging performance was significantly better than that of panoramic radiography for determining root resorption in the categories of slight and severe resorption. These results suggest that the CBCT radiographic method

is more sensitive than conventional radiography to detect simulated external root resorption cavities.

Introduction

The complexity of maxillofacial structures and the overlap between incisors and the ectopic canine can lead to misinterpretation.[46, 48, 135] Many studies have reported that root resorption of less than 0.6 mm in diameter and 0.3 mm in depth cannot be detected by using 2D intraoral radiography.[9] It has not yet been established whether these limits of detectability match the minimum size of clinically significant lesions.

The purpose of this study was to compare the radiographic diagnostic accuracy for detecting simulated external root resorption lesions between conventional 2D panoramic radiography and 2 CBCT systems in vitro.

Materials and methods

For this study, a child cadaver skull in the early mixed dentition with an impacted left maxillary canine was used. The skull was obtained with ethical approval from the Department of Anatomy, Hasselt University, Diepenbeek, Belgium *(Fig 3.1)*.

Panoramic and CBCT radiographs of the dry skull were taken in specific *in-vitro* conditions in eight setups. The maxilla was placed in a box of polystyrene foam filled with water to simulate soft-tissue attenuation and scattering. This set up caused no artifacts in the radiologic image. The panoramic exposures were made with Cranex Tome (Soredex, Helsinki, Finland). Exposure parameters were 15 seconds, 65 kV, and 15 mA by using storage phosphor plates, 15 x 30 cm (MD10XHQ, Agfa, Mortsel, Belgium), with detection in an ADC Solo phosphor plate scanner (Agfa). The CBCT images were acquired at the Oral Imaging Center, KULeuven, Leuven,

Fig 3.1: A. Impacted upper left maxillary canine in a child cadaver skull in the early mixed dentition phase; impacted canine is in contact with the root surface of the maxillary lateral incisor. B. Intraoral periapical radiograph showing the relative position of the impacted canine in contact with the root contour of the left maxillary lateral incisor.

Belgium. The examinations were made with 2 CBCT systems. First, a 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan) was used with a voxel size of 0.125 mm (FOV, 40 x 30 mm), a tube voltage of 80 kV, tube current of 3 mA, and scanning time of 18 seconds *(Table 3.1)*. The images were viewed with i-Dixel One Data Viewer software (Version 1.27, J. Morita). Second, a Scanora 3D CBCT (Soredex, Tuusula, Finland) was used with a voxel size of 0.133 mm (FOV, 75 x 100 mm), tube voltage of 85 kV, current of 15 mA, and scanning time of 3.7 seconds *(Table 3.1)*. In a pilot study, “medium field of volume” and “high resolution” were selected and found to provide better image quality for detecting root resorption than “small” or “large field of volume”, so parameters were selected for the in-vitro study. Images were viewed by using OnDemand3D software (Version 1.0, CyberMed, Seoul, South Korea). All the exposures were made by the same technical operator.

Table 3.1: Characteristics of CBCT scanners

	Accuitomo	Scanora
Gray scale (bit)	8	12
Potential (kV)	60-80	85
Current (mA)	1-10	8-15
Exposure type	Continuous	Pulsed
Scan Time (s)	18	2.25-4.5
Reconstruction time (min)	5	1-2
Voxel size (mm)	0.125	0.133-0.350
Object size (mm)	40x30	60x60, 75x100, 75x145
Focal spot (mm)	0.5	0.5
Detector type	Image Intensifier	Flat Panel

The maxillary left lateral incisor was extracted from the pediatric skull by using maxillary anterior forceps with gentle force. This allowed the same skull to be used as the standard setup for scanning various teeth (lateral incisors) with different resorption lesions. For each setup, a different maxillary left lateral incisor was placed in the extraction site of the maxillary left lateral incisor with a total of eight teeth. The selection criteria were teeth with normal roots without loss of cementum or dentin. Periapical radiographs were taken for assessment and selection with the Minray dental x-ray unit (Soredex) at 70 kV, 7 mA, and 0.12 seconds in combination with VistaScan phosphor plates (30x40 mm) (Dürr Dental, Bietigheim-Bissingen, Germany). Phosphor plates were scanned by using a VistaScan Perio photostimulable storage phosphor scanner (Dürr Dental). Radiographs were used to exclude internal root resorption and plan the location of the simulated resorption cavities, which were located in the contact area of the impacted maxillary left canine crown.

Each of the eight selected lateral incisors was specifically modified to simulate the resorption process according to the categories of Ericson and

Kurol: Eight slight (0.15, 0.20, and 0.30 mm), moderate (0.60 and 1.00 mm), and severe (1.50, 2.00, and 3.00 mm) resorption cavities were simulated by drilling at varying depths in each root of a lateral incisor on the distopalatal surface of the root in the middle or apical third. The cavities were prepared by using a low-speed handpiece with round diamond burs of 0.16 mm in diameter (International Organization for Standardization) and water as a coolant. All the tooth crowns were placed in plaster bases to ensure stability during drilling. The teeth were placed in the microspecimen former (University of Iowa College of Dentistry and Engineering Design and Prototyping Center, Iowa City, Iowa), a device especially constructed for the preparation of reliable and uniform cavities. An hydraulic system was used to control the movement of the diamond bur mounted in the low-speed handpiece, which gives 3D accuracy of 0.01 mm. Eight cavities ranging in depth from 0.15 to 3.00 mm were made. Each tooth was then removed carefully from the plaster and repositioned in the alveolus of the pediatric skull. Panoramic and CBCT images of the eight setups were acquired and subsequently analyzed by eight postgraduate orthodontic trainees. In addition, the same radiologic imaging was performed of two setups with intact lateral incisors. Thirty images were analyzed and viewed by each investigator in random order. The observers examined ten images of each type of radiograph (10 panoramic images and 20 CBCT images). They included eight views of the lateral incisors with simulated resorption cavities and two images of the sound lateral incisors (control teeth). The observers were instructed to manipulate the images with software enhancement tools according to their own preference. The evaluation process included a questionnaire to determine whether the examiners could detect a resorption defect in the lateral incisor. If resorption was found, the examiners were asked to score the degree of resorption according the criteria of Ericson and Kurol[51, 53]: 1) slight (resorption up to half of the dentin thickness to the pulp);

2) moderate (resorption midway or more to the pulp, with the pulp lining unbroken); or 3) severe (pulp exposed by resorption). The examiners were then asked to classify the location of the resorption defect in the apical, middle, or cervical third of the tooth root. The contact relationship between the canine and the lateral incisor was also recorded and defined as "contact" if the distance between the canine crown and root surface of the lateral incisor was less than 0.5 mm, or "no contact" if the distance between the canine crown and root surface of the lateral incisor was greater than 0.5 mm. Finally, the position of the canine in relation to the lateral incisor was scored as palatal, buccal, or in the line of the arch. The actual presence and extent of resorption was used as a gold standard to calculate the percentage of true-positive and false-positive readings. Root resorption defect assessments were defined: sensitivity, correct identification of resorption; specificity, correct identification of lack of resorption; false positive, identification of resorption when there was no resorption defect; false negative, lack of identification of a resorption defect.

Statistical analysis

Exact McNemar tests were performed to compare the proportion of correct classifications between the methods (panoramic vs Accuitomo, panoramic vs Scanora, and Accuitomo vs Scanora) for each parameter (presence, degree, and location of resorption; contact relationship; and canine position) and for each defect size separately. Perfect agreement was also introduced as a variable and defined as the percentage of correct evaluations for all the variables with respect to the gold standard. Spearman correlations were calculated to verify the relationship between the percentage of agreement and the size of the lesion. All *P* values were 2-sided and considered significant if less than 0.05. All analyses were performed by using SAS statistical software (Version 9.2, SAS Institute, Cary, NC).

Results

The percentages of correct readings for all the samples (including no resorption samples) with respect to resorption, degree of resorption, location of resorption, contact relationship, canine position and perfect agreement for each type of image (panoramic, Accuitomo CBCT and Scanora CBCT) are shown in *Table 3.2*.

The total numbers of images categorized as having no or slight, moderate, and severe resorption as well as the percentage of correct classifications for the degree of lateral incisor root resorption with the three image systems are shown in *Table 3.3*. More cavities were successfully observed when using the CBCT methods.

Both slight and severe resorption cavities were better observed with CBCT than with panoramic radiography. The percentage of false-negative evaluations of root resorption for panoramic imaging was 22%, which is higher than the 5% and 6% rates obtained with the Accuitomo and Scanora CBCT methods, respectively. The sensitivity values were 78% for panoramic imaging, 95% for Accuitomo CBCT, and 94% for Scanora

Table 3.2: Overall agreement level in terms of percentage for each parameter and each type of image (panoramic, Accuitomo CBCT and Scanora CBCT)

Test	Panoramic (%)	Accuitomo (%)	Scanora (%)
Presence of resorption	70	91	90
Degree of resorption	21	40	41
Location of resorption	49	60	61
Contact relationship	79	73	84
Canine position	60	69	65
Perfect agreement	16	19	28

Table 3.3: Percentage (%) of correct classification performed by eight observers with respect to degree of lateral incisor root resorption and lesion size when compared to gold standard for the three image systems: panoramic, Accuitomo CBCT and Scanora CBCT

Degree of resorption	Gold Standard	Size mm	Panoramic		Accuitomo		Scanora	
None	16	0.00		37.5%		75.0%		75.0%
Slight	24	0.15	37.5%	16.7%	62.5%	79%	50%	62.5%
		0.20	0%		87.5%		75%	
		0.30	12.5%		87.5%		62.5%	
Moderate	16	0.60	50.0%	62.5%	50%	37.5%	75.0%	43.8%
		1.00	75.0%		25%		12.5%	
Severe	24	1.50	25.0%	41.7%	100%	75%	100%	100%
		2.00	12.5%		37.5%		100%	
		3.00	87.5%		87.5%		100%	
Total	80			21.0%		38.5%		40.5%

CBCT, and the specificity values were 38% for panoramic imaging and 75% for both CBCT methods *(Table 3.4)*.

The differences in correct detection of root resorption for all resorption sizes (including teeth with no resorption) were significant (P < 0.001) between the panoramic and both of the CBCT systems. However, there was no statistical difference between the Accuitomo and Scanora CBCT systems *(Table 3.5, Fig 3.2)*. Moreover, CBCT imaging performance was significantly better (P < 0.001) than that of panoramic radiography for determining the root resorptions of all sizes (including teeth with no resorption) *(Table 3.5, Fig 3.3)*. Significant differences were also found between panoramic imaging and both of the CBCT systems as regards the correct classification of degree of resorption in the categories of slight and severe resorption *(Table 3.5)*. For the location of root resorption, a significant difference (P = 0.031) was found between panoramic imaging vs

Table 3.4: Sensitivity and specificity of resorption detection for each of the three radiological imaging methods expressed as percentages

	Panoramic	Accuitomo	Scanora
Sensitivity	78	95	94
Specificity	38	75	75
False positive errors	63	25	25
False negative errors	22	5	6

Accuitomo CBCT for correct classification at the 0.60 mm cavity size *(Fig 3.4)*. A significant Spearman correlation was observed between the agreement rate for the location of resorption and cavity size ($P = 0.01$) when using the Accuitomo CBCT (Spearman rho = 0.83). In addition, a significant relationship was found between perfect agreement and size ($P = 0.02$) for the Scanora CBCT (Spearman rho = 0.78) *(Fig 3.5)*.

Discussion

Previous studies have characterized the difficulties in diagnosing external root resorption with conventional radiography.[9, 24, 107, 125, 149] Intraoral 2D radiography is an inaccurate diagnostic tool for the detection of lingual root resorption.[56] A comparative study found that digital radiography was more sensitive for detecting external root resorption than was conventional radiography.[149] In contrast, other studies found the performance of digital systems to be equal to conventional systems for detecting simulated root resorption cavities.[24, 72] Digital subtraction radiography was shown to be superior to conventional radiography for detecting simulated external root resorption by eliminating anatomic noise.[65, 81]

Flat-panel volume computed tomography (fpVCT) as described by Hahn et al. [62] could be an alternative to detect simulated external root resorption cavities better than did conventional CT. However, flat-panel

Table 3.5: Comparison of correct classification rate for each parameter and for slight, moderate, and severe lesions of all sizes except those in intact teeth and for all sizes including intact teeth between Panoramic imaging and Accuitomo CBCT, Panoramic imaging and Scanora CBCT, and Accuitomo CBCT and Scanora CBCT

		Slight	Moderate	Severe	All sizes-IT	All sizes+IT
Presence of root resorption	Pan -Acc			N.S.	0.003	<0.001
	Pan -Scan	N.S.	N.S.	N.S.	0.021	0.002
	Accu -Sca			*	N.S.	N.S.
Degree of root resorption	Pan -Acc	<0.001		0.021	0.003	<0.001
	Pan -Scan	0.012	N.S	<0.001	<0.001	<0.0001
	Accu -Sca	N.S.		0.031	N.S.	N.S.
Location of root resorption	Pan -Acc	N.S.				
	Pan -Scan	N.S.	N.S.	N.S.	N.S.	N.S.
	Accu -Sca	0.021				
Contact relation ship	Pan -Acc			N.S.		
	Pan -Scan	N.S.	N.S.	N.S.	N.S.	N.S.
	Accu -Sca			0.015		
All parameters	Pan -Acc			N.S.		
	Pan -Scan	N.S.	N.S.	0.021	N.S.	N.S.
	Accu -Sca			N.S.		

Pan, Panoramic; Acc, Accuitomo; Scan, Scanora; NS, not significant; IT, intact tooth.

**No discordant pairs.*

volume CT has been used only in research applications.[62] In this study, we simulated small cavities because of the importance of accurate detection of early pathologic lesions. The smallest defect was 0.15 mm to determine a threshold value for detecting lesions in the lateral incisor root and to evaluate the detection of early root resorption. The number of cavities detected was higher when images were obtained with CBCT radiographic methods compared with the conventional panoramic method. Lesions of 0.20 mm in depth and 0.16 mm in diameter could not be detected with panoramic imaging *(Fig 3.6)*, whereas 87.5% and 75% of the observers could detect this stimulated external resorption lesion using the Accuitomo and the Scanora CBCT methods, respectively *(Figs 3.7 and 3.8)*.

Table 3.6: Exact McNemar test of correct classification rates for the degree of root resorption of the lateral incisor at each cavity size between Panoramic imaging and Accuitomo, Panoramic imaging and Scanora, and Accuitomo and Scanora

	Size in mm	0.00	0.15	0.20	0.30	0.60	1.00	1.50	2.00	3.00
Degree of root resorption	Pan –Acc			0.015	0.031			0.031	N.S.	*
	Pan -Scan	N.S.	N.S.	0.031	N.S.	N.S.	N.S.	0.031	0.015	N.S.
	Accu -Sca			N.S.	N.S.			*	N.S.	N.S.

*N.S. = not significant *=no discordant pairs.*

Both slight and severe but not moderate cavities were better observed with the CBCT method *(Table 3.3)*. The reason that the detection rate was not higher for moderate cavities might have been that all of the observers scored moderate cavities as severe with the CBCT. This might have been because the thicknesses of the high-resolution CBCT slices: the combination of thin slices and high resolution might have caused consistent overestimation of the cavities with moderate root resorption. On the other hand, the observers scored significantly better with the 3D CBCT images. The reliability of CBCT imaging was substantially better than that of panoramic imaging for the detection of small cavities, with a 16.7% detection rate for panoramic imaging as opposed to 79% and 62.5% for Accuitomo and Scanora, respectively. In addition, both CBCT imaging systems significantly outperformed panoramic imaging for the detection of incisor root resorption, especially for the 0.20 mm defect. This was also true for the Accuitomo CBCT for the 0.30-mm resorption defect *(Table 3.6)*.

This result might have been due to the inherent advantage of volumetric imaging, which avoids structural superimposition. Interestingly, we did not find improved accuracy for the detection of root resorption defects of using panoramic imaging, since the rate of correct identification of no resorption was only 37.5% compared with 75% for the Accuitomo and

Scanora systems. The radiographic findings with panoramic imaging showed higher rates of false-positive (63%) and false-negative (22%) errors than with the CBCT systems *(Table 3.4)*.

Our findings agree with those of Nance et al,[107] who studied digital radiography and tuned-aperture CT system. Conventional radiography for external root resorption detection showed false-negative results in about 51.9% of the cases and false-positive results in about 15.3%. An advantage of tuned-aperture CT is the low radiation dose compared with conventional CT. However, only 60% of the resorption lesions were detected with the tuned-aperture CT system, and the smallest was 0.25 mm in diameter and 0.50 mm in depth. This is still smaller than what can be detected with conventional radiography, which cannot detect lesions smaller than 0.60 mm in diameter and 0.30 mm in depth.[9, 149]

Moreover, the determination of the canine position was not significantly different when using panoramic and CBCT systems. This might be related to interobserver variability and the use of the resorption lesion as the reference point for localizing the canine in the dental arch. There were also no significant differences in the determination of the contact relationship between canines and lateral incisors. This result might have been due to the overlap of the canine and the lateral incisor in the 2D images and the study setup, which could have made it difficult to simulate the contact at the lesion site precisely.

Da Silveira et al.[40] found that CT was a good diagnostic tool and highly sensitive for detecting simulated external root resorption compared with conventional radiography, but the limitations included the detection of small resorptions in the apical third and the high dose of radiation required. The detection rate for root resorption was 71% for CT; the smallest resorptions detected were 0.60 mm in diameter and 0.30 mm in depth.[40] In our study, the smallest detected resorption was 0.15 mm in depth and 0.16 mm in diameter *(Fig 3.9)*. the detection rates for this lesion size were 62.5% and 50% for the Accuitomo and the Scanora CBCT systems, respectively. The false-negative rate for CT was 11%, which is higher than our observed rates of 5% and 6% for Accuitomo and Scanora CBCT. A recent study by Liedke et al.[91] evaluated the diagnostic capacity of CBCT for three voxel resolutions (0.4, 0.3, 0.2 mm) to detect simulated external root resorption cavities. This study showed high sensitivity and specificity for all three voxel resolutions; which agrees with our findings. Moreover, the three voxel resolutions produced the same result for the detection of simulated external root resorption cavities.[91]

Our study was limited by its low ability to detect differences in detection rates for lesions of each size independently and to determine the relationship between the detection rate and the size. To determine formally whether the defect size and probability of agreement differs between the methods, a logistic regression model (taking into account the repeated measurements from the 8 observers) to test the interaction between size and method should be considered if more data are available.

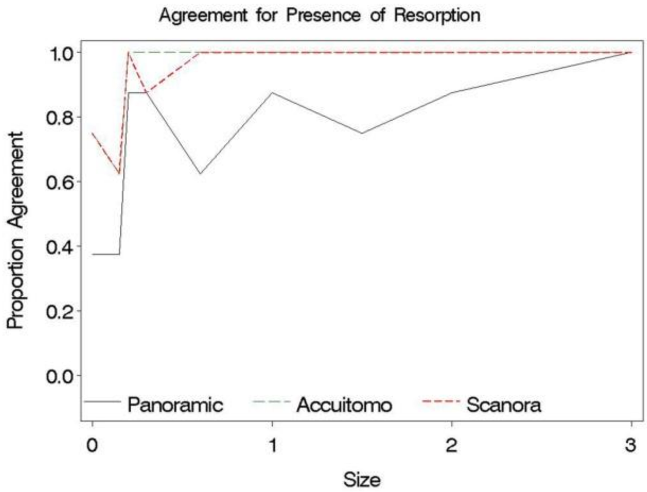

Fig 3.2: Agreement rates for the detection of stimulated root resorption in maxillary lateral incisors for each cavity size. Significant differences were found for all cavity sizes when comparing panoramic imaging versus Accuitomo CBCT, and panoramic imaging versus Scanora CBCT, P< 0.05.

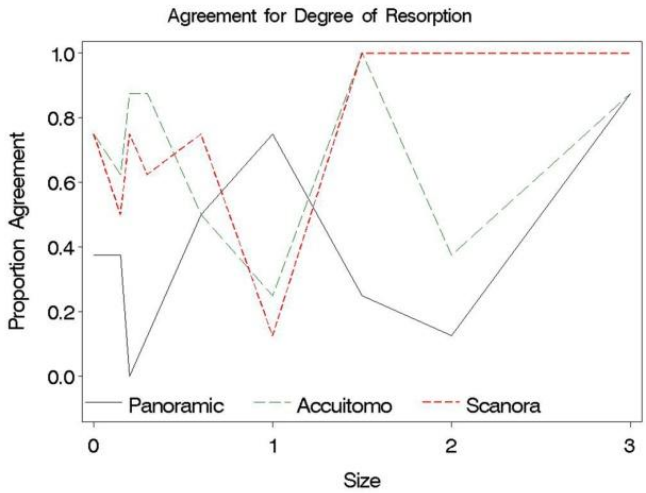

Fig 3.3: Agreement rates for the degree of root resorption: slight (0.15, 0.20, and 0.25mm), moderate (0.60 and 1.00 mm), and severe (1.50, 2.00, and 3.00 mm) resorptions were detected in maxillary lateral incisors. Significant differences were found for all cavity sizes when comparing panoramic imaging with Accuitomo CBCT and panoramic imaging with Scanora CBCT P<0.001.

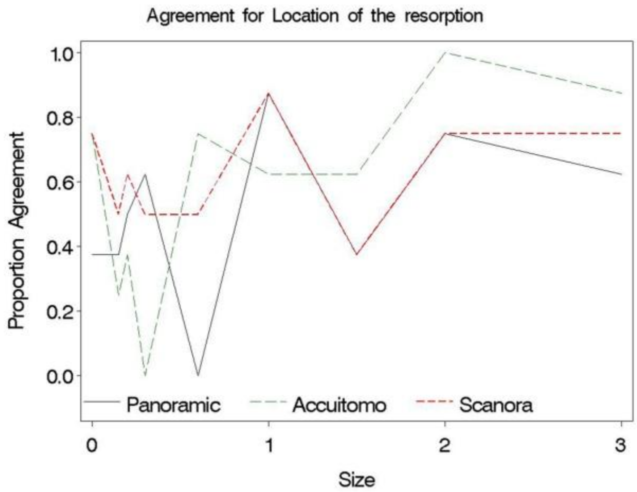

Fig 3.4: Agreement rates for the location of detected resorption (apical, middle and cervical thirds) in maxillary lateral incisors for each cavity size. Significant differences were found for slight resorption cavities (0.15 mm, 0.20 mm, and 0.30 mm) when comparing Accuitomo CBCT with Scanora CBCT, P =0.021.

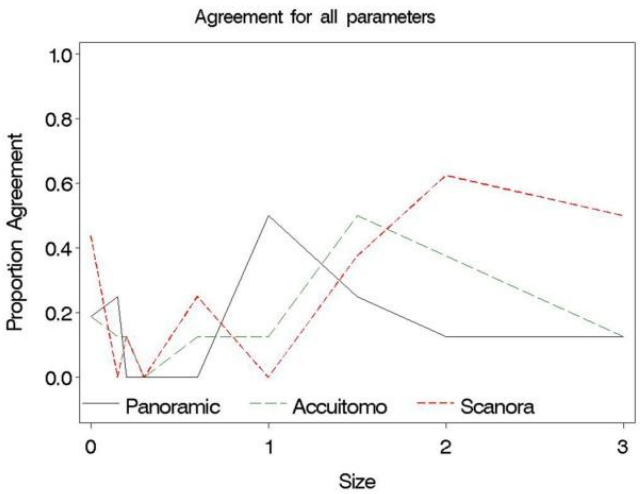

Fig 3.5: Agreement rates for all parameters "perfect agreement" for each cavity size. Significant differences were found for severe resorption cavities (1.50 mm, 2,00 mm, and 3,00 mm) when comparing panoramic imaging with Scanora.

Fig 3.6: A 2D panoramic radiograph reveals an impacted maxillary left canine with no sign of resorption for the left maxillary lateral incisor, which had a 0.20 mm cavity. The root contour of lateral incisor overlaps with that of canine and difficult to assess.

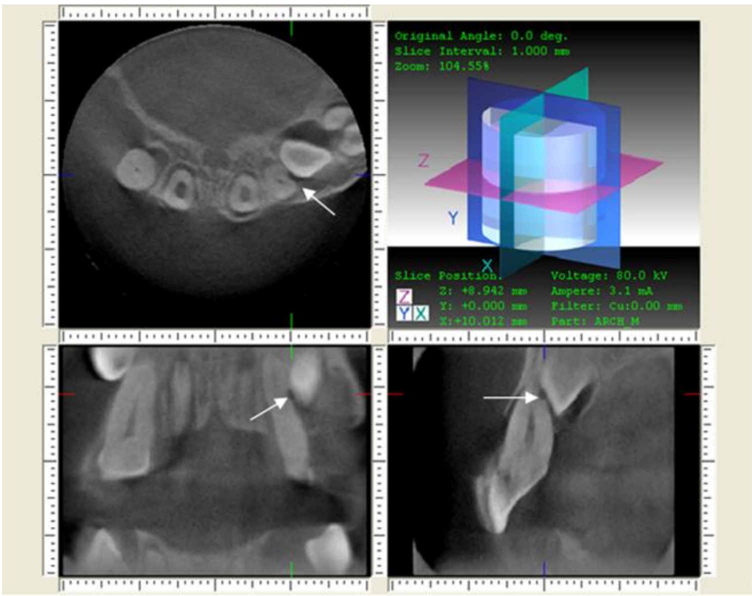

Fig 3.7: CBCT images obtained with Accuitomo 3D (Accuitomo, Morita, Kyoto, Japan) showing axial, sagittal, and coronal slices that were used to visualize the impacted maxillary left canine and 0.20 mm resorption defect in the maxillary left lateral incisor.

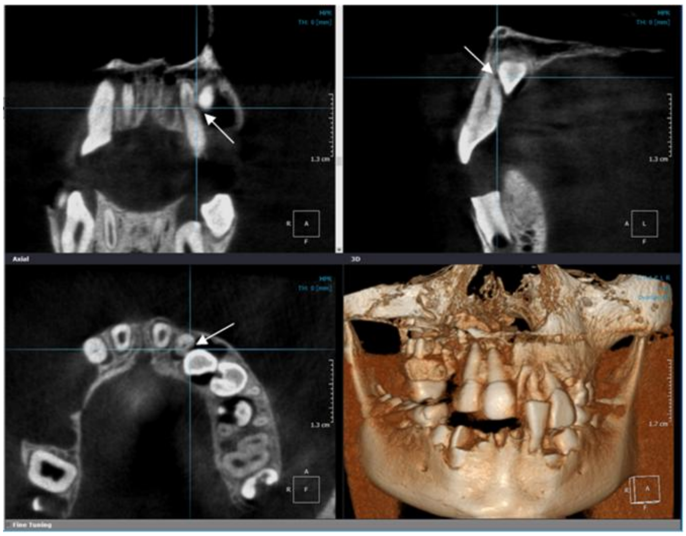

Fig 3.8: CBCT images obtained with Scanora 3D (Soredex, Tuusula, Finland) showing axial, sagittal, and coronal slices as well as a 3D model that were used to identify the impacted maxillary left canine and 0.20 mm resorption defect in the maxillary left lateral incisor.

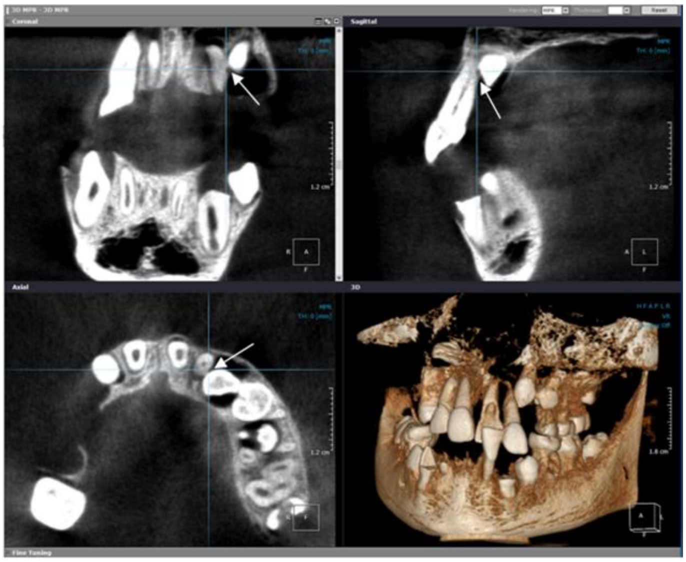

Fig 3.9: CBCT images obtained with Scanora 3D (Soredex, Tuusula, Finland) showing axial, sagittal, and coronal slices as well as a 3D model. The images show an impacted maxillary left canine and 0.15 mm resorption defects in the maxillary left lateral incisor.

Conclusion

The results of this in-vitro study suggest that the CBCT technique could be a reliable diagnostic tool for detecting canine impaction and associated lateral incisor root resorption. Lesions as small as 0.20 mm could be easily diagnosed. Thin slices and 3D information might well increase the detection rate. The typical overlap of dental structures on panoramic radiography was not observed with CBCT.

Chapter 4

An evaluation of image quality and diagnostic accuracy of different CBCT systems for the detection of lateral incisor root resorption *in vitro*

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Comparison of 6 cone-beam computed tomography systems for image quality and detection of simulated canine impaction-induced external root resorption in maxillary lateral incisors.

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Abstract

The most frequent adverse effect of canine impaction is resorption of the adjacent incisors. The subjective image quality and the radiographic diagnostic accuracy for the detection of simulated canine-induced external root resorption lesions in maxillary lateral incisors were compared with six CBCT systems *in vitro*. A child cadaver skull with early mixed dentition was obtained. This skull had an impacted maxillary left canine and allowed reliable simulation. Simulated root resorption cavities were created in 8 extracted maxillary left lateral incisors by the sequential use of 0.16-mm diameter round burs in the distopalatal root surface. Cavities of varying depths were drilled in the middle or apical thirds of each tooth root with three setups: slight (0.15, 0.20, and 0.30 mm), moderate (0.60 and 1.00 mm), and severe (1.50, 2.00, and 3.00 mm) resorption. The lateral incisors, including 2 intact teeth, were repositioned individually in the alveolus with approximal contacts with the impacted maxillary left canine. Six sets of radiographic images were obtained for each tooth set up with 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan), Scanora 3D CBCT (Soredex, Tuusula, Finland), Galileos 3D Comfort (Sirona Dental Systems, Bensheim, Germany), Picasso Trio (E-WOO Technology, Giheung-gu, Republic of Korea), ProMax 3D (Planmeca OY, Helsinki, Finland), and Kodak 9000 3D (Trophy, Croissy-Beaubourg, France). The CBCT images were acquired and subsequently analyzed by 12 observers. Linear models for repeated measures were used to compare the CBCT systems for the image quality and the degree of agreement between the diagnosed severity of root resorption and the true severity. The differences in the image quality of the CBCT systems were statistically significant ($P < 0.001$). The root resorption scores between the CBCT systems showed a significantly higher score for the ProMax than with the Galileos and the Kodak. However, the differences in agreement between the diagnosed

severity of root resorption and the true severity for all resorption sizes were not significantly different ($P > 0.05$) for the different CBCT systems. High image quality is important when detecting root resorption. The CBCT systems used in this study had high accuracy with no significant differences between them in the detection of the severity of root resorption.

Introduction

In Chapter 3, it was shown that the detection of root resorption was higher when using CBCT than with conventional radiography, and it was suggested that CBCT imaging is a reliable tool for the localization and detection of root resorption.[6] Although CBCT systems have rapidly developed while improving their overall image quality, all of these systems vary mainly in their field of volume (FOV) and the detector type: either an image intensifier tube and a charge-coupled device or a flat-panel detector. It has been reported that the detector type influenced the image: the IIT/CCD, for example, has more artifacts and produces more noise than do flat-panel detector systems.[96, 128] Moreover, the FOV was found to be correlated to spatial resolution and contrast.[90, 140] The radiation dose varies substantially between CBCT systems, depending on the FOV and the parameters.[96, 140] The voxel size plays a role in determining the image resolution, quality, and scanning and reconstruction times of the CBCT images.[128] Previous studies have compared only the effect of voxel size in one or two CBCT systems.[91] It was found that the three voxel sizes did not affect the diagnostic performance for the detection of external root resorption.[91]

The diagnostic ability of different CBCT systems in detecting root resorption caused by an impacted canine has not been sufficiently studied. Therefore, the purpose of the present in-vitro study is to compare the subjective image quality and the radiographic diagnostic accuracy in function of the detection of simulated external root resorption lesions caused by an impacted canine with six CBCT systems.

Material and methods

A child cadaver skull in the early mixed dentition phase was used. This skull had an impacted left maxillary canine *(Fig 4.1)*. CBCT radiographs of the dry skull were taken in specific in-vitro conditions as described in C**hapter 3**.

Fig 4.1: Three-dimensional image from Galileos 3D comfort of the child cadaver skull in the early mixed dentition phase showing an impacted maxillary left canine in contact with the root surface of the maxillary lateral incisor.

The samples were scanned according to the protocols recommended by the manufacturers. The CBCT systems were 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan), Scanora 3D CBCT (Soredex, Tuusula, Finland), Galileos 3D Comfort (Sirona Dental Systems, Bensheim, Germany), Picasso Trio (E-WOO Technology, Giheung-gu, Republic of

Korea), ProMax 3D (Planmeca OY, Helsinki, Finland), and Kodak 9000 3D (Trophy, Croissy-Beaubourg, France).

The machine specifications, scanning protocols, and the FOVs for each CBCT are shown in *Table 4.1*. After image acquisition, all the scans were exported as digital imaging and communications in medicine (DICOM) files and saved to a portable hard disk for later reconstruction. The images were exported and viewed with OnDemand3D software (Version 1, CyberMed, Seoul, South Korea), which provided slices in the axial, coronal, and sagittal planes and 3D models. All the exposures were made by the same operator (A. Alqerban).

Ten images from 5 CBCT systems (Accuitomo, Scanora, Galileos, Promax, and Kodak) were produced. These were the images of the eight lateral incisors with simulated resorption cavities and two sound lateral incisors (control teeth). However, for the Picasso CBCT system, only 6 teeth were scanned: four lateral incisors with resorption cavities (0.15, 0.20, 0.30, and 0.60 mm) and two sound lateral incisors. In total, 56 CBCT images were acquired and subsequently analyzed in two sessions. The first evaluation session was by eight postgraduate orthodontic residents, two orthodontic instructors, and two dental radiologists.

All of the images were viewed by each observer as screen shots. The slice that best showed root resorption in the axial, coronal, and sagittal views was used. The images for all of the CBCT systems were standardized with respect to the identical anatomic structures at the same location. To standardize viewing conditions, image brightness and contrast were calibrated by a light meter (PeakTech 5025, Dürr Dental, Bietigheim, Germany). The 12 observers were not allowed to adjust the brightness and contrast settings or the reconstruction views, thus ensuring standardized comparisons. All images were viewed on a 20-in flat panel screen (2007 FP

Table 4.1: Characteristics and technical specifications of CBCT systems

	Accuitomo 3D CBCT	Scanora 3D CBCT	Galileos 3D	Picasso Trio	Promax 3D	Kodak 9000 3D
Gray scale (bit)	8	12	12	12	12	14
Potential (kV)	80	85	85	85	84	85
Current (mA)	3	8-15	7	5	12	10
Exposure type	Continuous	Pulsed	Pulsed	Pulsed	Pulsed	Pulsed
Scan Time (s)	18	2.25-4.5	3.4-14	15	18	10
Reconstruction time (min)	5	1-2	7	4-6	3	2
Voxel size (mm)	0.125	0.133-0.350	0.29	0.2	0.16	0.076 - 0.2
Object size (mm)	30x40	75x100	120x150	70x120	80x80	37x50
Detector type	Image Intensifier	Flat Panel	Image Intensifier	Flat Panel	Flat Panel	Flat Panel

1600x1200, Brilliance 200WP, Philips, Brussels, Belgium). The images acquired in the first evaluation session were presented to the observers under the same conditions to avoid differences between observers while scoring the 6 CBCT systems. Observers used the screen shot and standardized contrast to decrease the role of other variables such as computer and viewing software experience and to become more user-friendly and efficient *(Fig 4.2)*.

The second evaluation session was performed by the two dental radiologists, who reviewed the 56 DICOM data sets again four weeks after the first session. The radiologists in the second session were allowed to reconstruct the images individually with OnDemand3D and to adjust the brightness and contrast settings with software enhancement tools. They also were able to scroll through the CBCT slices using their own preferences for the optimal display of root resorption in the three planes (axial, coronal, and sagittal). This observation design was used to mimic the routine diagnostic approach in which clinicians can adjust image display settings.

All of the observers were blinded as regards the type of CBCT machine used and the purpose of the study. The examiners were trained to use CBCT images for the detection of root resorption, and they assessed the images independently in the same random order. The observers were aware that not all of the images had root resorption, and they were encouraged to score only resorption in the root of the lateral incisor close to the impacted canine. The observation time was also not limited. The evaluation process of the two sessions included a questionnaire on the subjective diagnostic image quality on a 5-point rating scale (very poor, poor, acceptable, good, and excellent). This scale was used to assess the visibility of the following structures: pulp, dentin, and enamel; lamina dura; and overall image noise (brightness, contrast, and intensity). Excellent images were scored as those with clear visibility and distinguishable structures rather than for the esthetics of the image or the background.

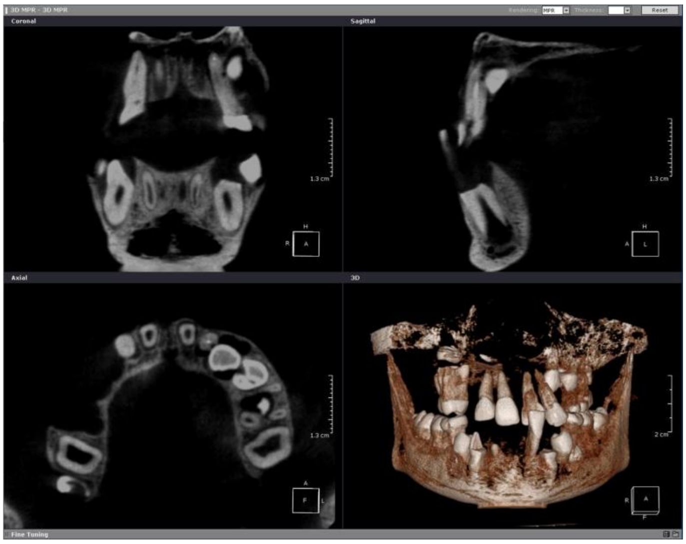


Fig 4.2: CBCT image (screen shot) obtained with Scanora 3D showing of axial, sagittal, coronal slices and the 3D model that were used in the first evaluation session to identify the 0.300 mm resorption defect in the maxillary left lateral incisor.

After assessing the image quality, the observers were asked to assess the presence of a resorptive defect in the lateral incisor. The identification of root resorption was done on a 5-step confidence scale: 1, definitely no resorption; 2, maybe no resorption; 3, unsure; 4, maybe resorption; 5, definitely resorption. If resorption was diagnosed, the examiners were asked to score the degree of resorption according to the criteria of Ericson and Kurol[51, 53]: slight (resorption up to half of the dentin thickness toward the pulp), moderate (resorption of half of the dentin thickness or more, with an unbroken pulp lining), or severe (pulp is exposed because of resorption). The examiners were then asked to classify the location of the diagnosed resorptive defect as apical, mid-apical (halfway between the apical and middle thirds), or middle third of the root.

Statistical analysis

In the first evaluation session, linear regression models for repeated measurements were used to analyze the relationships between the types of CBCT systems and various indexes of image quality (pulp, enamel, and dentin; lamina dura; overall image noise). The ordinal scores were treated as continuous variables in these analyses. An overall index of image quality was constructed by summing the scores of the four indexes. Tukey adjustments for multiple testing were used for pairwise comparisons between CBCT systems in the evaluation of image quality. The observers' scores for root resorption were categorized so that the scores of definitely resorption or maybe resorption were considered as "yes," and the scores of unsure, maybe no resorption, or definitely no resorption were considered to be "no." With the actual presence of resorption used as the gold standard, the percentages of correct identification of resorption (sensitivity) and the percentages of correct identification of lack of resorption (specificity) were calculated. Sensitivity and specificity were compared among systems by using the McNemar Test. A correction for multiple testing (false discovery rate) was applied on the set of pairwise comparisons between CBCT systems. The linear regression model was used to compare the eight setups with resorption for root resorption and to compare all ten setups for agreement between the diagnosed severity of the resorption and the true severity. The agreement scores were calculated based on *Table 4.2*. Perfect agreement was given a score of 3, and the most serious disagreement was given a score of 0. Moreover, the linear regression model was also used for lesions of 0.6 mm or less to obtain a fair comparison with the Picasso CBCT systems. All of the analyses were performed with SAS software (version 9.2, SAS System for Windows, SAS Institute, Cary, NC).

Table 4.2: Scores quantifying the agreement between the diagnosed severity of root resorption and the true severity

Agreement scores	Resorption	Given score for severity of diagnosed lateral incisor resorption			
		No resorption	Slight resorption	Moderate resorption	Severe resorption
True status	No	3	2	1	0
	Slight	2	3	2	1
	Moderate	1	2	3	2
	Severe	0	1	2	3

Perfect agreement was scored as 3, and the most severe disagreement (no/severe) as 0.

Results

The image quality scores of pulp, dentin, and enamel; lamina dura; and overall image noise scored by 12 observers (first evaluation session) of each CBCT system are shown in *Fig 4.3, A*. The results of the second evaluation session of the image quality of dental structures by the two radiologists are shown in *Fig 4.3, B*. *Fig 4.4* shows the sum of the image quality scores for each CBCT system. The differences in the image quality scores between the CBCT systems were statistically significant (*P* <0.001) for all indexes including the sum of all quality scores *(Fig 4.4, A)*. ProMax images had the best quality, with significantly higher scores than the other systems (*P* <0.0001). The Galileos CBCT ranked as the second best system (*P* <0.01). Moreover, the differences in scores between the CBCT systems followed a similar pattern in the second evaluation by the two radiologists *(Fig4. 4, B)*.

The radiologists rated the image quality of the CBCT systems higher than did the orthodontic observers *(Table 4.3)*. The second evaluation session of the radiologists was rated higher than the first evaluation session, which indicates that freely using the software improved their ratings of the image quality *(Table 4.3, Fig 4.5)*.

The sensitivity and specificity for the root resorption results of the first and second evaluation sessions are reported in *Tables 4.4 and 4.5*. In the first evaluation session, the highest sensitivity was observed in the ProMax system: it was significantly higher than the sensitivity of the Galileos and Kodak systems (*P* <0.01). Moreover, a significant difference (*P* = 0.003) was found between Scanora and Kodak. The overall specificity of detecting root resorption (percentage of control images scored as no resorption) was not significantly different among the CBCT systems (*P* >0.05). It has been found that the lowest specificity was observed for the CBCT with the highest image quality (ProMax and Galileos). In the second evaluation session, sensitivity and specificity did not differ significantly between the CBCT systems.

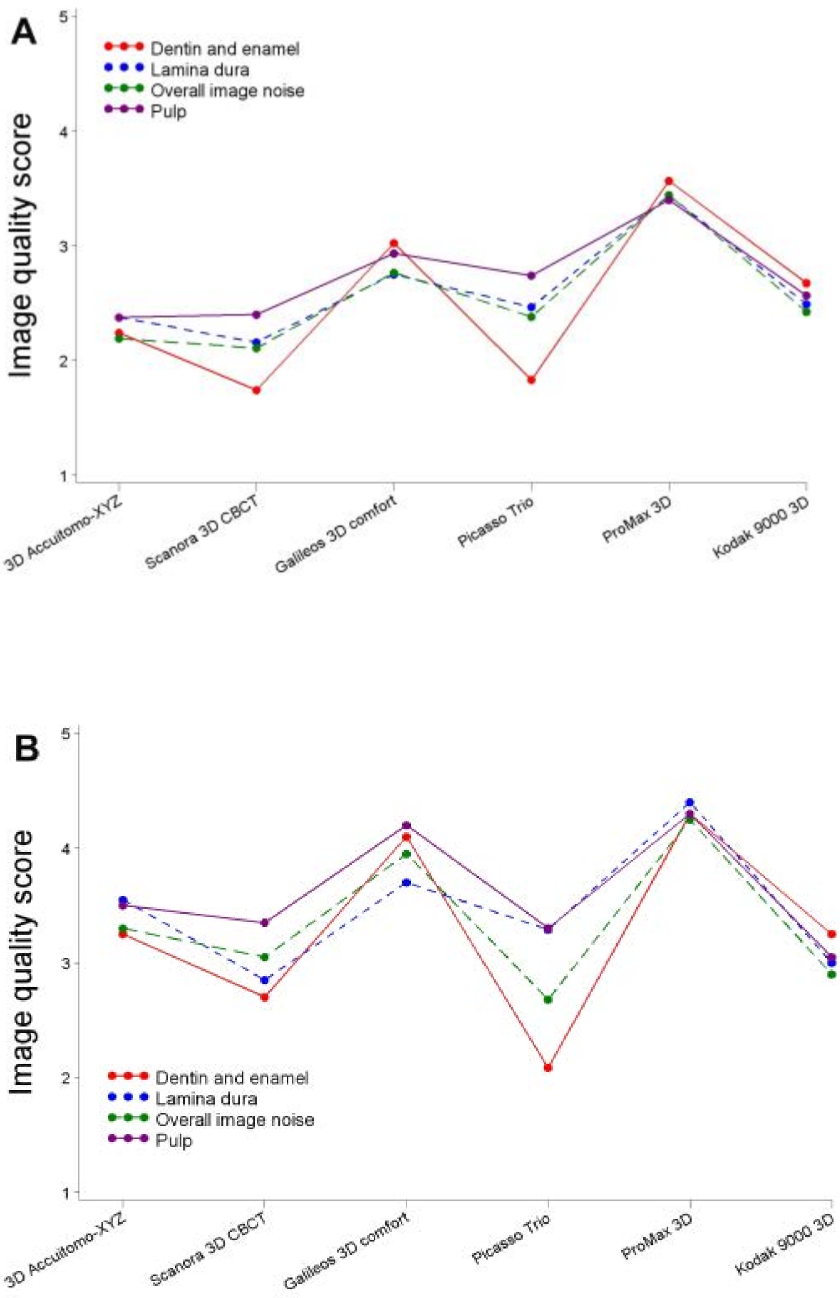


Fig 4.3: A. Image quality of dental structures scored by 12 observers based on images from the six CBCT systems (first evaluation session). B. Image quality of dental structures scored by two radiologists based on images from the six CBCT systems (second evaluation session).

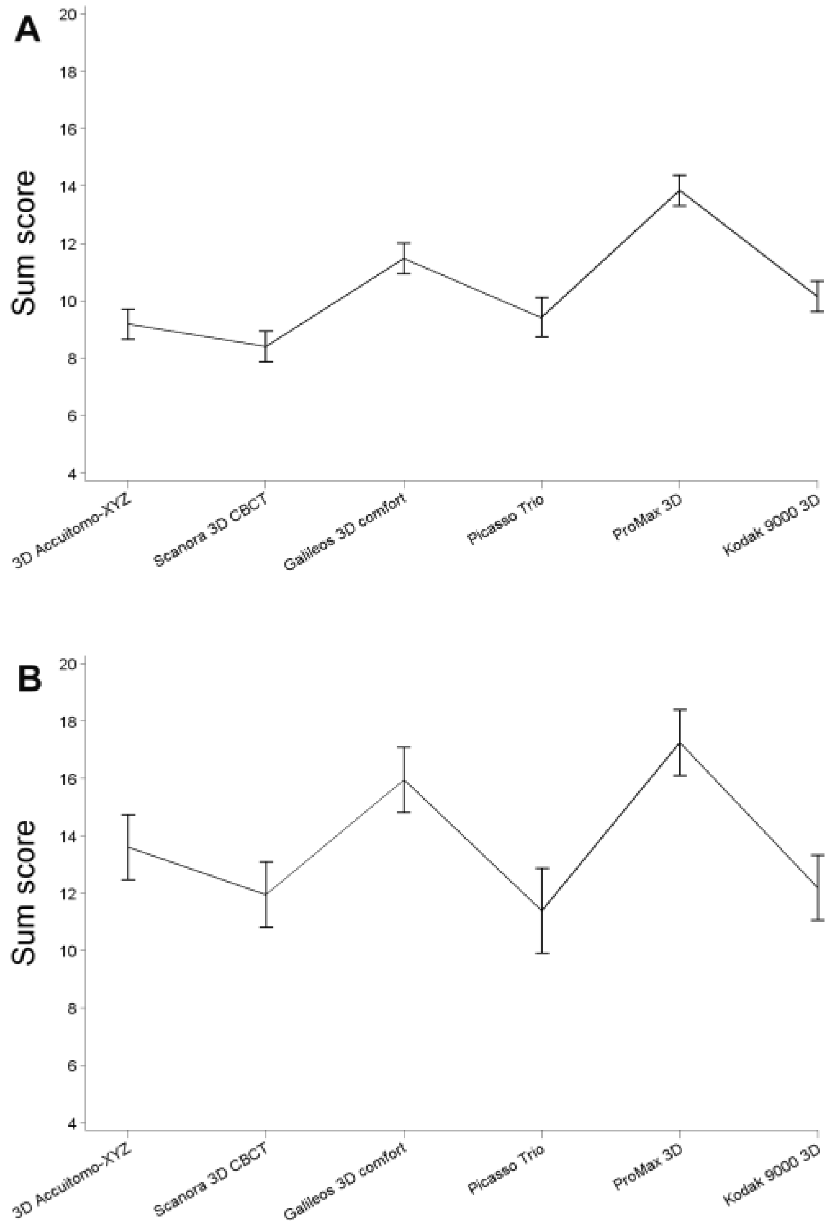


Fig 4.4: A. The sum of all of the image quality scores for anatomical structures of 6 CBCT systems scored by 12 observers (first evaluation session). B. The sum of all image quality scores for anatomical structures of 6 CBCT systems scored by two radiologists (second evaluation session). The vertical lines denote the 95% confidence intervals.

Table 4.3: Distribution (%) of the image quality scores from observers (eight postgraduate orthodontic residents, two orthodontic instructors and two dental radiologists)

	Scale	Orthodontic residents (n=8)	First evaluation Orthodontic instructors (n=2)	Radiologist (n=2)	Second evaluation Radiologist (n=2)
Pulp	Very Poor	13.17	3.57	0.89	0.00
	Poor	33.48	29.46	17.86	7.14
	Acceptable	37.50	40.18	47.32	34.82
	Good	14.29	25.89	27.68	44.64
	Excellent	1.56	0.89	6.25	13.39
Enamel and dentin	Very Poor	18.75	15.18	10.71	4.46
	Poor	34.15	33.93	29.46	10.71
	Acceptable	28.35	30.36	33.04	40.18
	Good	16.74	18.75	17.86	33.04
	Excellent	2.01	1.79	8.93	11.61
Lamina Dura	Very Poor	12.50	12.50	0.89	0.89
	Poor	38.17	37.50	34.82	16.07
	Acceptable	36.16	22.32	31.25	32.14
	Good	11.83	25.89	27.68	36.61
	Excellent	1.34	1.79	5.36	14.29
Overall structure	Very Poor	12.28	8.93	8.04	2.68
	Poor	38.62	37.50	38.39	15.18
	Acceptable	37.95	26.79	32.14	29.46
	Good	10.94	25.89	14.29	44.64
	Excellent	0.22	0.89	7.14	8.04

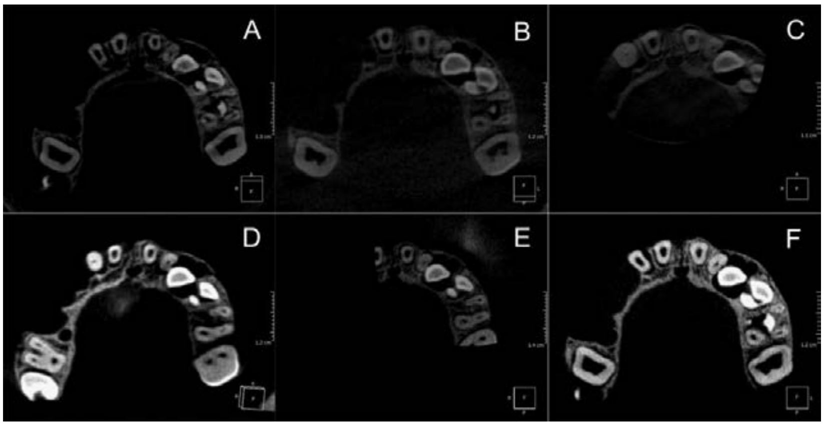


Fig 4.5: The axial slice sections showing the root resorption defect of 200 mm and the image quality ranked by score of the two radiologists (A. ProMax 3D, B. Galileos 3D comfort, C. 3D Accuitomo XYZ, D. Scanora 3D CBCT, E. Kodak 9000 3D, and F. Picasso Trio).

For the root resorption scores, significant differences were found in the first evaluation session between the CBCT systems (*P* = 0.0004), with a higher score for ProMax compared to Galileos (*P* = 0.0005) and Kodak (*P* = 0.005) *(Fig 4.6, A)*. In the second evaluation session, no significant difference was found between the CBCT systems *(Fig 4.6, B)*. slight, moderate, and severe for the lateral incisor, with the six-image systems being shown in *Table 4.6*. For the Pro- Max CBCT imaging, 72.17% of the lateral incisor root cavities (0.15, 0.20, and 0.30 mm) were correctly classified as slight resorption. ProMax CBCT had the highest score for slight resorption, followed by Accuitomo and Galileos.

Table 4.4: Sensitivity and specificity (%) for the CBCT systems by 12 observers (first evaluation session), with sensitivity based on the eight lateral incisors with simulated resorption cavities and specificity on two sound lateral incisors

CBCT system	Accuitomo	Galileos	Scanora	Kodak	Picasso	Promax
Sensitivity	93.75	87.50	95.83	86.46	85.42	98.96
Specificity	87.50	70.83	95.83	91.67	95.83	58.33

Table 4.5: Sensitivity and specificity (%) for the CBCT systems by the 2 radiologists (second evaluation session), with sensitivity based on the eight lateral incisors with simulated resorption cavities and specificity on two sound lateral incisors

CBCT system	Accuitomo	Galileos	Scanora	Kodak	Picasso	Promax
Sensitivity	100	87.50	100	93.75	100	100
Specificity	75	100	50	100	100	75

The distribution of the scores quantifying the agreement between the diagnosed severity of the resorption and the true severity for each CBCT system is shown in *Table 4.7*. The differences in the agreement were not significant (*P* >0.05) among the CBCT systems *(Fig 4.7)*. In addition, the results of the presence and the agreement between the diagnosed severity of the root resorption had a similar pattern after the exclusion of images with lesions less than 0.6 mm among the CBCT systems.

Table 4.6: Percentages of lateral incisor resorption correctly classified by the 12 observers

CBCT system	Degree of lateral incisor root resorption			
	No resorption None	Slight resorption 0.15, 0.20, 0.30 mm	Moderate resorption 0.60, 1.00 mm	Severe resorption 1.5, 2.00 ,3.00 mm
Accuitomo	79.17	66.67	50.00	83.33
Galileos	62.50	66.67	41.67	94.44
Scanora	87.50	61.11	37.50	94.44
Kodak	79.17	58.33	33.33	100
Picasso	75.00	63.89	66.67	0
Promax	58.33	72.22	41.67	100

Discussion

The 3D imaging has long been readily available for accurate, easily interpreted representations of root resorption. In previous studies, CBCT has been used to evaluate the severity of resorptive lesions and found to be a reliable tool in diagnosis and treatment planning.[113, 114] Even with the advantages of CBCT over the conventional methods, the challenges of detecting root resorption are due to the difficulty of distinguishing between mild root resorption and image artifacts. Previous studies comparing the subjective image quality of CBCT systems with conventional CT showed that the diagnostic image quality of CBCT is similar to or even better than that of CT.[90, 95] The diagnostic performance of CBCT might depend very much on the parameter settings as well as on the machines used. It was difficult to standardize the parameters of these six CBCT systems because

Table 4.7: Distribution (%) of quantifying the agreement scores between the diagnosed severity of the resorption and the true severity for the CBCT systems

CBCT system	Agreement between resorption and severity (%)			
	0	1	2	3
Accuitomo	0.00	2.50	26.67	70.83
Galileos	0.83	1.67	28.33	69.17
Scanora	0.00	3.33	25.00	71.67
Kodak	0.00	1.67	28.33	70.00
Picasso	0.00	2.78	29.17	68.06
Promax	0.00	1.67	26.67	71.67

P > .05 for the comparison of the distribution between the 6 CBCT systems. (3 is perfect agreement and 0 most severe disagreement).

each has its own parameters and settings. The CBCT settings in this study were chosen according to each manufacturer's protocol.

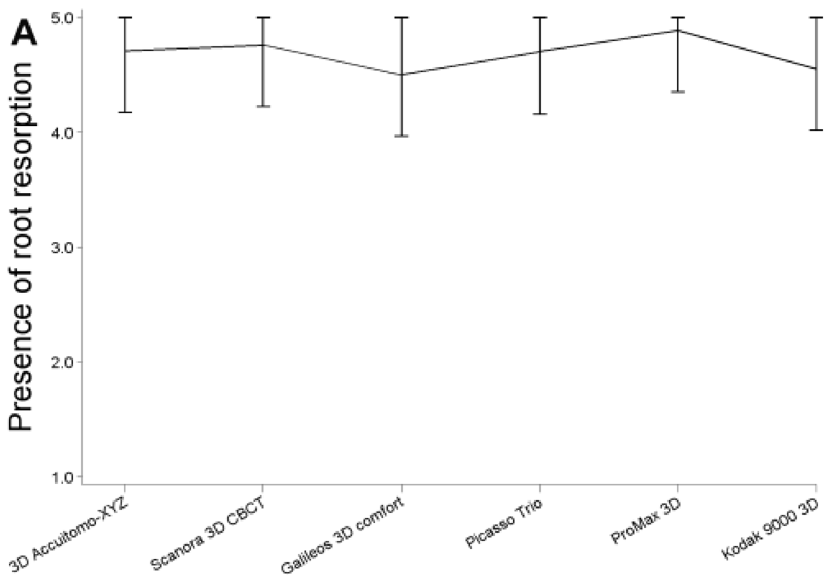
CBCT systems were found to vary in image quality and visualization of anatomic structures.[83, 95] This agrees with our results. ProMax was the best system with regard to image quality, followed by Galileos. The 3D Accuitomo that was used in this study had an image intensifier with a charge-coupled device sensor having an 8-bit gray scale. A new model, 3D Accuitomo 80, was developed with a flat panel detector and a 13-bit gray scale that might give higher scores for contrast and image quality.

By using five scores for detection of root resorption (rather than yes or no), a better range might have been obtained. However, the overall results show high accuracy for root resorption detection in all of the CBCT systems. The overall sensitivity of CBCT systems was also high for detecting root resorption. The high sensitivity of the CBCT systems is evidently the result of higher inherent contrast in CBCT images and the 3D view. However, there were significant differences in the determination of root resorption and sensitivity between ProMax and Galileos and between ProMax and Kodak. The overall specificity was also high for all of the CBCT systems, except for the ProMax and Galileos, which had the highest image quality.

With respect to the agreement between the diagnosed severity of the resorption and the true severity, no significant difference was found among the CBCT systems tested. This means that there is no evidence for a difference among the systems regarding the precision of determining root resorption. The perfect agreement of the diagnosed severity of the resorption and the true severity of the cavities was high for all of the CBCT radiographic methods. The size and location of root resorption were reported to have a role in the accuracy of detection.[40, 121] However, in this study, these factors did not affect the accuracy of detection of root resorption. The differences in parameters and clinical usage of the CBCT systems tested were all relevant to orthodontics practice. The results show that all of the tested CBCT systems can be used to detect root resorption.

Scanning with Picasso CBCT was limited to lesions of 0.6 mm or less because of the access and time limitations related to its use. The images of lesions greater than 0.6 mm (1.00, 1.50, 2.00, and 3.00 mm) were considered to provide missing values. To evaluate whether including only 6 Picasso CBCT images would give a fair statistical comparison, a second analysis was based only on the images of the lesions of 0.6 mm or less. The results were similar for both analyses.

The radiologists evaluated the root resorption in 2 sessions: a screen-shot session and a software-and-scroll session. The performance of the radiologists in the second evaluation session was similar to that of all of the 12 observers. However, the radiologists' evaluations of image quality and detection of root resorption scored higher than did the orthodontic instructors and the postgraduate residents because the radiologists had more experience and were more familiar with such images. These results were similar to those of a previous in-vitro study *(Chapter 3)* that found no significant differences between CBCT systems in the detection of root resorption.[6] Our findings demonstrate that the CBCT images tested in this study had high accuracy in the detection of root resorption. All of the CBCT systems used in this study had high accuracy. Artifacts in CBCT images might affect the diagnosis of root resorption, which is why high spatial resolution and minimal artifacts are important for the diagnosis of root resorption.



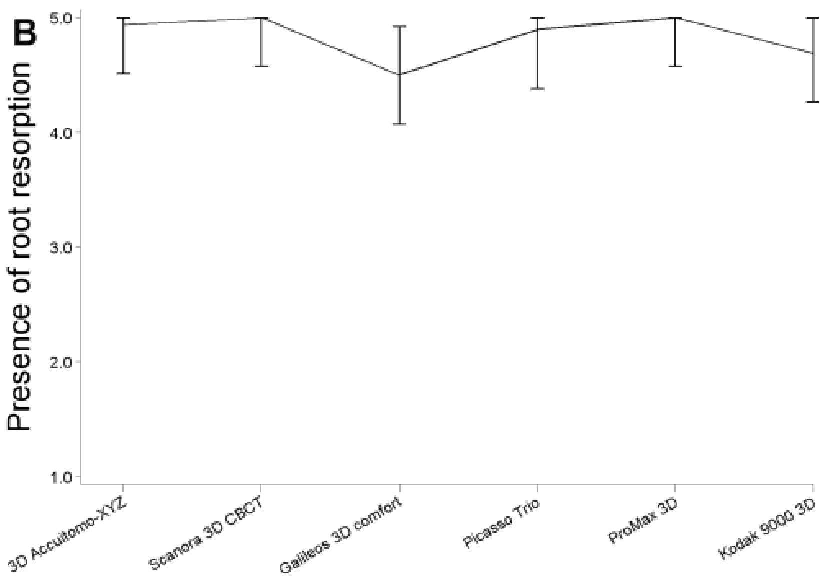


Fig 4.6: The difference between the 6 CBCT systems for of root resorption A. first evaluation session B. second evaluation session. Vertical lines denote the 95% confidence intervals.

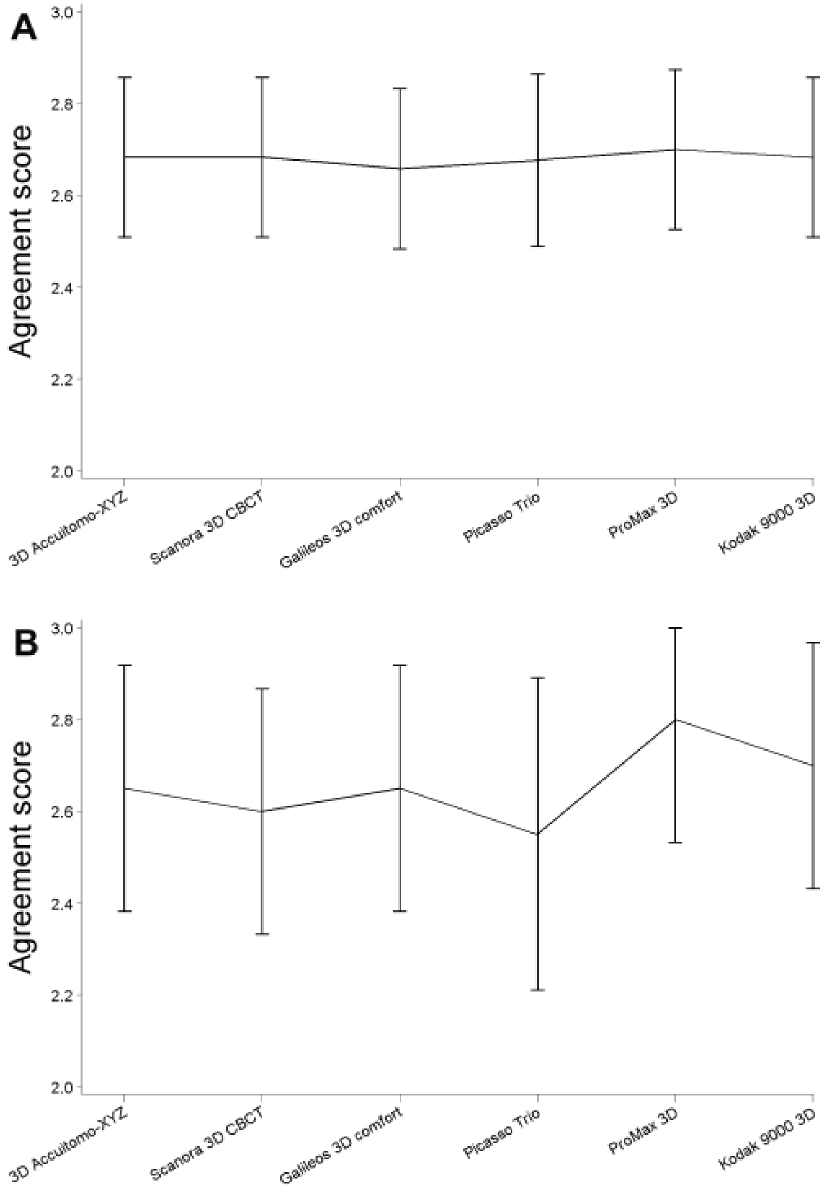


***Fig 4.7: The difference between the 6 CBCT systems of the diagnosed severity of the resorption and the true severity. A. the first evaluation session B. the second evaluation session.** Vertical lines denote the 95% confidence intervals.*

Conclusions

The results of this study show that the CBCT systems tested provide variable image quality. This might have surely affected the detectability and diagnostic accuracy of root resorption lesions. All of the CBCT systems in this study showed high accuracy in the detection of root resorption. There were no significant differences between the CBCT systems in the detection of the severity of root resorption.

Chapter 5

A comparison of the radiographic diagnostic accuracy of the conventional 2D radiographs versus CBCT for canine localization and detection of root resorption in vivo

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Comparison of two cone beam computed tomographic systems versus panoramic imaging for localization of impacted maxillary canines and detection of root resorption.

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Abstract

The diagnostic accuracy for the localization of impacted canines and the detection of canine-induced root resorption of maxillary incisors were compared between conventional radiographic procedures using one two-dimensional (2D) panoramic radiograph with those of two three-dimensional (3D) cone beam computed tomography (CBCT) scans. The clinical records of 60 consecutive patients who had impacted or ectopically erupting maxillary canines were identified from those seeking orthodontic treatment. For each case, two sets of radiographic information were obtained. The study sample was divided into two groups: Group A (n = 30) included those for whom a dental panoramic radiographs and CBCT obtained with a 3D Accuitomo-XYZ Slice View Tomograph® were available and Group B (n = 30) who had a panoramic and CBCT obtained with a Scanora.® The panoramic and CBCT images were subsequently analyzed by 11 examiners. The statistical analysis included an evaluation of the agreement between observers based on the standard error of the measurement, kappa statistics and coefficient of concordance, as well as an assessment of the differences between the 2D and the 3D imaging employing Wilcoxon signed rank and McNemar tests. There was a highly significant difference between the 2D and 3D images in the width of the canine crown (P <0.001) and in canine angulation to the occlusal plane. Moreover, there was a highly significant difference between the panoramic and Scanora CBCT images in canine angulation to the midline (P <0.001). There was also a significant difference between 2D and 3D images with respect to canine location (P = 0.0074 for Group A and P = 0.0008 for Group B). The presence or absence of root resorption of the lateral incisor was also significantly different in both groups (P = 0.0201 and P <0.001 for groups A and B, respectively). The detection of central incisor root resorption was significantly different between the Accuitomo and the panoramic images (P = 0.045). There was

also a significant difference in the severity of lateral incisor root resorption between the panoramic and CBCT in both groups ($P = 0.02$). The results of this study suggest that CBCT is more sensitive than conventional radiography for both canine localization and identification of root resorption of adjacent teeth.

Introduction

Many questions regarding both the panoramic imaging and CBCT need to be addressed. There has been no direct comparison hitherto of panoramic imaging and CBCT, and no data are available on whether 3D imaging provides significantly more information than the traditional radiographs for the diagnosis of root resorption and localization of impacted canines. Therefore, the purpose of this retrospective study was to compare the radiographic diagnostic accuracy of CBCT with that of panoramic radiography for the localization of impacted maxillary canines and incisor root resorption lesions.

Materials and methods

The clinical records of 60 consecutive patients who had impacted or ectopically erupting maxillary canines were identified from those seeking orthodontic treatment at the Division of Orthodontics, KULeuven. A total of 89 impacted maxillary canines were studied. The patients were 37 females and 23 males, with ages ranging from 6.3 to 28.9 years [mean: 13.2, median: 12.2, standard deviation (SD): 4.2].

For the purposes of this study, two groups were formed. For each subject, two sets of radiographic information had been obtained within a maximum interval of two weeks. The first set consisted of traditional panoramic radiographs and the second set of 3D volumetric images obtained from a CBCT scan. Group A ($n = 30$) consisted of those patients who had a panoramic images and CBCT obtained with a 3D Accuitomo-XYZ Slice View Tomograph® (J. Morita, Kyoto, Japan) and Group B (*n* = 30) who had a panoramic image and CBCT obtained with a Scanora 3D CBCT (Soredex, Tuusula, Finland).

The panoramic and CBCT images were acquired as described in Chapter 3 above**.** The images were viewed and measured using the OnDemand 3D®™ application, Version 1.0 software (CyberMed Inc., Seoul, South Korea). All of the exposures were made by the same technical operator.

Panoramic and CBCT images were produced and subsequently analyzed by two groups of examiners. The first group consisted of three experienced dental practitioners and the second group of eight postgraduates with a mean age of 27 years. The standardized protocol was explained to the observers. All of the observers received instructions and a demonstration before the data acquisition so that standardized evaluation could be maintained. There was no significant difference with respect to experience using the CBCT viewer between the various observers.

Radiographic evaluation of images

One hundred and twenty sets of images were reviewed and analyzed by each investigator in random order. The observers examined 60 panoramic images and 30 images of each type of CBCT. They were instructed to manipulate the images with the software enhancement tools according to their own preference.

The evaluation process involved two questionnaires. The first group of observers recorded the following variables:

1. The width of the permanent maxillary canine crown in millimeters measured from the mesial contour of the maxillary canine to the distal contour.

2. The width of the permanent maxillary canine follicle in millimeters defined as the largest distance from the cusp tip of the canine to the periphery of the follicle with the long axis.
3. The development of the permanent maxillary canine was assigned to four categories based on root development: complete development; two-thirds of the root developed; one-half of the root developed; and one-quarter of the root developed.
4. The permanent maxillary canine angulations. Three angles were measured for the localization of an impacted canine as follows: A) Canine angulation to the lateral incisor: The angles were measured between the two lines formed by a line through the canine cusp and the apex bisecting the long axis of the impacted canine and a line through the apex of the lateral incisor and the mid crown bisecting the long axis of the lateral incisor *(Figs 5.1 and 5.2)*.[47, 50] B) Canine angulation to the midline: The angles measured were formed by a line bisecting the midline of the jaws and a line through the canine cusp and the apex bisecting the long axis of the impacted canine *(Figs 5.1 and 5.2)*. C) Canine Angulation to the occlusal plane: The angles measured were formed by a line through the canine cusp and the apex

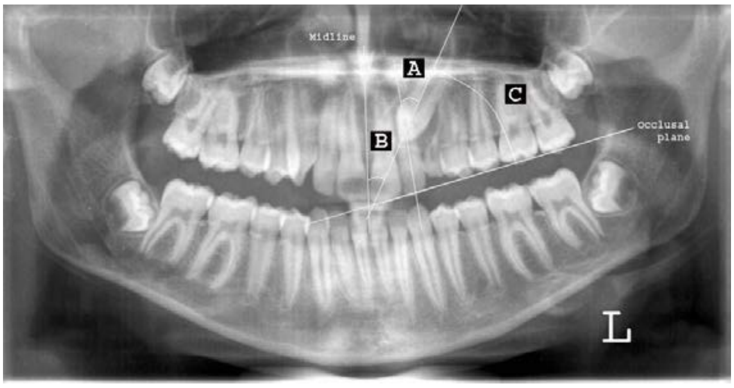

Fig 5.1: Panoramic view illustrating reference lines and angular measurements. A. Angle of impacted canine to the lateral incisor, B. angle of impacted canine to midline, and C. angle of impacted canine to occlusal plane.

bisecting the long axis of the impacted canine and the occlusal plane *(Figs. 5.1 and 5.2)*.[47, 50, 93, 147]

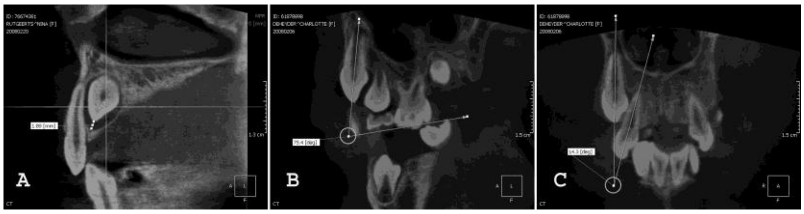

Fig 5.2: Cone beam computed tomographic (CBCT) views from the Scanora® three-dimensional CBCT system illustrating A. canine follicle width in millimeteres, B. angle of impacted canine to occlusal plane, and C. the angle of impacted canine to the lateral incisor.

5. Primary maxillary canines were assigned to one of four categories as suggested by Ericson *et al.*[44]: A) missing, where the primary canine had been extracted; B) no resorption of the primary maxillary canines; C) resorbed root, without contact between the follicle of the permanent and primary canines; and (d) resorbed root, with contact between the follicle of the permanent and primary canines.

6. Permanent maxillary canine location in relation to adjacent teeth palatally, buccally, or in the line of the arch.

7. Contact relationship between the canines and incisors. The contact relationship between permanent maxillary canines and incisors was assigned to one of two categories:[44] A) contact: the distance between the crown of the permanent maxillary canines and adjacent incisors less than 1 mm and B) no contact: the distance between the crown of the permanent maxillary canines and adjacent incisors more than 1 mm.

8. Severity of root resorption. The examiners were asked to determine whether they could detect a resorption defect in the lateral incisor. If resorption was diagnosed, the severity of resorption was rated based on the grading systems suggested by Ericson *et al.*:[44]A) no resorption: intact root

surfaces; B) slight resorption: resorption extending up to half of the dentine thickness to the pulp; C) moderate resorption: resorption midway to the pulp or more with the pulp lining being intact; and D) severe resorption: the pulp is exposed by the resorption.

9. Location of resorption. The location of the diagnosed resorption defect was also recorded as in the apical, middle, or cervical third.

The second group of observers completed a questionnaire related only to variables 5–9.

Statistical analysis

Agreement between observers.

For measurements of width and angulations, the agreement between the three observers was quantified using the standard error of measurement (SEM), which is the standard deviation (SD) of the measurements within a patient. A SEM equal to 0.5 implies that, for a specific patient, 95% of the obtained values (from various observers) are expected to fall in a range of ±1.96 × 0.5 around the true value. The SD of the difference between two values obtained from two observers is as follows:

$$SD(y_{ij} - y_{ik}) = \sqrt{0.5^2 + 0.5^2} = 0.707$$

Within-patient variability can also be expressed as a unitless measure:

1. Expressing the SEM relative to the mean of the measurements, which is known as within-subject coefficient of variation (WSCV).
2. Taking the ratio of the total variance minus the squared SEM over the total variance. This ratio is known as the intraclass correlation (ICC).

For the nominal and ordinal scorings, proportions of raw agreement (overall and specific to each category level) were also evaluated. A kappa coefficient for multiple raters was also quantified to assess inter-observer agreement. Kappas are constructed for overall agreement using the SASmacro percentage mkappa (version 9.2, SAS Institute Inc., Cary, North Carolina, USA). For the ordinal scores, Kendall's coefficient of concordance is reported.

Assessment of the differences between 2D and 3D imaging.

All of the measurements on panoramic radiographs were divided by the magnification factor of 1:3. The measurements of the width and angulation were compared between the 2D and 3D images using a non-parametric Wilcoxon signed rank test on the mean measurement of the three observers. Since this test treats bilateral and unilateral cases equally, the robustness of the conclusion was verified using a linear mixed model. For categorical responses, tests of symmetry were used for each observer separately to explore differences. Furthermore, instead of performing observer-specific analyses, the modus (over the observers) of the scores was used to compare the 2D and 3D images. All comparisons between the 2D and 3D images were undertaken separately on the set of patients' data. *P* values less than 0.05 were considered significant.

Results

The distribution of the number of impacted canines diagnosed in the 60 patients is given in *Table 5.1*. The mean values for the linear and angular measurements, the SEM, and ICC are shown in *Table 5.2*. *Table 5.3* displays the percentages of the total number of a reproducibility of agreement for all diagnostic variables for each patient in Groups A and B (Accuitomo CBCT versus panoramic and Scanora CBCT versus panoramic, respectively).

The root resorptions detected in the lateral and central incisors are shown in *Table 5.4*. Compared with panoramic radiography, lateral incisor root resorption cavities were more distinguishable using CBCT *(Table 5.4)*.

Table 5.1: Distribution of the 89 impacted maxillary canines and percentage (%) for group A: patients who had a panoramic radiograph and cone beam computed tomographic (CBCT) obtained with Accuitomo; group B: patients who had panoramic radiographs and cone beam computed tomographic (CBCT) obtained with Scanora

	Male	Female	Bilateral	Unilateral	Right	Left
Group A	12 40%	18 60%	9 30%	21 70%	17 44%	22 56%
Group B	11 37%	19 63%	20 67%	10 33%	25 50%	25 50%

Table 5.2: Agreement between the three experienced observers for linear measurements of width in millimeters and angulations for the three different imaging systems: Panoramic, Accuitomo 3D CBCT and Scanora 3D CBCT

Measurement	*Set*	*Mean*	*Between-unit Standard Deviation (SD)*	*Within-unit SD (=SEM)*	*Intraclass correlation*	*Within-unit coefficient of Variation (%)*
Width of canine dental follicle	Accuitomo	0.83	0.76	0.35	0.83	41.8
	Scanora	0.99	0.65	0.48	0.65	47.7
	Panoramic	1.03	0.48	0.62	0.37	60.2
Width of canine crown	Accuitomo	7.96	0.61	0.41	0.69	5.1
	Scanora	7.92	0.36	0.55	0.30	6.9
	Panoramic	8.78	1.20	0.61	0.79	6.9
Canine angle to lateral incisor	Accuitomo	30.30	17.93	5.61	0.91	18.5
	Scanora	31.58	14.40	4.75	0.90	15.0
	Panoramic	33.28	18.19	3.33	0.96	10.0
Canine angle to midline	Accuitomo	25.45	13.88	7.57	0.77	29.7
	Scanora	14.52	12.33	3.76	0.91	25.9
	Panoramic	24.07	17.05	3.72	0.95	15.4
Canine angle to occlusal plane	Accuitomo	63.09	12.27	9.68	0.62	15.3
	Scanora	62.43	9.04	4.94	0.77	7.9
	Panoramic	55.80	18.11	4.69	0.94	8.4

All measurements in mm of the panoramic radiographs are divided by the magnification factor of 1.3.

Table 5.3: Overall agreement level for each variable in terms of percentage each patient group

		Group A		*Group B*	
		Accuitomo (%)	*Panoramic (%)*	*Scanora (%)*	*Panoramic (%)*
Canine development	Complete	50.4	58.9	44.7	36.7
	2/3 of the root	5.1	11.1	6.6	15.3
	1/2 of the root	35.0	27.4	48.7	48.0
	1/4 of the root	9.5	2.6	0	0
Primary Canine	No resorption	11.4	18.2	39.2	35.9
	Resorption without contact	56.0	47.9	19.6	32.6
	Resorption with contact	32.6	33.9	41.2	31.5
Canine Location	Line of the arch	22.1	35.7	21.8	36.7
	Palatally	39.2	45	34.0	42.7
	Bucally	38.7	19.3	44.2	20.6
Contact with the lateral incisor	Contact	89.0	73.9	92.5	84.0
	No contact	11.0	26.1	7.5	16.0
Severity of resorption of the lateral incisor	No resorption	46.1	70.6	49.1	69.3
	Slight	35.9	18.0	39.8	19.1
	Moderate	9.9	6.0	5.1	4.3
	Severe	8.1	5.4	6.0	7.3
Location of resorption of the lateral incisor	Apical	26.6	14.2	21.5	15.1
	Middle	19.6	13.3	28.0	14.2
	Cervical	7.8	2.1	1.3	1.1
Contact with the central incisor	Contact	23.8	31.7	16.0	19.5
	No contact	76.2	68.3	84.0	80.5
Severity of resorption of the central incisor	No resorption	84.9	87.0	95.1	94.5
	Slight	7.9	5.1	4.7	3.8
	Moderate	1.4	2.1	0.2	0.5
	Severe	5.8	5.8	0	1.2
Location of resorption of the central incisor	Apical	8.7	6.1	3.1	2.7
	Middle	6.7	6.8	1.3	2.7
	Cervical	0.5	0	0.4	0

Greater agreement between observers for all of the variables was achieved when using CBCT. The results show that the proportion of agreement was high for the assessment of CBCT images *(Table 5.5)*. For the presence of lateral incisor root resorption, Kendall's coefficient of concordance for an ordinal response was 0.48 for the Accuitomo and Scanora images and 0.41 for the panoramic images. The value for central

Table 5.4: Overall agreement level of the detection of root resorption of the maxillary incisors in terms of percentage for each patient group

		Group A		*Group B*	
		Accuitomo (%)	*Panoramic (%)*	*Scanora (%)*	*Panoramic (%)*
Lateral incisor	No resorption	46.1	70.6	49.1	69.3
	Resorption	53.9	29.4	50.9	30.7
Central incisor	No resorption	84.9	86.9	95.1	94.5
	Resorption	15.1	13.1	4.9	5.5

incisor root resorption was 0.72 for Accuitomo, 0.43 for Scanora, and 0.34 for panoramic images. The comparison of linear measurements and angulations between 2D and 3D are shown in *Table 5.6*.

Based on the analysis using the protocol (over the observers) for the categorical outcomes, there was only evidence for a difference between 2D and 3D imaging with respect to canine location; $P = 0.0074$ for Group A and $P = 0.0008$ for Group B. The detection of the presence or absence of root resorption of the lateral incisor was also significantly different in both groups ($P = 0.0201$ and $P < 0.001$, respectively). The detection of the presence of central incisor root resorption was significantly different between the Accuitomo and panoramic images in group A ($P = 0.045$). There was also a significant difference in the severity of lateral incisor root resorption between the panoramic and CBCT in both groups ($P = 0.02$).

Discussion

In the present study, patients with slight or non-resorbed lateral incisors were randomly selected. There were more females than males in the study, which is consistent with other reports.[46, 53] The incidence of palatally impacted canines appears to be twice that in females than in males.[20] On the other hand, this could also be due to more females than males seeking orthodontic treatment.[87]

Several authors have suggested that the linear measurement is a reliable method for panoramic radiographs, considering the magnification factors and correct patient position.[86, 138, 146] The patient position during panoramic image acquisition was considered but the findings showed that it did not influence the results of this study, since all of the images were

Table 5.5: Reproducibility level of the proportion of agreement and Kappa coefficient of inter-observer agreement between 11 observers for scoring each variable for the three different image systems: Panoramic, Accuitomo 3D CBCT and Scanora 3D CBCT

		Accuitomo	Scanora	Panoramic
Canine development	Proportion of agreement	0.84	0.81	0.71
	Kappa	0.74	0.66	0.53
	Standard error	0.06	0.06	0.04
Primary Canine	Proportion of agreement	0.80	0.65	0.54
	Kappa	0.65	0.44	0.32
	Standard error	0.03	0.02	0.01
Canine Location	Proportion of agreement	0.79	0.76	0.56
	Kappa	0.68	0.63	0.31
	Standard error	0.01	0.01	0.01
Contact to lateral incisor	Proportion of agreement	0.86	0.92	0.73
	Kappa	0.31	0.42	0.18
	Standard error	0.02	0.01	0.01
Detection of root resorption of lateral incisor	Proportion of agreement	0.65	0.63	0.48
	Kappa	0.24	0.26	0.26
	Standard error	0.02	0.01	0.01
Location of resorption of lateral incisor	Proportion of agreement	0.53	0.53	0.65
	Kappa	0.30	0.26	0.26
	Standard error	0.01	0.01	0.01
Contact to central incisor	Proportion of agreement	0.88	0.90	0.86
	Kappa	0.67	0.64	0.64
	Standard error	0.02	0.01	0.01
Detection of root resorption of central incisor	Proportion of agreement	0.90	0.94	0.87
	Kappa	0.63	0.36	0.23
	Standard error	0.02	0.01	0.01
Location of resorption of central incisor	Proportion of agreement	0.88	0.93	0.86
	Kappa	0.57	0.30	0.17
	Standard error	0.01	0.01	0.01

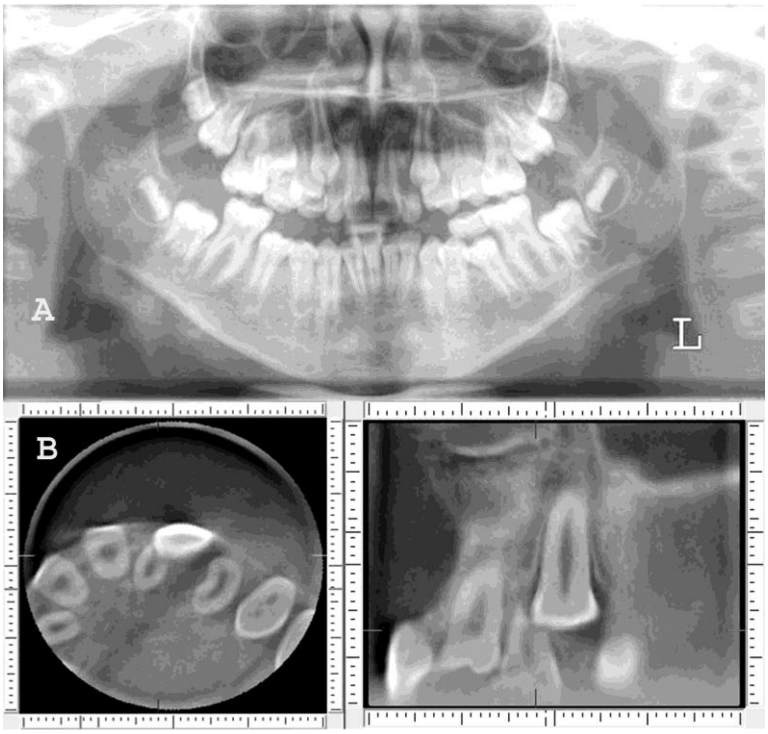

Fig 5.3: A. Two-dimensional panoramic radiograph of an 11-year-old female with bilateral impacted maxillary canines with no sign of resorption of the left maxillary lateral incisor. The root contour of the lateral incisor overlaps that of the canine and is difficult to assess. B. Three-dimensional (3D) cone beam computed tomographic image from the Accuitomo 3D system showing axial and coronal views of the left maxillary lateral incisor with severe root resorption of the cervical third.

acquired by one operator, and a standardized patient position was maintained. The magnification factor was also considered by dividing all panoramic radiograph measurements by the magnification factor of 1.3. Compared with the CBCT images, the panoramic radiographs were less reliable and resulted in lower measurement accuracy and less agreement between the observers. This may have been because of inadequate diagnosis of the surrounding anatomical structures and because panoramic radiographs lack the third dimension. Deformations on panoramic images are not seen on 3D CBCT. However, CBCT images were less influenced by patient position and free from the influence of the pattern of superimposition of the anatomical structures, which may have a significant influence on the measurement. Moreover, CBCT reconstruction allows greater accuracy and reliability for linear measurements with improved visualization of the anatomical situation of the impacted maxillary canine.[85] However, the results of the current study show that the linear measurement of the two imaging modalities was statistically different in the width of the canine crowns. This may occur because every system has various sources of display and measurement error. In panoramic images, structures closer to the X-ray source appear more magnified than those closer to the detector, such as palatally impacted canines. The canine angle to the midline was statistically different between the Scanora and the panoramic images but not between the Accuitomo and panoramic radiograph. This could be a result of the small field of view of the Accuitomo system (30 × 40 mm). Re-slicing of the image at a plane vertical to the area of interest may prevent, in some cases, accurate determination of the midline. In agreement with Peck *et al.*[117], it was found that the accuracy in the determination of linear root angulations between the panoramic and CBCT was not a reliable tool, particularly in the canine region. This is in agreement with a recent study that found panoramic images were not a reliable method for the localization of impacted canines.[106]

Table 5.6: Differences between linear measurement of width and angulations between the Accuitomo three-dimensional (3D) cone beam computed tomographic (CBCT) images and panoramic images and between the Scanora 3D (CBCT) images and panoramic images using the Wilcoxon signed rank test on the mean measurement of the three observers

Measurement	*set*	*Difference*	*SD*	*P-wilcoxon*	*P-value*
Width of the canine dental follicle	Accuitomo versus Panoramic	-0.20	0.96	0.19631	0.1184
	Scanora versus panoramic	-0.03	0.75	0.93964	0.7573
Width of the canine crown	Accuitomo versus Panoramic	-0.71	0.96	0.00003	<0.0001
	Scanora versus panoramic	-0.94	1.44	0.00001	<0.0001
Canine angle to the lateral incisor	Accuitomo versus Panoramic	-2.52	10.60	0.38624	0.1412
	Scanora versus panoramic	-2.06	8.21	0.06531	0.0795
Canine angle to the midline	Accuitomo versus Panoramic	-1.41	11.32	0.51005	0.4341
	Scanora versus panoramic	-7.38	8.60	9.22890	<0.0001
Canine angle to the occlusal plane	Accuitomo versus Panoramic	7.61	17.79	0.00213	0.0101
	Scanora versus panoramic	6.39	13.01	0.00310	0.0010

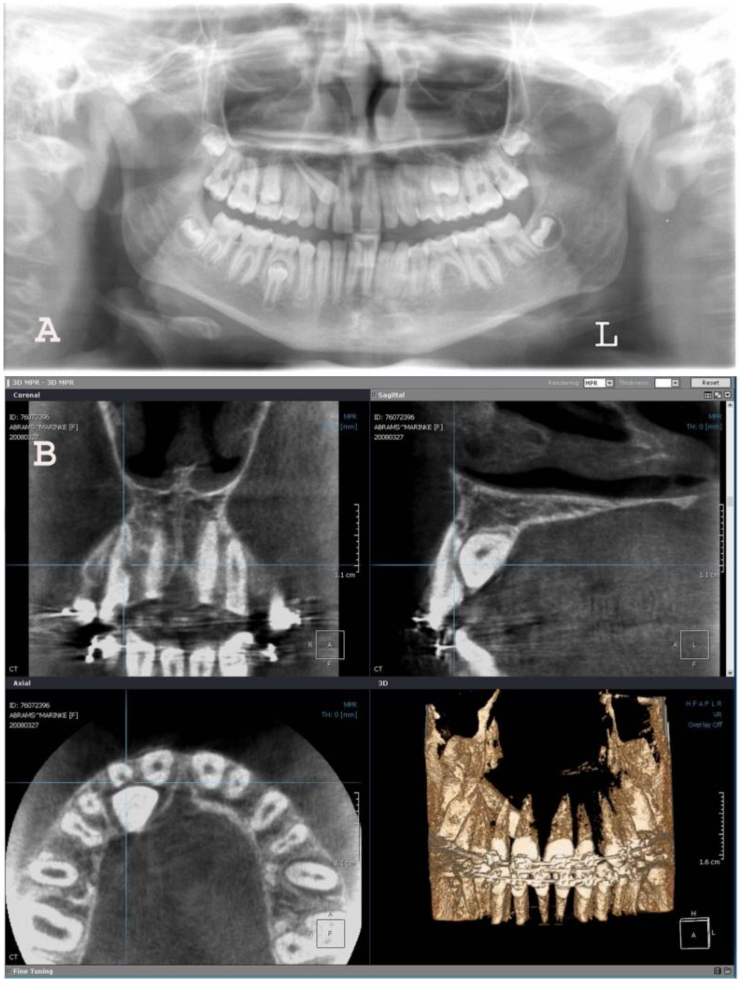

Fig 5.4: A. Two-dimensional panoramic radiograph of a 16-year-old male with an impacted maxillary right canine with no sign of resorption of the right maxillary lateral incisor. The root contour of the lateral incisor overlaps with that of the canine and is difficult to assess. B. Three-dimensional 3D CBCT image from the Scanora® 3D system showing axial, sagittal, and coronal slices as well as a 3D model that were used to identify the impacted maxillary right canine and severe root resorption of the middle third of the right maxillary lateral incisor.

Conclusion

Early radiographic examination and diagnosis are essential to recognize impacted canines. The sequela of delayed eruption or treatment of impacted canines may be severe resorption of the adjacent lateral and central incisors. CBCT may be a reliable method for detecting canine impaction and root resorption of adjacent teeth. A CBCT image establishes the link between 2D and 3D imaging and is more accurate for the different diagnostic tasks in canine impaction than panoramic radiography. Using CBCT with the maximum data available would help reduce radiation exposure. The use of CBCTs rather than panoramic imaging for the assessment of impacted canines has a potential diagnostic effect and may influence the outcome of treatment. Such a technique of free overlap may improve the interpretation of treatment outcome and treatment progress.

Chapter 6

The effect of using 2D versus 3D radiographs on the surgical treatment planning of impacted maxillary canine cases

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Pre-Surgical Treatment Planning of Maxillary canine Impactions using Panoramic versus 3D imaging

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Abstract

This prospective study compares the impact of using two dimensional (2D) panoramic radiographs and three-dimensional (3D) cone beam CT for the surgical treatment planning of impacted maxillary canines. This study consisted of 32 subjects (19 females, 13 males) with a mean age of 25 years, referred for surgical intervention of 39 maxillary impacted canines. Initial 2D panoramic radiography was available, and 3D cone beam CT imaging was obtained upon clinical indication. Both 2D and 3D pre-operative radiographic diagnostic sets were subsequently analyzed by six observers. Perioperative evaluations were conducted by the treating surgeon. McNemar tests, hierarchical logistic regression and linear mixed models were used to explore the differences in evaluations between imaging modalities. Significantly higher confidence levels were observed for 3D image-based treatment plans than for 2D image-based plans ($P < 0.001$). The evaluations of canine crown position, contact relationship and lateral incisor root resorption were significantly different between the 2D and 3D images. In contrast, pre- and perioperative evaluations were not significantly different between the two image modalities. Surgical treatment planning of impacted maxillary canines was not significantly different between panoramic and cone beam CT images.

Introduction

With delayed eruption of maxillary canines, the radiological examination serves to determine the position and spatial context. Using this evaluation, clinicians can assess the chance of a normal eruption or create an adequate therapeutic plan. In the absence of early diagnosis and prevention, the impacted canine usually requires a combination of multidisciplinary interventions to bring it into occlusion. Several methods have been used for the treatment of impacted canines, including interceptive treatment by extracting the primary canine alone,[49] surgical exposure with or without attachment,[69] autotransplantation[115] and canine extraction.

Previous studies of treatment planning were conducted on the basis of 2D radiographic procedures. Radiographic factors and treatment methods have been correlated with the duration of treatment by several authors.[55, 69, 135, 154] However, predicting the treatment duration associated with impacted canines is difficult.[55] The angulations and position of the canines in the dental arch, the overlap between the lateral incisor and canine, and the presence of root anomalies have all been proposes as having a role in the treatment decision.[105, 135, 137] Haney et al.[63] evaluated the difference between a 2D data set (including panoramic, occlusal and two periapical radiographs) and CBCT images and showed a discrepancy between the two sets in the assessment of both the position of the impacted canine and the type of treatment chosen.[63] However, previous studies have not clearly explained the influence of 2D vs 3D diagnosis on the assessment of impacted canines and subsequent surgical management. The potential influence of CBCT on pre-surgical treatment planning has not yet been evaluated. Thus, the aim of this prospective study is to compare the impact of using 2D panoramic radiographs vs 3D CBCT for the surgical treatment planning of impacted maxillary canines.

Materials and methods

Thirty-two subjects (19 females, 13 males; mean age 25, standard deviation 14 years) with impacted maxillary canines participated in the study. A total of 39 impacted maxillary canines were referred for surgical intervention because they had failed to erupt normally. Seventeen of the impacted maxillary canines were located on the right side (Tooth 13) and 22 on the left side (Tooth 23). The study protocol was approved by the medical ethics committee board of UZ-KU Leuven, Leuven, Belgium (approval number: B32220083749, S50910). Two sets of radiographs were obtained within a maximum interval of six weeks. The first set consisted of 2D panoramic radiographs, and the second set consisted of 3D volumetric images obtained from CBCT scans. All panoramic radiographs were taken with Veraviewepocs 2D® (J. Morita, Kyoto, Japan). The images were viewed and analyzed with Digora® software (Soredex, Tuusula, Finland). The CBCT analyses were conducted using a 3D Accuitomo-XYZ Slice View Tomograph (J. Morita). The CBCT images were analyzed using i-Dixel One Data Viewer Version 1.27 software (J. Morita). In this study, all of the patients were referred for a CBCT examination because 3D visualization of the canine relative to the adjacent teeth was clinically indicated to prepare the treatment plan. CBCT images were taken whenever the canine was displaced from its normal position or if it was very difficult to be localized, deeply impacted, horizontally impacted or associated with suspected root resorption on adjacent incisors. No patients received any additional radiographic exposure during this evaluation.

Pre-operative radiographic evaluation

A therapeutic decision for each case was made by six observers (four orthodontists and two oral surgeons), based on panoramic radiographs and CBCT radiographs. The panoramic and CBCT images were presented separately and in a random order at a two-week interval. The observers prepared the therapeutic plan and completed a questionnaire for the following parameters:

1. The observer's confidence in successful treatment planning and in performing a complete treatment without complications using the information provided. The following five-step confidence scale was used: 1) very confident, 2) confident, 3) no opinion, 4) doubtful/unsure, and 5) very doubtful/unsure.
2. The type of treatment, including simple surgical exposure of the canine, surgical exposure with attachment, and canine extraction.

Pre-surgical treatment planning

3. Open or closed eruption technique.
4. Permanent maxillary canine crown position in the sagittal plane relative to the adjacent teeth (palatal, buccal or in line with the arch).
5. The position of the permanent maxillary canine in the axial plane relative to the occlusal plane (high, close to the apical third of the lateral incisor root; medium, near the middle third of the lateral incisor root; and low, near the coronal third of the lateral incisor root).
6. Contact relationship between the canine and the adjacent teeth. The contact relationship between the permanent maxillary canines and incisors was assigned to one of the following two categories: [44] 1) contact, indicated by a distance between the crown of the permanent maxillary canine and the adjacent incisors of less than 1mm; and 2) no contact, indicated by a distance between the crown of the permanent maxillary canine and adjacent incisors of greater than or equal to 1mm.
7. Presence of root resorption in the adjacent lateral incisors.
8. Prediction of complications, including infection, swelling and bleeding.
9. Linear measurements (in millimeters) were obtained by three observers (two orthodontists and one surgeon) for the following values: A) the total canine length (i.e., the distance from the canine cusp tip to the apex), B) canine crown width, C) distance from the canine cusp tip perpendicular to the axis of the ideal position, D) distance from the canine apex perpendicular to the axis of the ideal position and E) mesiodistal space (i.e. from the distal surface of the lateral incisor to the mesial surface of the first premolar) *(Fig 6.1)*.

Perioperative evaluation

During surgery, the operating surgeon used both image modalities, recorded the type of treatment chosen and the eruption technique, confirmed the type of canine impaction and the canine location in the sagittal and axial planes, and predicted complications. Root resorption of the lateral incisor

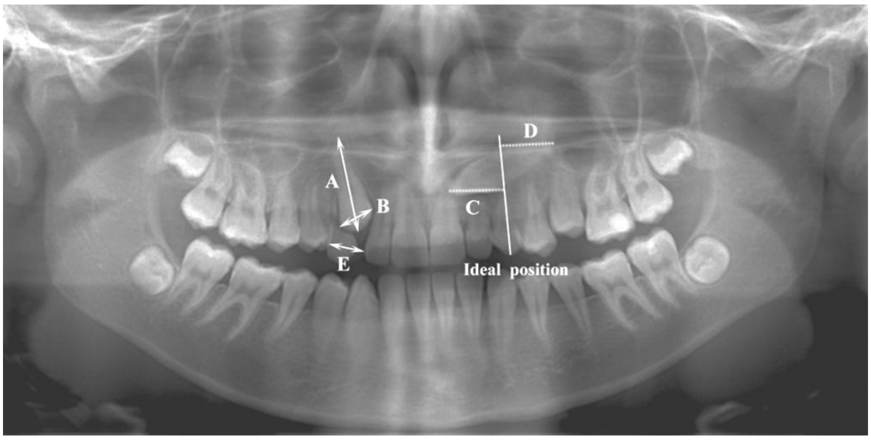

Fig 6.1: Panoramic image of 15 years old female patient with bilateral impacted canine illustrating the reference lines of ideal canine position as well as the linear measurements as follow: A. the canine total length from the canine cusp tip to the apex, B. the canine crown width, C. the distance from the canine cusp tip to the axis of the ideal position, D. the distance from the canine apex to the axis of the ideal position, and E. the mesiodistal space from the distal surface of the lateral incisor to the mesial surface of the first premolar.

and the contact relationship between the impacted canine and adjacent teeth were not included because it was not possible to assess them during surgery. After analyzing the CBCT images, the surgeon was asked to express his opinion on the use of CBCT images for diagnosis and surgery. The following information was recorded: 1) whether or not the CBCT added valuable diagnostic information that would not have been obtained otherwise, 2) whether or not the surgical plan had changed because of the diagnostic information obtained from the CBCT images and 3) whether or not CBCT should be used for surgery to treat canine impactions.

Statistical analysis

McNemar Tests were used to explore the differences in evaluations between 2D and 3D imaging, but they assumed the 234 scores from 39 cases evaluated by 6 observers to be independent, an inappropriate assumption that artificially inflated the amount of information provided. Therefore, a hierarchical logistic regression model was used for the comparisons where a significant result was obtained with the McNemar Test. Only binary models were used (i.e., evaluations with more than two levels were dichotomized). To account for the correlation in the data, the model contained random effects of the observer and the subject, as well as their interactions. Linear mixed models with the same random-effect structure were used to compare measurements between 2D and 3D. $P < 0.05$ was considered significant. All analyses were performed using SAS software V. 9.2 of the SAS System for Windows (SAS[a] Institute Inc, Cary, NC). The SAS GLIMMIX procedure was used to fit the hierarchical logistic regression models.

Results

The pre-operative radiographic evaluation of the treatment plans using panoramic radiographs (2D) and CBCT radiographs (3D) are shown in *Table 6.1*. The observers had a significantly higher level of confidence in their 3D image-based surgical treatment plans than in their 2D image-based plans ($P < 0.001$). The treatment decision regarding the canine crown position in the sagittal and axial planes, the contact relationship, and the presence of lateral incisor root resorption was significantly different when it was based on 2D than on 3D information *(Table 6.1)*.

Root resorption of the lateral incisors was detected more often with CBCT images than with panoramic images (18% vs 11.5%, respectively). Regarding pre-surgical treatment planning, no significant differences were found for either the type of treatment chosen, the surgical technique, or the prediction of complications. However, CBCT was associated with fewer canine extractions than panoramic evaluation (13% vs 18%). Moreover, no significant correlations were found between CBCT and panoramic radiographs regarding the type of treatment chosen (e.g. simple surgical exposure with or without attachment and canine extraction), regarding the

Table 6.1: The pre-operative radiographic evaluation of the treatment planning and the differences between two-dimensional panoramic imaging and three-dimensional cone-beam computed tomography (CBCT). The table values are percentages of the 234 scores in total (6 observers, 39 cases)

		Panoramic (%)	CBCT (%)	*P*-value
Confidence level in treatment planning	Very convinced	3.9	40.6	<.0001
	Convinced	26.1	47.5	
	No opinion	5.9	4.7	
	Doubtful	49.6	5.9	
	Very doubtful	14.5	1.3	
Type of treatment	Simple surgical exposure	6.5	8.1	N.S.
	Surgical exposure with attachment	75.6	79.1	
	Canine extraction	17.9	12.8	
Technique	Open	93.9	86.9	N.S.
	Closed	6.1	13.1	
Canine crown position in sagittal plane	Buccal	26.2	20.2	0.002
	Palatal	64.4	61.4	
	Close to the line arch	9.4	18.4	
Canine crown position in axial plane	High	30.3	29.0	0.005
	Medium	51.7	43.6	
	Low	18.0	27.4	
Contact relationship	Contact	81.6	89.7	0.008
	No contact	18.4	10.3	
Resorption of lateral incisors	Resorption	11.5	18.0	0.025
	No Resorption	88.5	82.0	
Prediction of complication	Complication	17.5	25.6	N.S.
	No complication	82.5	74.4	

N.S.= not significant (P >0.05)

eruption technique chosen (e.g. open or closed eruption)n or other diagnostic factors.

The mean, median and standard deviation values as well as the systematic differences for the linear measurements are shown in *Table 6.2*. The linear measurements of the width of the canine crowns, the canine root length, and the distance between the canine apex and the ideal were significantly different between the two imaging modalities. *Table 6.3* gives the percentage of correct agreement between the pre- and perioperative evaluations and the decisions related to treatment planning. This agreement was not significantly different between panoramic and CBCT images. After

Table 6.2: Descriptive information and the differences between the linear measurements (in millimeters) using two-dimensional panoramic imaging and three-dimensional CBCT

		Panoramic	CBCT	*P*-value
Canine total length	Mean	14.6	14.2	0.04
	Median	14.4	14.2	
	SD	2.5	2.3	
Canine crown width	Mean	7.7	7.4	0.03
	Median	7.3	7.4	
	SD	1.7	0.9	
Distance from cusp tip of canine to ideal axis	Mean	6.3	5.8	N.S.
	Median	5.2	4.6	
	SD	4.5	3.9	
Distance from apex of canine to ideal axis	Mean	7.1	8.1	0.002
	Median	6.3	6.7	
	SD	4.4	5.4	
Mesio-distal space	Mean	4.9	4.8	N.S.
	Median	5.8	5.8	
	SD	3.1	2.9	

N.S.= not significant (P>0.05)

evaluating the CBCT images, the surgeon considered the extra diagnostic information to be valuable in 92.3% (36/39) of the cases. Changes in the therapeutic plan occurred in 79.5% (31/39) of the cases when 3D information was obtained in addition to panoramic information. CBCT was recommended in 61.5% (24/39) of the canine impaction cases.

Discussion

There is much debate about the utility of panoramic radiographs for canine localization.[32, 33, 59, 71, 73, 92, 106, 139] Reports in the literature state that, when clinical information is insufficient to identify the position of the impacted canines, a 2D imaging technique such as a panoramic radiograph should be supplemented by another radiograph.[47] A study by Jung et al.[71]

Table 6.3: Correct agreement (expressed in percentages) between pre-operative treatment planning and peri-operative treatment information when using two-dimensional panoramic imaging versus three-dimensional CBCT. None of these comparisons was significantly different (p>0.05)

		Panoramic (%)	CBCT (%)
Type of treatment	Simple surgical exposure	0.4	0.9
	Surgical exposure with attachment	51.7	51.7
	Canine extraction	13.25	8.12
Technique	Open	78.2	75.2
	Closed	3.0	6.8
Canine crown position in sagittal plane	Buccal	5.2	7.3
	Palatal	42.9	46.6
	Close to the line arch	6.4	7.3
Canine crown position in axial plane	High	16.7	15.0
	Medium	25.2	20.9
	Low	8.6	12.0
Prediction of complication	Complication	3.9	6.4
	No Complication	58.1	52.6

correlated the diagnostic positions of panoramic with those of CBCT radiographs of impacted maxillary canines. The results showed that the panoramic radiographs were useful for predicting canine buccolingual locations based on sectors.[71] Impacted canine angulation was also used to differentiate the canine positions based on panoramic radiographs.[73]

Other studies have compared the diagnosis and treatment planning based on CBCT images with those based on 2D panoramic images in combination with a lateral cephalogram, available periapical radiographs and/or a dental cast.[26, 63, 150] The results indicated that information from CBCT was superior to that obtained from conventional 2D radiographs, which may affect treatment planning.[26, 150] This study, however, did not focus on treatment opinions or treatment planning. Therefore, lateral cephalograms were not used because insufficient information related to canine impaction caused by superimposition (i.e., mainly in the case of bilateral impaction) was provided and because they had the same limitations as panoramic

Fig 6.2: Two-dimensional panoramic radiograph of a 15 year-old female with an impacted maxillary right canine. The root contours of the central and lateral incisors overlap with that of the canine. The canine crown is magnified indicating that it is palatally impacted with the exact location for surgical intervention is very difficult to assess.

images for the diagnosis of the presence or absence of root resorption of the adjacent lateral incisors. Two intraoral periapical radiographs were not used because of limitations such as the small field of view. When the canines were bilaterally impacted, four periapical radiographs were needed for each patient, which was considered to be unjustified. In addition, intraoral 2D images are subject to the same constraints as panoramic imaging and have been found to be an inaccurate diagnostic tool for the detection of root resorption of the adjacent incisor.[56] Furthermore, the combination with the 2D radiographs was not used in this study because two periapical radiographs are insufficient to provide the vertical canine crown location or the canine apex relative to the surrounding structures, and because they cannot be reproduced accurately with the same angulation projections for all patients referred for surgery.[17] Moreover, these radiographs, according to the SLOB rule (same lingual opposite buccal), were largely intended for canine crown localization instead of detection of root resorption on the adjacent incisors. By contrast, since CBCT was introduced at our center (2004), it has

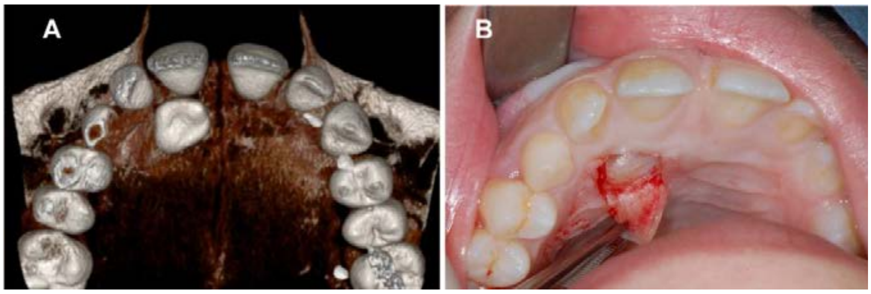

Fig 6.3: A. Three-dimensional cone beam computed tomography (CBCT) image from the Accuitomo 3D system showing the exact location of the right maxillary canine. B. Occlusal intraoral photograph showing the crown of the impacted upper right maxillary canine during surgery.

replaced other modalities in cases requiring additional radiographs for impacted canines. As a result, unnecessary radiation has been avoided because of optimization and low-dose exposures.

Linear measurements were included in comparisons between panoramic and CBCT images because they were frequently used as comparative parameters for radiological assessment (Chapter 5). Several authors have suggested that linear measurements are reliable in panoramic radiographs for the assessment of correct patient position.[86, 146] All panoramic images in this study were acquired with patients in standardized positions and were performed by experienced technical operators. In our previous study, panoramic radiographs were found to be less reliable as they resulted in lower measurement accuracy and less agreement compared with CBCT images for different diagnostic tasks related to canine impaction.[4] Moreover, in agreement with our findings, CBCT had better agreement than panoramic radiography regarding canine position and the detection of external root resorption of adjacent lateral incisors.[4, 6]

In this study, the observers had a higher level of confidence in their CBCT image-based therapy plans than in their 2D radiograph-based plans.

The treatment of canine impaction was influenced by canine location, contact with adjacent teeth and the site and severity of the root lesion, all of which were significantly different between the panoramic and the CBCT images. Moreover, the exact location of the impacted canines in the 3D images (sagittal, coronal and axial) and their contact with adjacent teeth allowed the clinicians to determine the direction of traction to avoid injury to adjacent teeth as well as to provide better surgical access *(Figs 6.2 and 6.3)*. Confidence in the therapeutic plan was also influenced by the presence and severity of root resorption, although confidence decreased when the type of treatment was chosen based on 2D radiographic images. Bjerklin and Ericson[22] found that treatment approach was modified when additional 3D information was available as regards the extent of root resorption present on the maxillary lateral incisors.

In the pre-operative evaluations, no significant difference was observed between 2D and 3D information regarding the type of treatment chosen (e.g., surgical exposure with or without attachment and canine extraction) or regarding eruption technique (e.g., open vs closed eruption). One possible reason is that surgical treatment is normally based on the surgeon's personal preference and experience regarding the best surgical approach.[112] Moreover, proposed treatments for impacted canines did not differ, whether based on 2D or 3D images, which is in agreement with our findings.[150]

There were no statistically significant differences in agreement between the pre- and perioperative surgical plans for the two imaging modalities. The perioperative evaluation was used as a reference standard for comparison of what was planned pre-operatively (by six observers) and the treatment that actually occurred during surgery. Surgery was performed by an independent surgeon who completed the clinical examination autonomously and had access to all the available image modalities that represented normal clinical practice. The same questionnaire was completed pre- and perioperatively. Therefore, the confidence level was not assessed based on the perioperative evaluation because the operating surgeon used both panoramic and CBCT images during surgery. Moreover, root resorption of the lateral incisor and the contact relationship between the canine and the adjacent teeth were difficult to assess during surgery. Consequently, the assessments of root resorption and contact relationship were not included in the perioperative evaluation.

Conclusion

Pre-surgical treatment planning did not differ significantly between panoramic and CBCT modalities in terms of the type of treatment chosen, the surgical technique or the prediction of complications. Moreover, the agreements between pre- and perioperative evaluations and the decisions about treatment planning did not differ significantly whether panoramic or CBCT images were used. Compared with panoramic radiographs, CBCT images helped to increase the confidence level of the clinician regarding treatment planning, the diagnosis of the canine location, the contact with the adjacent teeth, and the presence of root resorption.

Chapter 7

A comparison of orthodontic treatment planning carried out based on conventional and CBCT information

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Orthodontic Treatment Planning for Impacted Maxillary Canines using Conventional Records vs. 3D CBCT

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Abstract

The aim of this study was to compare the orthodontic treatment planning for impacted maxillary canines based on conventional orthodontic treatment records versus three-dimensional (3D) information taken from single cone beam computed tomography (CBCT) scans. This study concerned 40 individuals with impacted maxillary canines. The patients were identified from among those referred for orthodontic treatment (26 females, 14 males) with a mean age of 12.5 years (± SD 3). In total, 64 impacted canines were identified, thus justifying the need for CBCT scans by the treating orthodontist. Two sets of information were obtained. The first set consisted of conventional planning records [two-dimensional (2D) panoramic, 2D lateral cephalograms, and dental casts] and the second set of 3D volumetric images obtained from a single CBCT scan (3D panoramic, 3D lateral cephalograms, 3D virtual study model). For both sets, intra- and extraoral images were included. The radiographic diagnostic features, treatment planning, orthodontist opinions, and case classifications of both sets were produced and subsequently analyzed by four orthodontists. There was no statistically significant difference in treatment planning between the use of the two sets in terms of either orthopedic growth modification or orthodontic compensation. Also, anticipated complications during treatment and expected treatment duration did not differ significantly. The orthodontists found the conventional set to be insufficient for treatment planning in 22.5% and requested additional radiographs in 63% of the cases, compared with 1.3% and 0.5%, respectively (P <0.001). The observers' confidence level was higher for therapy based on the 3D set compared with the conventional set (96.3% versus 61.9%, P <0.001). There was no statistically significant difference in treatment planning between the use of conventional and CBCT sets. CBCT images have been shown to offer useful

orthodontic treatment planning information similar to that of conventional planning with a high confidence level.

Introduction

A 3D imaging technique providing precise canine location and the potential presence of root resorption in adjacent teeth may influence treatment planning strategies. However, there are conflicts between the results of studies and evaluations where CBCT was used for obtaining supplementary radiographic information. Previous studies have shown that information from 3D images is better than that from combined conventional 2D radiographs and may alter treatment planning.[21, 22, 26, 63] However, other investigators have compared diagnosis and treatment options based on information from CBCT images with the information obtained from 2D panoramic images or in combination with dental casts and found that the treatment proposal for impacted canines did not differ whether based on 2D or 3D information.[3, 150] Further studies should be conducted to quantify the impact of CBCT in orthodontic treatment planning if conventional methods fail to provide the clinicians with needed information. Therefore, there is a great need to evaluate the added value of CBCT scanning in treatment planning and patient management. The question is whether there are any differences between treatment planning based on conventional treatment records and that based on records obtained from one single CBCT scan. It might be hypothesized that the new treatment planning methodology that can be obtained from CBCT, with minimal radiation dose levels and costs and might be better than the conventional method by providing more effective information in diagnosis and orthodontic treatment planning. Therefore, the aim of this study was to compare the orthodontic treatment plan for maxillary canine impaction using conventional treatment records consisting of 2D radiographs (panoramic, lateral cephalograms) and dental casts with the information generated from one single CBCT scan (3D panoramic, 3D lateral cephalograms, and 3D virtual study models) and to investigate changes in orthodontic treatment planning and the concomitant choice of teeth for extraction based on 3D information.

Materials and methods

Patients with impacted maxillary canines were identified from among those seeking orthodontic treatment at the Department of Oral Health Sciences, KU Leuven & Dentistry, University Hospitals Leuven, Belgium, and were selected for this study according to the following selection criteria: 1) All patients were non-syndromic, with complete conventional dental records (2D panoramic radiograph, 2D lateral cephalograms, intra- and extraoral photographs, dental casts); 2) each patient presented at least one impacted maxillary canine; 3) no orthodontic treatment had been administered; and 4) the patient had CBCT scans within a maximum interval of two weeks. The study protocol was approved by the medical ethics committee board of UZ-KU Leuven University, Belgium (Approval number: B32220083749, S50910). For all of the patients, CBCT scans were indicated and taken to define the treatment plan because of the canine location, the presence of root resorption on the adjacent teeth, and the treatment requirements.

The treatment records of 40 consecutive patients were used. In total, 64 impacted maxillary canines were identified, with the diagnosis being determined as failure of the canine to erupt at its appropriate site in the dental arch as determined by clinical and radiographic assessment. The patient population consisted of 26 females and 14 males with a mean age of 12.5 years and a median age of 12.0 years (± SD 3.05).

For the purpose of this study, two sessions were held. The first session consisted of traditional treatment records usually used in orthodontic practice, such as 2D panoramic radiographs, 2D lateral cephalometry, and dental casts. The second set consisted of 3D volumetric dentition images generated from single CBCT scans including 3D views (sagittal, axial, and coronal), 3D panoramic images, 3D cephalometry, and 3D virtual study models. For both sets, intra- and extraoral images were included. The digital panoramic and lateral cephalometric radiographs were taken with Veraviewepocs 2D® (J. Morita, Kyoto, Japan) equipped with a charge-coupled device sensor (J. Morita) with exposure parameters 7.4 second, 64 kV, and 8.9 mA. All of the 2D images were extracted from their originating software (capturing software) as JPEG format files and imported into the VistaDent® OC orthodontic tracing software (DENTSPLY GAC, Birmingham, Alabama, USA). Cephalometric analyses of Steiner, Wits, and Tweed were performed.[103] The CBCT scans were carried out with a 3D Accuitomo 170 (J. Morita, Kyoto, Japan) with a voxel size of 0.125 mm, a medium field of volume, and high resolution (FOV, 14 × 10 cm). The parameters included a tube voltage of 85 kV, a tube current of 10 mA, and a scanning time of 10 seconds. The 3D images, constructed panoramic image, and 3D view of the skull were viewed with the SimplantOrtho®™ App. version 2.0 software (Materialise, Leuven, Belgium). The 3D models of the dentition and tracings of the 3D cephalometric radiographs were generated by the same SimplantOrtho software with tracing methods of Steiner, Wits, and Tweed analysis.[103] All segmentations and 2D and 3D tracings were performed by the same operator (A. Alqerban).

The 40 patients were presented to the observers in random order. The conventional and CBCT sessions were completed and subsequently analyzed by four experienced orthodontists. All of the orthodontists who participated in this study were dedicated to the treatment of impacted canines and had more than five years of clinical experience in all aspects of orthodontic treatment. All of the observers received instructions and a demonstration before the data acquisition of each viewing session in order to obtain standardized evaluation. The standardized protocol was explained to each observer, and each orthodontist was trained to use CBCT images for the different applications. They assessed the images independently in the same random order with a minimum interval of four weeks between the two sessions to avoid eye fatigue and to minimize subjective error. They were instructed to manipulate the constructed panoramic, 3D cephalometry, 3D models, and soft-tissue reconstructions with the viewing software according to their own preferences and were allowed to adjust the brightness and contrast settings with software enhancement tools. The orthodontists were permitted to adjust image display settings freely. They were also able to scroll through the CBCT slices according to their own preferences for the optimal display of the impacted canine (axial, coronal, and sagittal). The patients' gender and age were provided without name or identification. The observation time was unlimited. The evaluation process for the two sessions involved the use of a questionnaire with three categories:

(A) Diagnostic evaluation

1. Skeletal relationship, either neutro, disto, or mesiorelation.
2. Angle classification of occlusion based on Class I, Class II, and Class III molar relationships.
3. Canine crown position in relation to adjacent teeth, either palatal, buccal, or in the line of the arch.
4. Type of canine impaction, either vertical or horizontal.
5. Two categories of canine development based on root development: incomplete or complete.
6. Detection of abnormalities, such as dilacerations of the canine root, mesiodens, and supernumerary tooth/teeth.
7. Severity of root resorption. The examiners were asked to determine whether they could detect a resorption defect in the adjacent teeth. If resorption was diagnosed, the score of the severity of resorption was graded

in one of the categories based on the grading systems suggested by Ericson et al.[44]

8. Location of resorption, recorded to be in either the apical, middle, or cervical third.

9. Permanent maxillary canine situation, scored in one of three categories (easy, moderate, and difficult) according to the following: 1) ‘Canine angulation to the midline’, the angle formed by the long axis of the impacted canine and the midline of the maxilla *(Chapter 5, Fig 5.1*). If the canine angle increased, difficulty increased. 2) “Canine angulation to the occlusal plane”, the angles formed by the long axis of the impacted canine and the occlusal plane. If the canine angle increased, the difficulty decreased *(Chapter 5, Fig 5.1*). 3. The vertical location of the maxillary canine crown. If the canine was located more apically, the difficulty increased *(Fig 7.1)*. 4. The canine overlap of the adjacent teeth (sector; *Fig 7.2*). If the canine was located more mesially, difficulty increased.

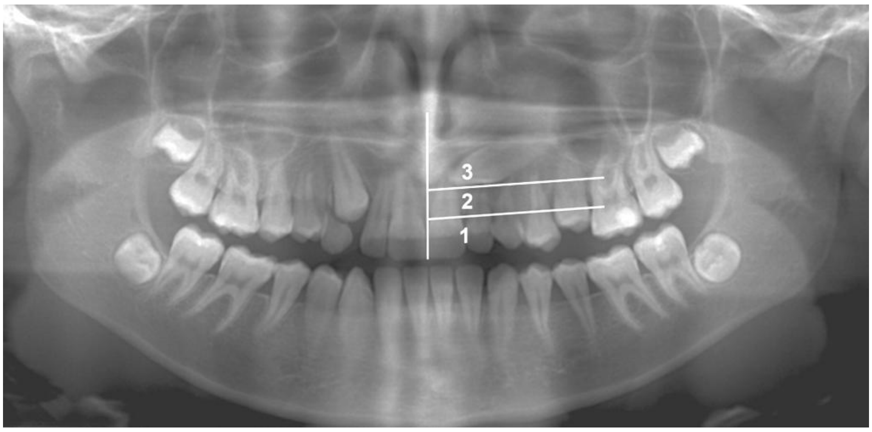

Fig 7.1: Panoramic image of a 14-year-old female patient with a bilateral impacted canine, illustrating the reference lines of the vertical canine location, If the canine was located more apically, the difficulty increased 1. below the level of the cemento-enamel junction of the adjacent teeth, 2. in the middle third of the adjacent lateral incisor root, or 3. in the apical third of the adjacent teeth root.

(B) Treatment planning

1. The skeletal treatment proposal method with either dental compensation, orthopedic growth modification, or orthognathic surgery.
2. Treatment methods that can be used either separately or in combination as follows: extraction of the primary canine, transpalatal arch, headgear, coffin spring appliance, extrusion removable appliance, expansion of the maxillary arch, and fixed appliance.
3. Extraction or non-extraction. In cases of extraction, the orthodontists were asked to identify which tooth/teeth would be extracted: extraction of the two lateral incisors, extraction of the two premolars, extraction of the four premolars, and extraction of the permanent canine.
4. Type of surgical exposure if needed, either the open- or closed-eruption technique.

(C) Orthodontists' opinions on treatment planning

After the diagnoses and treatment planning evaluations, the orthodontists were asked to express their opinions on the following variables:

1. whether the materials presented were sufficient to establish a treatment plan;
2. whether the radiographic images presented were sufficient to perform the correct diagnosis and treatment plan;
3. whether materials necessary for completion of the treatment plan were missing;
4. whether the confidence level in successful treatment planning and in performing complete treatment was satisfactory with the information provided, according to the following five-step confidence scale: very confident, confident, no opinion, doubtful/unsure, and very doubtful/unsure;
5. whether complications were expected during the treatment process;

6. which treatment duration in months was expected;
7. classification of the difficulty of the treatment plan: easy, moderate, or difficult.

Statistical methodology

Depending on the question, the analysis was performed with the patient or with the canine as the unit of analysis. Four repeated measures were presented for the analyses on patient level (four orthodontists) and up to eight repeated measures for the analyses on canine level (four orthodontists, possible two canines). Every analysis that ignores the correlation between the scorings is likely to produce *P*-values that are too liberal. This holds for the *P*-values obtained with McNemar's Tests (and their extension for more than two levels) and Wilcoxon signed-rank tests comparing conventional with CBCT in all cases. To obtain more appropriate *P*-values, statistical models were used to take the correlations into account

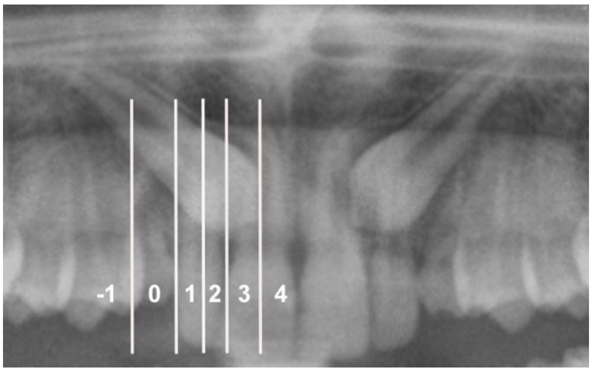

Fig 7.2: Panoramic view illustrating reference lines of canine overlap (sectors) assigned to one of five categories: -1. Distal to the normal position (in the premolar region), 0. Normal position (primary canine), 1. Distal to the long axis of the lateral incisor, 2. Mesial to the long axis of the lateral incisor, 3. Distal to the long axis of the central incisor, or 4. Mesial to the long axis of the central incisor.

when conventional and CBCT modalities were compared. Binary logistic regression models, multinomial regression models, and linear models were extended with random effects. However, due to the small number of independent units (40 participants) and the large number of repeated measures, these models yielded only approximate results. *P*-values are based on large sample properties that did not hold in this small sample. Further, in most situations, only simplified correlation structures could be used to model the correlation among the four repeated measures, between both canines, and between both modalities. Therefore, to verify if the conclusion derived from the model on all data, we also used per observer McNemar's Tests (and their extension for more than two levels) and Wilcoxon signed rank tests. *P*-values less than 0.05 were considered significant. All the analyses were performed with SAS software, Version 9.2 (SAS System for Windows© 2002, SAS Institute Inc.). SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of the SAS Institute Inc., Cary, North Carolina, USA.

Results

The distribution of impacted canines diagnosed in the 40 patients is given in *Table 7.1. Table 7.2* shows the comparison of the diagnostic variables between the conventional and the CBCT records. Significant differences were found for the diagnosis of angle classifications of occlusion, canine position, canine development, detection of abnormality, and vertical canine crown height. The root resorptions diagnosed in the

Table 7.1. Distribution of 40 patients and 64 impacted maxillary canines (in percentages)

Male	Female	Bilateral	Unilateral	Right	Left
14 35%	26 65%	24 60%	16 40%	33 51.5%	31 48.5%

lateral and central incisors as well as premolars are shown in *Table 7.3*. Compared with conventional records, the presence, severity, and location of lateral incisor root resorption were detected significantly more often by CBCT *(Table 7.3)*. There was also a significant difference in the presence of central incisor root resorption between the two modalities ($P = 0.02$).

For treatment planning, there was a significant difference between the two modalities for the direction of canine traction only in cases of

Table 7.2: Comparisons of the diagnostic variables in percentage (%) between conventional and CBCT records

	Level	Conventional (%)	CBCT (%)	*P*-value
Skeletal classification (*)	Neutral relation	48.75	54.38	N.S.
	Mesial relation	8.75	5.63	
	Distal relation	42.50	40.00	
Classification of occlusion (molar relationship) (§)	Class I	47.66	34.77	0.0005
	Class II	48.05	58.59	
	Class III	4.30	6.64	
Canine crown position (§)	Palatal	50.39	34.38	<0.0001
	Buccal	13.67	37.89	
	Line of the arch	35.94	27.73	
Type of impaction (§)	Vertical	82.81	87.11	N.S.
	Horizontal	17.19	12.89	
Canine development (§)	Incomplete	51.17	57.81	0.04
	Complete	48.83	42.19	
Detection of abnormality (§)	No abnormality	93.75	92.58	0.03
	Abnormality	6.25	7.42	
Canine angulation to the midline (§)	Easy	60.55	56.25	N.S.
	Moderate	25.00	26.17	
	Difficult	14.45	17.58	
Canine angulation to the occlusal plane (§)	Easy	62.89	57.03	N.S.
	Moderate	23.83	27.73	
	Difficult	13.28	15.23	
Vertical canine crown height (§)	Easy	37.22	23.77	0.001
	Moderate	40.36	51.57	
	Difficult	22.42	24.66	
Canine overlap of adjacent teeth (*)	Easy	58.74	53.81	N.S.
	Moderate	25.56	30.49	
	Difficult	15.70	15.70	

(*) patient as unit of analysis, (§) canine as unit of analysis

surgical exposure *(Table 7.4)*. With respect to orthodontic opinions, the orthodontists considered the conventional records insufficient in 22.5% of cases compared with 1.25% with CBCT. The radiographic information was also insufficient with conventional records (63.1% compared with 0.63%). The perception of the need for extra diagnostic material was significantly higher with conventional records compared with CBCT. The orthodontists needed 3D visualization in 62.5% of cases when using conventional records and needed dental casts in 1.88% of cases evaluated by CBCT records *(Table 7.5)*. The orthodontists had a significantly higher level of confidence (P <0.0001) when treatment planning was based on CBCT information than with conventional information (in 96.3% versus 61.9% of the cases the orthodontists were confident using CBCT and conventional records, respectively). The classifications of treatment-plan difficulty were significantly different between the two modalities. In 42.5% of cases, the treatment plan was easy when based on 3D instead of conventional information (23.1%; *Table 7.5*).

Table 7.6 presents a summary of the results with account being taken of the correlation between or among the variables or performance of the analysis for each observer separately. The significant difference between conventional and CBCT was found only for the diagnosis of the canine position (more buccally with 3D, more palatally and line-of arch with 2D). Moreover, there was no evidence of a difference in the treatment planning based on conventional versus 3D CBCT dataset. The confidence level of the orthodontists increased significantly when using 3D CBCT and when there was no need for extra materials to perform correct diagnoses and treatment plans.

Table 7.3: Comparisons of the presence, severity, and location of root resorption in percentages (%) between conventional and CBCT records

			Conventional (%)	CBCT (%)	*P*-value
Lateral incisors	Presence of root resorption	No resorption	85.55	76.56	0.002
		Resorption	14.45	23.44	
	Severity	Slight	5.86	11.33	0.003
		Moderate	3.52	2.34	
		Severe	5.08	9.77	
	Location	Cervical third	2.34	3.52	0.007
		Middle third	3.91	16	
		Apical third	8.20	9.77	
Central incisors	Presence of root resorption	No resorption	99.22	94.92	0.003
		Resorption	0.78	5.08	
	Severity	Slight	0.39	4.30	N.S.
		Moderate	0.39	0.39	
		Severe	0	0.39	
	Location	Cervical third	0.78	1.56	N.S.
		Middle third	0	1.17	
		Apical third	0	2.34	
Premolars	Presence of root resorption	No resorption	98.05	95.70	N.S.
		Resorption	1.95	4.30	
	Severity	Slight	0.39	2.34	N.S.
		Moderate	1.17	1.56	
		Severe	0.39	0.39	
	Location	Cervical third	0.39	0.78	N.S.
		Middle third	0.39	1.95	
		Apical third	1.17	1.56	

Canine is the unit of the statistical analysis.

Discussion

Treatment planning and decision-making are essentially influenced by radiographic and clinical diagnostic information. Orthodontists typically use different approaches to the treatment of impacted canines, and conventional diagnostic methods have served them well for many years. Traditional radiological examination of patients undergoing orthodontic treatment usually relies on a panoramic or lateral cephalometric radiograph that may be supplemented by intraoral periapical or occlusal radiographs if necessary. In this study, panoramic and lateral cephalometric radiographs were chosen to represent conventional 2D radiographs because they are the most common modality used clinically for the diagnosis and treatment planning of patients undergoing orthodontic treatment.

The position of impacted canines in the dental arch, canine development, overlap with the roots of adjacent incisors, the presence of root resorption and anomalies were recorded because they have been discussed as

Table 7.4: Comparisons of treatment planning variables in percentages (%) between conventional and CBCT records

Treatment		Conventional (%)	CBCT (%)	*P*-value
Skeletal treatment (*)	No skeletal treatment	73.75	79.38	N.S.
	Orthopedic growth modification	23.75	17.50	
	Orthognathic surgery	2.50	3.13	
Number of interceptive treatment methods (*)	No interception	20.63	18.75	N.S.
	1 method	31.88	38.13	
	2 methods	38.13	33.75	
	3 methods	6.88	6.88	
	4 methods	2.50	1.88	
	5 methods	0.00	0.63	
Extraction (§)	No extraction	71.88	73.83	N.S.
	Extraction of 2 lateral incisors	7.81	7.42	
	Extraction of 2 premolars	5.86	7.03	
	Extraction of 4 premolars	12.11	10.16	
	Extraction of canine	2.34	1.56	
Surgical exposure (§)	No surgery	50.39	51.95	N.S.
	Closed-eruption technique	33.20	33.98	
	Open-eruption technique	16.41	14.06	
Direction of traction (in case of surgical exposure) (§)	No direction	50.39	52.34	0.03
	Bucco-vertical direction	13.28	4.69	
	Palato-vertical direction	1.56	2.34	
	Mesio-vertical direction	0.39	0.00	
	Disto-vertical direction	34.38	40.63	

(*) patient as unit of analysis, (§) canine as unit of analysis

having a an important role in the decision-making process for the treatment of impacted maxillary canines.[5, 22, 105, 135, 137] In our study, significant differences were found for the diagnosis of canine position, canine development determination, abnormality detection, vertical canine crown height establishment, and root resorption diagnosis in the adjacent teeth because the use of CBCT substantially increased the perceptibility of canine

Table 7.5: Comparisons of orthodontists' opinions in percentages (%) between conventional and CBCT records

		Conventional (%)	CBCT (%)	*P*-value
Materials presented were sufficient to establish a treatment plan?	No	22.50	1.25	<.0001
	Yes	77.50	98.75	
Radiographic images presented were sufficient to perform the correct diagnosis and treatment plan?	No	63.13	0.63	<.0001
	Yes	36.88	99.38	
Materials necessary for completion of the treatment plan were missing	No	37.50	98.13	<.0001
	Yes	62.50	1.88	
Confidence level	Very convinced/confident	12.50	53.75	<.0001
	Convinced/confident	49.38	42.50	
	No opinion	11.88	3.13	
	Doubtful/unsure	22.50	0.63	
	Very doubtful/unsure	3.75	0	
Expect complications during the treatment process?	No	80	85	N. S.
	Yes	20	15	
Expected treatment duration (months)	Mean (SD)	28.75(5.4)	28.68 (5.7)	N. S.
Classification of treatment plan difficulty	Easy treatment plan	23.13	42.50	0.0008
	Moderate treatment plan	49.38	35.00	
	Difficult treatment plan	27.50	22.50	

Patient was the unit of the statistical analysis.

and root resorption with 3D views.[6, 26, 63] When the correlation between or among the variables or performance of the analysis for each observer separately was taken into account, canine position determination yielded the only significant difference between conventional and CBCT views. Although not being significant, the incidence of incisor root resorption was higher when CBCT was used than with conventional records.

No significant difference was found for extraction versus non-extraction decisions between the two modalities. The decision to extract anterior teeth, including impacted canines, is rare because it affects the aesthetics of the patient's smile as well as his/her functional occlusion. However, extraction could be considered, rather than premolar extraction, in cases of dento-alveolar compensation if there is severe root resorption of the incisors and the prognosis of the tooth is poor. Canine extraction could also be considered if the canine is located high in the palate or is horizontally impacted, or if ankylosis, transmigration, dilaceration, and/or resorption of the impacted canine is present.

The expected treatment duration did not differ significantly between the two modalities (30 months). However, it is difficult to predict treatment time, potential complications, and challenges in canine impaction cases. Numerous investigators have evaluated the length of orthodontic treatment time based on radiographic factors and treatment methods.[55, 69, 135, 154] However, the position of impacted canines, linear measurements, and their angulations have been found by some authors to be invalid as indicators of successful outcome of interceptive orthodontic treatment, length of treatment, and periodontal status[38, 61, 88, 148] The risk of failure to erupt and the extended treatment time in cases of impaction should also be taken into consideration in treatment planning.[16, 135] Therefore, predicting the treatment duration for impacted canines remains problematic.[55]

In the present study, the medium (FOV, 14 × 10 cm) was chosen to include the region of interest covered by conventional 2D radiographs. A panoramic and lateral cephalogram was constructed from the CBCT scan. If the FOV of the CBCT is smaller, the extracted images will have less of the information needed for orthodontic diagnosis. Our concern was to compare the complete 3D set constructed from CBCT not treated as supplemental radiographs. CBCT scan with a medium field of volume allows us for 3D reconstruction generated from the image volume for different orthodontic uses, including constructed panoramic, lateral, and virtual study models.[99] Several studies have shown that traditional cephalometric tracing may be done *via* CBCT images, and the measurements from CBCT-synthesized cephalograms are similar to those from conventional cephalograms.[82] However, the norms for 3D analysis are not available. In addition, the linear and angular measurements obtained from CBCT images have been found to be more accurate than those from conventional 2D radiographs, with high reproducibility for orthodontic applications.[85, 104]

Orthodontic study models are an essential component of orthodontic records. The use of CBCT models is also advantageous in treatment planning for impacted canines by providing accurate localization and facilitating understanding of the anatomic relationships between the impacted tooth and the adjacent roots, such as the presence of abnormalities, dilacerations, root resorption of the adjacent incisors, and mesiodistal root angulation. 3D images allow clinicians to obtain the accurate knowledge necessary for optimal confidence in treatment planning. Furthermore, the accuracy and reliability of CBCT models has been found to be equivalent to the digital models obtained from plaster casts.[142] In the present study, a significant difference was found for the diagnosis of angle classifications of occlusion, possibly because the observers had a higher level of preference and agreement when using dental casts than with the CBCT virtual study models.

The classifications of treatment plan difficulty were significantly different when based on conventional information than with 3D information. This could be because the orthodontists considered the conventional records and 2D radiographic information insufficient and needed additional diagnostic material. Moreover, the orthodontists had a significantly lower level of confidence when treatment planning was based on conventional information.

This study does not reflect reality of treatment planning or present the actual and routine orthodontic records used for treatment planning. Thus, the routine use of CBCT for all patients requiring orthodontic treatment is not recommended by this study. The new methods of 3D application, which are either under development or under investigation, may bridge the gap of transition from conventional to 3D CBCT images. The potential replacement of conventional records by low-dose 3D CBCT is a useful step forward to navigate to 3D applications. However, further study would be useful to determine on the basis of on clinical and radiographic factors whether CBCT radiographs are justified for specific patients. Meanwhile, CBCT developers are now focusing on producing low-dose CBCT, with doses at lower levels than panoramic radiography so the entire justification process will have to be revisited. Conversely, the characteristics of old- and new-generation 2D radiographs influence the radiation dose. New-generation panoramic and cephalometric equipment provides very low-dose radiation. A reduction in the radiation dose is usually desirable and results in the use of a fluorescent intensifying screen or film combinations and machine technology.

Table 7.6: Summary of comparisons showing the significant differences between the two modalities for each variable performed on the scores from all observers (Naïve P-value), on correlations between the repeated measures of the same score on the same participant (Clustering P-value), and number of observer-specific tests (on a total of 4) being significant (Sensitivity)

		Level	Naïve	Clustering	Sensitivity
DIAGNOSIS	Skeletal classification	*	n	n	0
	Classification of occlusion	§	y	n	2
	Canine crown position	§	**y**	**y**	**4**
	Type of impaction	§	n	n	1
	Canine development	§	y	n	2
	Detection of abnormality	§	y	-	0
	Presence of lateral root resorption	§	y	n	2
	Presence of central root resorption	§	y	n	0
	Presence of premolar root resorption	§	n	n	0
	Severity of lateral root resorption	§	y	n	1
	Severity of central root resorption	§	n	-	0
	Severity of premolar root resorption	§	n	-	0
	Location of lateral resorption	§	y	n	1
	Location of central resorption	§	n	-	0
	Location of premolar resorption	§	n	-	0
	Canine angulation to the midline	§	n	n	0
	Canine angulation to the occlusal plane	§	n	n	1
	Vertical canine crown height	§	y	n	2
	Canine overlap of adjacent teeth	§	n	n	0
TREATMENT PLANNING	Skeletal treatment	*	n	n	0
	Number of interceptive treatment methods	*	n	n	0
	Extraction	§	n	n	0
	Surgical exposure	§	n	n	1
	Direction	§	y	-	0
ORTHODONTISTS'† OPINIONS	Materials presented were sufficient to establish a treatment plan?	*	**y**	**y**	**4**
	Radiographic images presented were sufficient to perform the correct diagnosis and treatment plan?	*	**y**	**y**	**4**
	Materials necessary for completion of the treatment plan were missing	*	**y**	**y**	**4**
	Confidence level	*	**y**	**y**	**4**
	Expected complications during the treatment process	*	n	n	0
	Expected treatment duration	*	n	n	2
	Classification of the treatment plan difficulty	*	y	y	1

Scores with evidence of a difference between conventional and 3D CBCT are indicated in bold. Clustering P-values were from models with a random patient effect, unless stated otherwise. n = P > 0.05; y = P < 0.05; - = not feasible.

** patient as unit of analysis.*

*** canine as unit of analysis.*

Conclusion

The treatment planning was not found to differ when conventional and CBCT sets were used. Nevertheless, CBCT allows clinicians to obtain 3D images with visualization of craniofacial structures and significantly increases the orthodontists' confidence level as it provides more information on canine localization and detects possible root resorption on adjacent incisors.

Chapter 8

The influence of CBCT on the treatment methods used and treatment outcomes achieved for orthodontically treated patients with impacted maxillary canines

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Effect of using CBCT in maxillary canine impaction in orthodontic treatment outcome

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Abstract

The objective is to determine the added-value of using CBCT in the orthodontic treatment of maxillary impacted canines and treatment outcome. The sample consisted of 118 treated patients. The CBCT group (*n* = 58) (39 females/19 males with the mean age of 14.3 years) included those with conventional treatment records consisting of panoramic and cephalometric radiographs, intra- and extra-oral photographs, and dental casts complemented with a CBCT scan for additional diagnostic information. The conventional group (*n* = 60) (31 females/29 males with mean age 13.1 years) consisted of those with similar conventional treatment records but without CBCT imaging. There were significant differences in the canine-related variables between the two groups. The CBCT group had the higher level of difficulty and more severely displaced canines than did the conventional group. However, no significant difference was found between the groups either in the number of treatment methods used or in the use of interceptive methods combined with other treatment modalities or choice of extraction versus non-extraction. In terms of treatment success and interval duration, no significant differences were found. However, treatment duration was significantly shorter in the CBCT group (4 months) than in the conventional group ($P = 0.023$). CBCT has been used in cases with more severe signs of maxillary canine impaction. The use of CBCT improved the diagnostic capabilities and also the chance of success in the more difficult cases to a level similar to that of the simpler cases treated on the basis of 2D information.

Introduction

The aim of this retrospective study was to evaluate the outcomes of the orthodontic treatment method and treatment with or without the presence of complementary CBCT imaging.

Materials and methods

This investigation was a retrospective study based on the treatment records of patients who were treated by postgraduate residents at the Department of Oral Health Sciences, KU Leuven and Dentistry, University Hospitals Leuven, Leuven, Belgium. All of the patients were non-syndromic and selected according to the following inclusion criteria: 1) each patient had to present at least one impacted maxillary canine; and 2) complete orthodontic diagnostic pre- and post-treatment dental records had to be present (initial records and final records). The conventional treatment records included panoramic and cephalometric radiographs, intra- and extra-oral photographs, and dental casts. CBCT images were included if available.

The sample consisted of 118 patients treated consecutively (26 patients were used from chapter 5 and 92 patients were new patients). The diagnosis of impacted canines was determined from the patients' dental records. For the purpose of this study, the patients were divided into two groups. The CBCT group (*n* = 58) (39 females/19 males with the mean age of 14.3 years) consisted of those with conventional treatment records complemented with a CBCT scan for additional diagnostic information. The conventional group (*n* = 60) (31 females/29 males with the mean age of 13.1 years) consisted of those with similar conventional treatment records but without CBCT imaging. In all of the patients, the CBCT images were obtained at the same time as conventional radiographs or within a maximum interval of two weeks before the treatment start. All of the patients were referred for a CBCT examination because 3D visualization of the canine relative to the adjacent teeth was clinically indicated to develop the treatment plan.

The digital panoramic and lateral cephalometric radiographs were taken with two systems: a Cranex TOME® (Soredex, Helsinki, Finland) and the Veraviewepocs 2D® (J. Morita, Kyoto, Japan). The exposure parameters of Cranex TOME® were 15 s, 65 kV, and 15 mA. The Veraviewepocs 2D® panoramic and lateral cephalometric images were taken with a high-resolution CCD sensor (32-bit microprocessor) (J. Morita, Kyoto, Japan) with exposure parameters 7.4 s, 64 kV, and 8.9 mA. The CBCT scans were conducted with two CBCT systems. The first one involved a 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan) with a voxel size of 0.125 mm (FOV, 30×40 mm). The parameters included a tube voltage of 80 kV, a tube current of 3 mA, and a exposure time of 18 s. The second system was a SCANORA® 3D CBCT (Soredex, Tuusula, Finland) with a voxel size of 0.2 mm (FOV, 75×100 mm), tube voltage of 85 kV, a current of 10 mA, and an exposure time of 3.7 s.

The treatment protocol was standard for all patients in both of the groups, and modified standard edgewise appliances with conventional 0.018-inch bracket slots (GAC Dentsply, NY, USA) were used.

The evaluation protocol

The protocol included the evaluation of variables related to specific features obtained from dental and radiographic records, which were analyzed by one investigator (A. Alqerban). The variables were categorized as:

<u>Patient-level variables:</u>

1. Patient age
2. Patient gender

3. Treatment methods that were used either separately or in combination: A) interceptive treatment, B) extraction or non-extraction, C) removable extrusion appliance, and D) functional appliance.
4. Successful treatment was recorded if the treatment goals were achieved by the alignment of the impacted canine into the normal position and if the case resulted in stable occlusion.
5. The total treatment duration obtained from dental records.
6. The interval duration was calculated as the time between the start of the treatment and the start of orthodontic traction on the impacted canine for extrusion purposes.

Canine-level variables:

1. Canine crown position in relation to adjacent teeth: palatal, buccal, or in the arch line.
2. Type of canine impaction: partial vertical impaction, complete vertical impaction, and complete horizontal impaction.
3. Canine root development was assigned to one of two categories: incomplete root development, or complete root development.
4. The presence of abnormalities, such as mesiodens, peg-shaped lateral incisor, agenesis of permanent teeth, and impaction of other permanent teeth.
5. Pre-treatment presence and severity of incisor root resorption, and whether resorption defects were present in the lateral and/or in the central incisor. The severity of root resorption was recorded on the basis of the grading systems suggested by Ericson and Kurol.[52]
6. The mesio-distal space available for the canine was assigned to one of three categories, modified from Cernochova *et al.*,[31] as follows: A) lack of space for the erupting canine, B) complete loss of space, and C) sufficient space available for the canine.

7. The vertical location of the maxillary canine crown was assigned to one of five categories, modified from Power and Short[120] *(Fig 8.1)*.
8. The canine overlap with adjacent teeth (sector) was assigned according to one of six categories, modified from Ericson and Kurol[49] *(Chapter 7, Fig 7.2)*.
9. Permanent maxillary canine angulations: Three angles were measured on the panoramic radiographs: A) canine angulation to the midline, B) canine angulation to the lateral incisor, and C) canine angulation to the occlusal plane *(Fig 8.1)*.
10. The surgery performed during treatment was recorded.
11. Complications during treatment included: canine root resorption, canine extraction, extraction of the lateral incisor, poor oral hygiene, and poor patient cooperation.
12. The post-treatment presence and severity of root resorption of lateral and/or in the central incisors were recorded.

Statistical Methodology

The Fisher's Exact, Mann–Whitney U, and Trend tests were used to compare the two groups. A propensity score (PS) was used to balance differences between groups.[39] The PS was defined as the conditional probability of using 3D given the patient and canine variables. This probability was determined according to a multivariable logistic regression model in which several covariates were considered as predictors. The covariates were those that differed (P <0.10) between groups in a univariate setting. The Area Under the Curve (AUC) is known as the C index of the propensity model, which reflects the amount of overlap in differences between groups (0.5 = no discrimination, 1 = perfect discrimination and no overlap at all). Moreover, the higher the AUC, the less meaningful the between-group comparison. To evaluate the differences between groups,

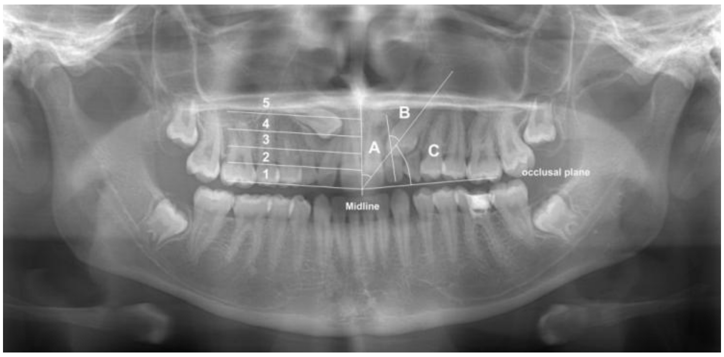


Fig 8.1: Panoramic image of a 14-year-old female patient with a bilateral impacted canine, illustrating the reference lines of the vertical canine location 1. below the level of the cemento-enamel junction of the adjacent lateral incisor, 2. in the cervical third of the adjacent lateral incisor root, 3. in the middle third of the adjacent lateral incisor root, 4. in the apical third of the adjacent lateral incisor root, or 5. above the apical third of the adjacent lateral incisor root. as well as the canine angulation measurements A. to the midline, B. to the lateral incisor, and C. to the occlusal plane.

corrected for imbalances, the propensity score (PS) was used as a covariate in regression models. Linear regression models were used for continuous outcomes (treatment duration and interval duration). The risk ratios for binary outcomes were obtained from a binomial regression model with a log-link function. Linear regression models were used for treatment outcomes. A robust variance estimate (GEE) was used for outcomes, which can vary within a patient with a bilateral impaction.[134] In addition, the receiver operating characteristic analysis (ROC), based on the empirical distribution to derive the optimal cutoff point for the canine angulation measurements, was used to discriminate between groups. The optimal point was defined as the value that maximizes the Youden Index (the sum of sensitivity and specificity minus one).

P-values less than 0.05 were considered significant. All of the analyses were performed with SAS software, Version 9.2, of the SAS System for Windows (Copyright © 2002, SAS Institute Inc., Cary, NC, USA).

Results

Comparison between CBCT and conventional groups

Table 8.1 presents descriptive statistics for the general evaluation variables of the two patient groups. The patients' ages and genders were significantly different between the two groups. The CBCT patients were older, and there were more female patients than in the conventional group. In the CBCT group, the following canine-related variables were noted significantly more often: complete horizontal impaction, canine crown location in the apical third or above the adjacent teeth and mesially located to the lateral incisor root *(Table 8.2)*. The canine angulations to the midline as well as to the lateral incisor were increased and decreased to the occlusal plane *(Table 8.3)*. The optimal cutoff points for canine angulation measurements were used to discriminate between groups: 16.4° to the midline, 33.2° to the lateral incisor, and 66.7°to the occlusal plane. Moreover, the presence of abnormalities and the pre-treatment lateral incisor root resorption were higher in the CBCT group *(Table 8.2)*.

Table 8.1: Descriptive statistics of general evaluation based on patient-level variables of two patient groups

		CBCT group *n*=58	Conventional group *n*=60
Age (years)	Mean (SD)	14.3 (5.1)	13.1 (2.8)
	Median (range)	13.2 (9.3-37.3)	12.3 (10.1-24.1)
Gender	Male	19 (33%)	29 (48%)
	Female	39 (67%)	31 (52%)
Skeletal relation	Neutro-relation	27 (46%)	36 (60%)
	Disto-relation	23 (40%)	21 (35%)
	Mesio-relation	8 (14%)	3 (5%)

Table 8.2: Comparisons of canine-level variables (CBCT group n=74 impacted maxillary canines and conventional group n=81 impacted maxillary canines) in percentage (%) between two patient groups

		CBCT n=74	Conventional n=81	P-value
Angle classification before treatment	Class I	28 (38%)	26 (32%)	N.S.
	Class II	44 (59%)	55 (68%)	
	Class III	2 (3%)	0 (0%)	
Canine location	Palatally	27 (37%)	33 (41%)	N.S.
	Buccally	35 (47%)	40 (49%)	
	Line of the arch	12 (16%)	8 (10%)	
Type of impaction	Partial vertical impaction	7 (10%)	18 (22%)	0.01
	Complete vertical impaction	56 (75%)	59 (73%)	
	Complete horizontal impaction	11 (15%)	4 (5%)	
Canine root development	Incomplete development	31 (42%)	39 (48%)	N.S.
	Complete development	43 (58%)	42 (52%)	
Presence of abnormality	No abnormality	42 (57%)	61 (75%)	0.01
	Abnormality	32 (43%)	20 (25%)	
Presence of root resorption pre-treatment	No root resorption	46 (62%)	78 (96%)	<.001
	Root resorption	28 (38%)	3 (4%)	
MD space	Lack of space	32 (43%)	45 (56%)	N.S.
	Complete loss of space	19 (26%)	16 (20%)	
	Sufficient space without crowding	23 (31%)	20 (25%)	
Vertical canine crown height	In occlusion	3 (4%)	5 (6%)	<.001
	In the cervical third	21 (28%)	44 (54%)	
	In the middle third	33 (45%)	30 (37%)	
	In the apical third	15 (20%)	2 (2%)	
	Above the apical third	2 (3%)	0 (0%)	
Canine overlap of adjacent teeth	Distal to the normal position	3 (4%)	1 (1%)	0.006
	Normal position	18 (24%)	36 (44%)	
	Distal to the lateral incisor	24 (33%)	32 (40%)	
	Mesial to the lateral incisor	15 (20%)	5 (6%)	
	Distal to the central incisor	8 (11%)	5 (6%)	
	Mesial to the central incisor	6 (8%)	2 (2%)	

The non-randomized characteristics of the study showed that the between-group patient and canine variables differed, especially as the choice for the use of CBCT as a diagnostic tool was related to the anticipated level of diagnostic difficulty and complexity or to the treatment planning needs. This yielded a potentially biased estimate of the differences in treatment methods and outcomes between groups. Therefore, the PS (the probability) for CBCT was used as a covariate in regression models to correct the imbalance. The AUC of this model quantified the amount of overlap of

Table 8.3: Comparisons of impacted maxillary canine angulations (CBCT group n= 74 maxillary canines and conventional group n=81 impacted maxillary canines) in degree between two patient groups

		CBCT *n*=74	Conventional *n*=81	*P*-value
Canine angulation to the midline	Mean (SD)	23.3 (19.7)	14.1 (12.4)	0.003
	Median (range)	18.9 (0.3-87.0)	10.7 (0.1-52.7)	
Canine angulation to the lateral incisor	Mean (SD)	34.3 (19.5)	24.5 (12.5)	0.002
	Median (range)	30.0 (2.2-81.2)	23.4 (1.9-55.9)	
Canine angulation to the occlusal plane	Mean (SD)	57.3 (20.2)	65.9 (13.5)	0.008
	Median (range)	59.6 (4.1-95.1)	69.8 (22.6-96.9)	

variables between groups and was equal to 0.755 (95% CI: 0.68–0.83). A reasonable amount of overlap between the CBCT and conventional groups was found to facilitate the comparison of treatment methods and outcomes.

Comparison of treatment methods and outcomes

There was no difference between groups in either the number or choice of treatment methods used, i.e., interceptive methods combined with other treatment modalities such as choice of extraction vs. non-extraction or type of appliance used. Both groups showed almost identically successful treatment rates (respectively, 90% and 87%). Treatment duration was significantly (four months) shorter in the CBCT group than in the conventional group (P = 0.023), and the interval between the start of treatment and the start of traction was slightly shorter (2.6 months) but not significantly different in the CBCT group *(Table 8.4)*. However, the surgical interventions needed during treatment and the incidence of complications as well as the incidence of root resorption post-treatment were higher in the CBCT group but not significantly different after imbalances were corrected *(Table 8.5)*. The presence and the severity of root resorption detected in lateral and central incisors pre- and post-treatment are shown in *Table 8.6*. The relative risks for the incidence of complications, the need for surgical

Table 8.4: Comparison of patient-level variables of treatment methods and treatment outcomes (CBCT group n=58 patients and conventional group n=60 patients) between two patient groups. None of these comparisons differed significantly (p>0.05)

		CBCT *n*=58	Conventional *n*=60
Number of treatment methods used	One method	3 (5%)	1 (2%)
	2 methods	17 (29%)	17 (28%)
	3 methods	28 (48%)	31 (51%)
	> 4 methods	10 (18%)	11 (19%)
Interceptive treatment with another	No	28 (48%)	28 (47%)
	Yes	30 (52%)	32 (53%)
Extraction treatment	No	30 (52%)	37 (62%)
	Yes	28 (48%)	23 (38%)
Successful treatment	No	6 (10%)	8 (13%)
	Yes	52 (90%)	52 (87%)
Treatment duration (months)	Mean (SD)	30.1 (9.4)	34.1 (7.7)
	Median (range)	33.7 (5.4-49.8)	34.3 (17.1-51.7)
Interval duration (months)	Mean (SD)	8.2 (6.3)	10.4 (6.6)
	Median (range)	8.1 (-0.2-23.7)	9.0 (-1.9-24.8)

intervention, and root resorption are shown in *Table 8.7*. The relative risk for the increased incidence of complications during treatment was not negligible [RR = 1.93 (95%CI: 0.80; 4.66)].

Discussion

The orthodontic treatment methodology for impacted canines depends on various factors such as the location of the impacted canine in the dental arch relative to adjacent incisors, the distance from the occlusal plane, canine crown overlaps, and canine angulations.[69, 135] These variables are also used as predictors of the duration of orthodontic treatment until alignment of the canine is achieved.[135, 154] In the present study, radiographic variables were evaluated in pre-treatment panoramic and lateral cephalometric radiographs and with CBCT if it was available. As both groups had panoramic images, the angulation measurements, overlaps, and vertical

Table 8.5: Comparison of canine-level variables treatment outcomes (CBCT group n= 74 impacted maxillary canines and conventional group n=81 impacted maxillary canines) in percentage (%) between two patient groups. None of these comparisons was significantly different (P >0.05)

		CBCT *n*=74	Conventional *n*=81
Surgery	No	33 (45%)	62 (77%)
	Yes	41 (55%)	19 (23%)
Complication during treatment	No	52 (70%)	73 (90%)
	Yes	22 (30%)	8 (10%)
Presence of root resorption post-treatment	No	19 (26%)	34 (42%)
	Yes	55 (74%)	47 (58%)
Post treatment Angle classification	Class I	51 (69%)	58 (72%)
	Class II	21 (28 %)	19 (23%)
	Class III	2 (3%)	4 (5 %)

canine height determinations were performed on panoramic radiographs rather than on CBCT images. Linear measurements were not performed on panoramic radiographs due to the amount of distortion and magnification.[4, 55, 131] Therefore, overlap with adjacent teeth and vertical height were used instead of linear measurement to locate the impacted canine.

Complications are common during treatment in patients with impacted canines.[141] The increased incidence of complications and surgeries in the CBCT group was because of between-group differences: most cases in the CBCT group had more severely displaced canines (more complete horizontal impaction, severe angulation, location in the apical third or above the adjacent teeth, and mesial location with respect to the lateral incisor root ≥ sector 2) when compared with those of the conventional group. Another reason for this difference could be patient age and gender. The mean age of those in the CBCT group was higher, and there were more females than in the conventional group. According to the literature, the incidence of females exhibiting maxillary canine impaction shows strong prevalence, with more

Table 8.6: Comparison in percentage (%) of the presence and severity of root resorption, pre and post-treatment between two patient groups

	Tooth	Severity	CBCT *n*=58 (%)		Conventional *n*=60 (%)		*P*-value
Root resorption pre-treatment	Lateral incisor	Slight	37.9	32.5	2.5	2.5	<0.0001
		Moderate		2.7		0	
		Severe		2.7		0	
	Central incisor	Slight	4.0	2.7	1.3	1.3	N.S.
		Moderate		1.3		0	
		Severe		0		0	
Root resorption post-treatment	Lateral incisor	Slight	56.8	20.3	55.6	33.4	N.S.
		Moderate		24.3		18.5	
		Severe		12.2		3.7	
	Central incisor	Slight	44.6	9.5	29.7	14.8	N.S.
		Moderate		23.0		12.4	
		Severe		12.1		2.5	

root resorption and more complications that with the incidence in males.[18, 20, 141] Previous investigations have compared treatment planning differences between the use of 2D images and of CBCT images.[26, 63, 150] The results in two studies showed that there was a difference in treatment planning.[26, 63] However, it has been found that the treatment proposal for impacted canines did not differ whether based on 2D or 3D information, which is in agreement with our findings.[150]

The mean treatment duration in the CBCT group was 32.9 months (SD, 9.3 months) and for control group, 34.1 months (SD, 7.7 months). In our study, all of the patients were treated by postgraduate residents under supervision as a part of their clinical training, which took longer than with treatment by an experienced orthodontist. All of the clinical supervisors were experienced in the treatment of impacted canines and had at least five years of clinical experience in all aspects of orthodontic treatment. The second reason for the differences could be that the treatment times were recorded as

Table 8.7: Relative risk (RR) of treatment methods and outcomes between the CBCT group and the conventional group

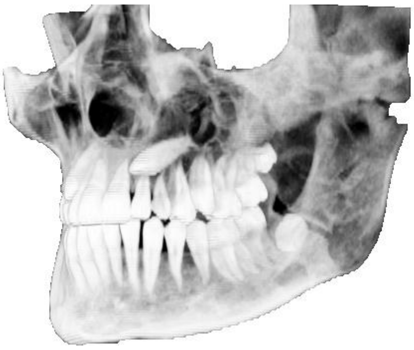
	Relative risk
Interceptive treatment with another	1.01 (0.70;1.46)
Extraction treatment	1.41 (0.91;2.20)
Successful treatment	0.70 (0.21;2.32)
Surgery	1.45 (0.78;2.71)
Complication during treatment	1.93 (0.80;4.66)
Root resorption post-treatment	1.16 (0.87;1.54)

the period from the date of treatment began to the date it ended (start of the retention phase) and not from the date of surgical exposure to the date of alignment correction. Treatment duration was found to be 4 months shorter in the CBCT group. Defining the exact location of the impacted canine in three dimensions is crucial in treatment planning and facilitates decision-making, which may result in direct access or traction, and less invasive and less time-consuming treatment. Moreover, the accurate 3D visualization of the impacted canine helped the treating orthodontist move the canine into normal occlusion without further delay.

A randomized clinical trial cannot be performed in this kind of study because it is unethical to expose patients randomly to CBCT without clinical or radiological justification. Our concern was that patients with impacted canines should not be exposed to additional radiation for the sole purpose of study. Further studies, both randomized and prospective should be performed to verify treatment outcomes and the benefits of using CBCT in cases of impacted canines.

Conclusion

CBCT has been used in cases with more that usually severe symptoms of maxillary canine impaction and may well reduce the duration of treatment. The use of CBCT improved the diagnostic capabilities of the orthodontist and improved the chances of success in the more difficult cases to a level similar to that of simpler cases treated on the basis of 2D information.



Chapter 9

The prediction of lateral incisor root resorption based on conventional 2D radiographs

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Predictors of root resorption associated with maxillary canine impaction in panoramic images

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Abstract

The aim was to identify a prediction model for root resorption caused by impacted canines based on radiographic variables assessed on 2D panoramic radiographs in order to reduce the need for additional CBCT imaging. Three hundred and six patients (188 female, 118 male; mean age, 14.7 years; SD, 5.6; range, 8.4-47.2 years) were included in the study. In total, 406 impacted maxillary canines were studied involving 206 patients with unilateral impaction and 100 patients with bilateral impaction. Initial 2D panoramic radiography was available, and 3D CBCT imaging was obtained upon clinical indication. The generated radiographic variables and specific features investigated were collected with 2D panoramic imaging and were correlated with the presence or absence of root resorption detected on CBCT. A validation sample consisted of 55 canines from 45 patients with maxillary canine impactions was collected to validate the outcome of the present study. The incidence of root resorption of the adjacent teeth was 33.8%. A prediction model using panoramic images for the possible presence of root resorption was established (AUC = 0.74, 95%CI: 0.69; 0.79) and validated by applying leave-one-out cross-validation (AUC = 0.71, 95%CI: 0.66; 0.77). For the subgroup of presence of severe root resorption, the discriminative ability increased to 0.80. In this prediction model, patient gender, canine apex, vertical canine crown position, and canine magnification were the strongest predictors for root resorption. Prediction of root resorption based on panoramic radiographs is difficult. The final prediction model for root resorption based on available panoramic radiographs could be a helpful tool for justifying the need of additional CBCT examination.

Introduction

Hitherto, CBCT could not be used as a primary imaging mechanism for impacted canines, replacing the conventional modality, because of radiation dose, equipment availability and cost. Moreover, patients undergoing orthodontic treatment receive repeated x-ray exposure after the initial radiographic examination.[68] Indeed, radiation exposure must be minimized as much as possible. A number of factors of root resorption have been proposed.[31, 44, 50, 53, 76, 84, 123, 151] However, there has been considerable debate regarding the radiographic predisposing factors of root resorption. Moreover, no validation of the suggested predictive factors has been conducted, nor has a prediction formula been developed based on 2D panoramic radiographs to identify the risk of root resorption (RR) and the need for supplementary CBCT examination.

The aim of this study is to identify a prediction model for root resorption caused by impacted canines based on parameters evaluated on 2D panoramic radiographs with the intention of reducing the use of additional CBCT imaging.

Materials and methods

Three hundred and six patients (188 female, 118 male; mean age, 14.7 years; SD, 5.6; range, 8.4-47.2 years) were included in the study. The patients were identified and selected from among those seeking orthodontic treatment at the Department of Oral Health Sciences, KU Leuven & Dentistry, University Hospitals Leuven, Leuven, Belgium. The selection criteria were: 1) All patients must be non-syndromic; 2) each patient must present at least one impacted maxillary canine; 3) no prior orthodontic treatment has been performed; and 4) each patient must have had 2D panoramic radiographs and CBCT scans within at most 2 weeks.

In total, 306 patients were selected for the study (251 patients were collected from the database from the period 2004-2013 following the inclusion criteria. 55 patients were used from the sample of chapter 8-Patients). 100 patients had a bilateral impaction, so there were 406 impacted maxillary canines. For all of the patients, CBCT scans had been clinically justified prior to the start of this study to determine the canine location, the presence or not of RR on adjacent teeth, and the treatment requirements.

Digital panoramic radiographic images were acquired with two systems: Cranex TOME® (Soredex, Helsinki, Finland) and the Veraviewepocs 2D® (J. Morita, Kyoto, Japan). CBCT scans were carried out with 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan) and SCANORA® 3D CBCT (Soredex, Tuusula, Finland).

The radiographic measurements along with measurement of specific features were obtained from 2D panoramic images and correlated to the presence or absence of RR detected on CBCT, which was used as a gold standard (baseline).

The Evaluation Protocol

1. The presence and severity of incisor RR and of resorption defects in lateral and/or central incisors were determined. The severity of RR was recorded from CBCT images based on the grading systems suggested by Ericson and Kurol.[52]
2. When RR was diagnosed from CBCT images, its location in either the apical, middle, or cervical third was recorded.
3. Canine position in relation to adjacent teeth was determined from CBCT images to be palatal, buccal, or in the line of the arch.
4. The primary maxillary canine was assigned to one of three categories: 1) missing tooth, where the deciduous canine had been extracted; 2) no RR; or 3) RR.

5. Crowding in the upper anterior region.

6. The anterior apical area was recorded as optimal, small, or severe.

7. The mesio-distal space available for the canine was assigned to one of three categories, modified from Cernochova et al.,[31] as follows: A) lack of space for the erupting canine, B) complete loss of space, or C) sufficient space available for the canine.

8. The canine magnification. If the impacted canine is relatively magnified in comparison to the adjacent teeth or in comparison to the contra- lateral canine.[101]

9. The canine apex was determined to be either open, closed, or dilacerated.

10. The canine impaction was determined to be either vertical or horizontal.

11. The canine development was assigned to 1 of 4 categories based on root development: complete development; 3/4 of the root developed; 1/2 of the root developed; and 1/4 of the root developed.

12. The presence of abnormalities, such as a mesiodens or supernumerary tooth, peg-shaped lateral incisor, agenesis of permanent teeth, and impaction of other permanent teeth, was identified.

13. The permanent maxillary canine angulations: Three angles were measured on the panoramic radiographs: canine angulation to the midline, to the lateral incisor; and to the occlusal plane *(Chapter 8, Fig 8.1*).

14. The vertical location of the maxillary canine crown was assigned to one of five categories, modified from Power and Short *(Chapter 8, Fig 8.1*).[120]

15. The canine overlap with adjacent teeth (sector) was assigned to one of six categories, modified from Ericson and Kurol.[49]

A validation sample was collected to validate the outcome of the present study. The validation sample consisted of 55 canines from 45 patients with maxillary canine impactions (in the period from 1/10/2013 until 18/03/2014).

Statistical Methodology

The variables between resorbed and non-resorbed teeth were compared by exact trend, Fisher's exact and Mann-Whitney U-tests. For each variable, based on its empirical distribution function, the degree of discrimination (resorption vs. non-resorption), was quantified with the area under the curve (AUC), known as the concordance index (c-index). This index ranges from 0.5 (random prediction) to 1 (perfect discrimination). A multivariable prediction model was obtained by a backward selection procedure with 0.157 as the critical level for the *P*-value, which corresponds to the use of the Aikake Information Criterion (AIC) for model selection. With AIC, it was required that the increase in model χ^2 must be more than twice the degrees of freedom. A bootstrap re-sampling procedure was used to verify if variables retained in the final multivariable model were 'truly' independent predictors or were merely noise variables.[11] In the applied modeling approach, the same data were used to develop and validate the model. There was also a risk of overfitting due to the consideration of so many predictors compared with the number of resorptions and from the application of an automated model selection procedure.[136] The resulting prediction model and its related AUC would, therefore, be overoptimistic in the sense that future performance in a new study population would be overestimated. Therefore, a leave-one-out cross-validation was applied. Further, an optimism-corrected estimate of the performance (AUC) was obtained by a bootstrap re-sampling procedure. Finally, a (uniform) shrinkage factor based on the χ^2 model of the final model and the total number of degrees of freedom considered (df = 17) was applied to the estimates from the final model.[136] Application of this shrinkage factor avoids extreme predictions.

The prediction model was constructed on the side level and not on the patient level. As such, *P*-values obtained in the univariable and multivariable analyses were based on the assumption that both sides were independent. Although this assumption is too simplistic [the ICC equals 0.37 (95% CI: 0.17-0.55),[153] indicating that the probability of having resorption was related between both sides], note that the interest was not in the *P*-values as such but in the predictive ability of the model. All analyses were performed with SAS software, Version 9.2, of the SAS System for Windows (Copyright © 2002 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.).

Results

The incidence of RR of adjacent teeth was 33.8%. *Table 9.1* shows the presence, severity, and location of detected RR in adjacent teeth. *Table 9.2* gives the results of the univariable logistic regression models to predict the presence of resorption. The results from the multivariable model are given in *Table 9.3*.

The prediction formula of the probability of presence of RR is:

Probability of RR = exp (μ)/1+exp(μ), where

μ = (-0.031 x Age in years + 0.499 x Female – 0.384 x Optimal apical Area+ 0.585 x canine magnification - 1.380 x Open canine apex - 0.532 x Horizontal + 0.434 x Detection of abnormality + 0.018 x Canine angulation to the midline + 0.837 x Vertical canine crown above middle third + 0.118 x Vertical canine crown position - 0.671).

Predictor not present = 0, Predictor present = 1

To avoid too extreme predictions due to over-fitting, a shrinkage factor should be applied to each of these estimates (by multiplying each estimate with this factor). The shrinkage factor equals 0.85 which is derived from the model χ^2 of 113.1 and the 17° of freedom in the initially considered list of predictors.

Among the 9 variables retained in the final multivariable prediction model, 4 variables (patient gender, canine apex, vertical canine crown position, and canine magnification) are strong independent predictors for RR. The index of discrimination (AUC) of this final model equals 0.75 (0.69; 0.79) *(Fig 9.1)*. Application of a leave-one-out cross-validation resulted in an AUC equal to 0.71 (0.66; 0.76). An optimism-corrected estimate of the AUC which also accounted for the model-building approach equals 0.70 (hence, the over optimism in AUC equals 0.04). The performance on validation group was comparable with the estimate obtained after cross-validation. The

Table 9.1: The presence, severity, and location of root resorption in percentages (%)

Tooth			*n*	%
Lateral incisors	Presence of root resorption	No resorption	282	69.46
		Resorption	124	30.54
	Severity	Slight	64	15.76
		Moderate	26	6.40
		Severe	34	8.37
	Location	Cervical third	15	3.69
		Middle third	39	9.61
		Apical third	70	17.24
Central incisors	Presence of root resorption	No resorption	384	94.58
		Resorption	22	5.42
	Severity	Slight	9	2.22
		Moderate	6	1.48
		Severe	7	1.72
	Location	Cervical third	2	0.49
		Middle third	4	0.99
		Apical third	16	3.94
Premolars	Presence of root resorption	No resorption	401	98.77
		Resorption	5	1.23
	Severity	Slight	3	0.74
		Moderate	1	0.25
		Severe	1	0.25
	Location	Cervical third	0	0
		Middle third	1	0.25
		Apical third	4	0.99

Table 9.2: Results from univariable logistic regression models to predict the presence of root resorption

	Odds Ratio (95%CI)	*P*-value	AUC (95%CI)
Age (years)	1.019 (0.98;1.06)	0.29	0.595 (0.54;0.65)
Female vs. male	0.524 (0.34;0.81)	0.004	0.574 (0.53;0.62)
Resorbed root for primary canine	1.012 (0.66;1.55)	0.95	0.501 (0.46;0.55)
Crowding in the upper anterior region	0.598 (0.36;0.98)	0.04	0.547 (0.50;0.59)
Optimal apical area	0.933 (0.62;1.42)	0.74	0.508 (0.46;0.56)
Sufficient MD space	1.054 (0.70;1.59)	0.80	0.506 (0.46;0.56)
Canine location		0.14	0.555 (0.50;0.61)
Buccally	0.967 (0.71;1.32)	0.83	
Line of the arch	0.787 (0.56;1.12)	0.18	
Canine magnification	2.412 (1.56;3.74)	<.0001	0.604 (0.56;0.65)
Open canine apex	0.302 (0.19;0.47)	<.0001	0.641 (0.59;0.69)
Type of impaction (Horizontal vs. vertical)	1.727 (1.04;2.87)	0.03	0.544 (0.50;0.59)
Complete canine development	2.722 (1.63;4.55)	0.0001	0.593 (0.55;0.64)
Detection of abnormality	1.322 (0.83;2.11)	0.24	0.527 (0.48;0.57)
Canine angulation to the midline	1.025 (1.01;1.04)	<.0001	0.657 (0.60;0.71)
Canine angulation to the occlusal plane	1.020 (1.01;1.03)	0.0004	0.610 (0.55;0.67)
Canine angulation to the lateral incisor	0.975 (0.96;0.99)	<.0001	0.644 (0.59;0.70)
Vertical canine crown position		0.0025	0.595 (0.54;0.65)
Above middle third	1.693 (1.26;2.28)	0.0006	
In the middle third	0.887 (0.67;1.18)	0.41	
Canine overlap distal to the lateral incisor or below	0.365 (0.24;0.56)	<.0001	0.621 (0.57;0.67)

AUC of the prediction model after validation equals 0.687 (CI: 51.4 to 86.0) with a sensitivity of 50% (CI: 24.7% to 75.4%) and a specificity of 84.6% (CI: 69.5% to 94.1%) when 0.50 is used as cutoff. *Fig 9.2* shows the distribution of the cross-validated predicted probabilities of RR for patients without RR and for patients with slight, moderate and severe RR. *Fig 9.3* shows the probability of RR for a patient using the final prediction model.

Discussion

This study tested the variables and factors associated with panoramic radiography and confirmation of the presence of RR as well as canine localization and was performed with CBCT images (as a gold standard), since the diagnostic ability of CBCT for these application has been

Table 9.3: Results from the final multivariable logistic regression model (obtained after applying a backward selection procedure with 0.157 as the critical level for a P-value to remain in the model) and results from the bootstrap resampling procedure

	Estimate	Odds ratio (95%CI)	*P*-value	BIF (%)
Age (years)	-0.031	0.968 (0.93;1.00)	0.075	62
Female vs. male	-0.499	0.599 (0.37;0.97)	0.038	82
Optimal apical area	-0.384	0.690 (0.43;1.11)	0.124	61
Canine magnification	0.585	1.801 (1.10;2.95)	0.019	82
Open canine apex	-1.380	0.250 (0.15;0.41)	<.0001	100
Type of impaction (Horizontal vs. vertical)	-0.532	0.605 (0.31;1.19)	0.144	38
Detection of abnormality	0.434	1.530 (0.90;2.61)	0.117	53
Canine angulation to the midline	0.018	1.018 (1.00;1.04)	0.052	50
Vertical canine crown position			0.024	90
Above middle third	0.837	2.282 (1.10;4.72)	0.026	
In the middle third	0.118	1.133 (0.61;2.12)	0.696	
Intercept	-0.671			

Estimate: estimates on the logit scale. BIF: bootstrap importance frequency, which indicates the percentage of the specific predictor that retained in the final model (bootstrap). The AUC of the final model equals 0.744 (95% CI: 0.695;0.794).estimate of the AUC which also accounted for the model-building approach equals 0.70 (hence, the over optimism in AUC equals 0.04).

demonstrated with high sensitivity and better specificity than that achievable with panoramic images.[4] The contact relationship between the impacted canine and adjacent teeth was not examined nor were linear measurements taken because of the limitations of panoramic radiographs. Predisposing factors such as patient age and gender have been extensively studied.[45, 123] Conversely, no differences were found in either the severity or the location of RR.[47] Our results confirmed that female patients exhibit more RR than do males because females experience more canine impaction.[45, 123] However, other studies have shown no relation between gender and the presence of RR,[31, 76, 84] while gender has been found to be a factor in RR only in the central incisor.[151]

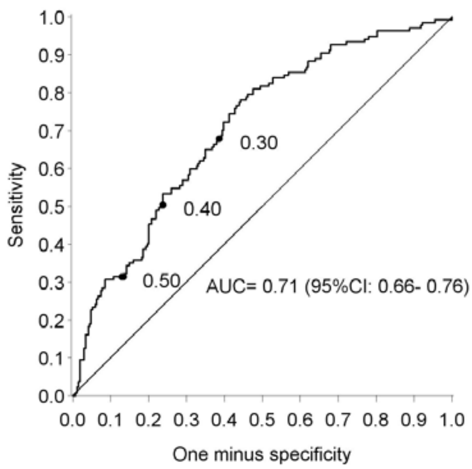

Fig 9.1: The ROC-curve of the final multivariable model. This curve presents the sensitivity and (one minus) specificity of all possible classifications using different cut-offs for the (cross-validated) predicted probability of root resorption. As an illustration, three cut-offs for the probability are labeled.

The use of 3D images has shown no relationship between resorption and enlarged dental follicles of impacted canines, as well as the retention or premature loss of the deciduous canine.[44, 121, 123, 130] In a 2D study, the combination of mesially located canines, angulations to the midline exceeding 25°, and completed root development, the risk of RR increased by 50%.[50] However, there has been considerable debate regarding the radiographic predisposing factors of RR. Several studies have investigated possible radiographic predictors for RR and have shown significant interaction among several factors, including: canine development, space available for the impacted canine, contact relationship, canine overlap, canine position, vertical location of canine, and linear and angular measurements.[31, 44, 50, 76, 84, 123, 151] With CBCT, studies have shown that there were correlations between RR and contact relationship, closed canine apex, canine position, mesial overlap with adjacent teeth, and space available for the impacted canine.[31, 71, 76, 129, 151] In contrast, canine overlap,[8, 121, 130] contact

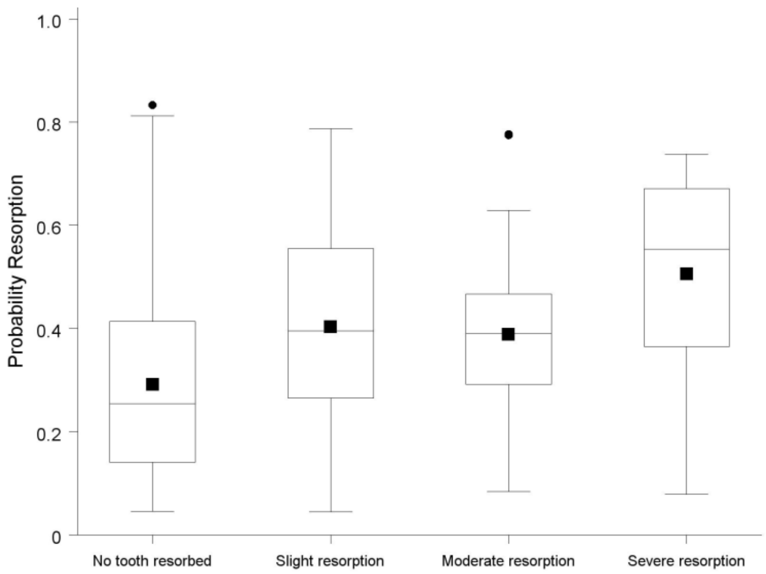

Fig 9.2: Boxplots of the cross-validated probabilities for canines without resorption and subjects with various degrees of resorption. The AUC quantifying the overlap between root resorption and without resorpion equals 0.673, 0.666 and 0.799 for slight (n=69), moderate (n=29) and severe (n=39) resorption, respectively.

relationship,[121, 130] canine inclinations,[31, 76] and canine position[84] were not found in other studies to be factors involved in lateral incisor RR. In addition to the contradictory results of previous studies, those studies showed only the significant relation between RR and radiographic factors. Furthermore, they failed to verify whether those factors were independent predictors or whether they showed interaction between each other and they also failed to validate the proposed predictors.

In the present study, univariable analysis revealed that crowding, complete canine development and canine mesial overlap with adjacent teeth have significant relations with the presence of RR. However, when considering the multivariable analysis, they were not confirmed as predictors of RR, so they were not incorporated in the final prediction model. Gender, canine apex, vertical canine crown position, and canine magnification were

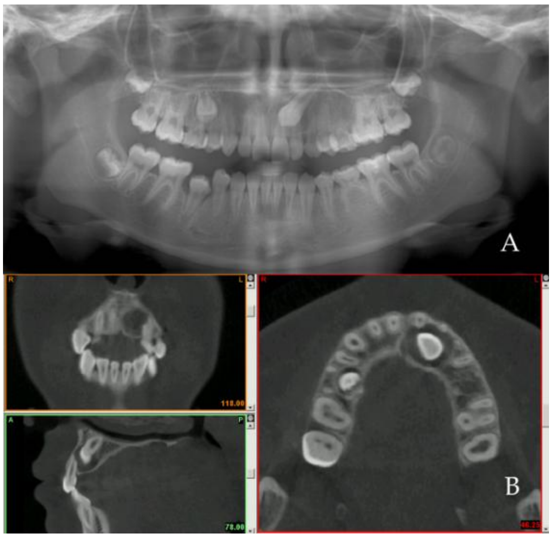

Fig 9.3: An example of prediction model of root rsorption of 13 years and 6 month old female patient with unilateral impacted canine illustrating the probability of root resorption as follow:

$$\mu = (-0.031 \times 13.6 + 0.499 \times 1 - 0.384 \times 1 + 0.585 \times 1 - 1.380 \times 0 - 0.532 \times 0 + 0.434 \times 1 + 0.018 \times 41 + 0.837 \times 1 + 0.118 \times 0 - 0.671) = 1.6164$$

Probability of RR = exp (1.6164)/1+ exp(1.6164)= 83%

A) Panoramic image. B) CBCT views (coronal, sagittal, and axial) confirming the presence of root resorption of the adjacent lateral incisor.

the strongest predictors for RR in the prediction model because they were significant at the $P<0.05$ level in the final model, and, more importantly, they were also retained in the final multivariable model in at least 80% of the bootstrap samples with which the same model selection method was used as in the original sample. This is in accordance with results from another CBCT study showing that, when an impacted canine crown is located apically to adjacent teeth with closed apex, a higher rate of RR occurs.[84]

The AUC index of the final model was overoptimistic, since the same data were used to build and validate the model (leave-one-out cross-validation). Therefore, a new validation sample was used to validate the final prediction model. The AUC index of the prediction model after validation equals 0.687 (CI: 51.4 to 86.0) with a sensitivity of 50.0% (CI: 24.7% to 75.4%) and a specificity of 84.6% (CI: 69.5% to 94.1%) when 0.50 is used as cutoff. The ROC curve shows the implications on sensitivity and specificity of various choices for the cut-off value of the predicted probability. For instance, when 0.50 was used as a cut-off, the specificity equals 85.1% (95%CI: 80.3; 89.2). This implies that 85% of the non-resorbed teeth will be correctly identified. However, this results in low sensitivity, i.e. 34.3% (95%CI: 26.4%; 42.9%). To increase the sensitivity, the cut-off needs to be lowered. For example, if one would decide not to undergo CBCT if the probability of RR is lower than 0.30, the sensitivity increases to 71.5% but at the cost of a decreased specificity (60.1%). Even if the emphasis would be put on maximizing the sensitivity by lowering the cutoff, the false-negative rate would remain non-negligible. For example, with the cut-off put at 0.10, still 13.9% of the 'non-resorption' predictions would be false. However, the results in *Fig 9.2* indicate that false-negative predictions are less likely for severe resorption. The discriminative ability of the prediction model was indeed substantially higher when comparing the non-resorbed only with the severely resorbed (AUC = 0.799 instead of AUC = 0.709 for all RR combined). It would be of interest to develop a prediction model specifically for the presence of severe RR. To accomplish this with a multivariable model, a larger number of severe RR is needed.

This study was not carried out to emphasize that panoramic radiographs could be used to detect RR. However, the prediction model was generated and tested to help the clinician estimate the probability of presence of RR on the basis of the available panoramic radiograph in order to justify the use of CBCT. Therefore, the need for CBCT diagnosis of root resorption due to maxillary canine impaction can be judged by using the prediction model together with the clinical parameters, and specific treatment plan options.

Conclusions

The prediction of root resorption based on panoramic radiographs is difficult. The final prediction model for root resorption based on available panoramic radiographs may help to justify the need for additional CBCT examination.

Chapter 10

Radiographic predictors for canine impaction based on CBCT images

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Radiographic Factors in Unilateral Maxillary Canine Impaction

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Abstract

The aim is to compare 3D CBCT images of patients affected with unilaterally impacted canines and to determine possible radiographic factors relevant for predicting maxillary canine impaction. The sample consisted of 65 patients ranging in age from 9.6 to 13.8 years. The patient population was consisted of 43 females and 22 males, with a mean age of 12.1 yrs and a median age of 12.2 yrs (± SD, 1.23). Of the impacted maxillary canines, 32 were located on the right side (Tooth 13) and 33 on the left side (Tooth 23). CBCT radiography was available for all of the patients. The diagnosis of unilaterally impacted canine was determined from the patients' dental records as a unilateral failure of the canine to erupt at its appropriate site in the dental arch in contrast to normal eruption of the contralateral side. Radiographic follow-up assessment to identify unilateral impaction was performed for a period of 1 year. The radiographic variables generated and specific features investigated were collected on 3D CBCT imaging and were correlated with the impacted maxillary canine. Statistically significant differences were found between the impacted and the non-impacted canines. Canine rotation, canine crown position, canine cusp tip to the midline and to the occlusal plane, canine angle to the midline, and canine angle to the lateral incisor were selected and considered as variables in a multivariable prediction model because they were clinically relevant and not correlated with each other. A prediction model using CBCT for canine impaction was established (AUC = 0.965; 95% CI, 0.936, 0.995). Canine crown position, canine cusp tip to the occlusal plane, and canine angulation to the lateral incisor were defined as predictors in the CBCT model. The final prediction model for canine impaction was excellent and may help orthodontists to identify the probability of impaction for defining optimal intervention method.

Introduction

Early prediction as well as early diagnosis of impaction by means of 2D radiographs remains problematic. It is challenging to distinguish structures based on conventional 2D radiographs, which often lead to misinterpretations.↱ CBCT images, by their nature, have significant advantages over 2D images.[4] When a 3D view is available, many diagnostic issues related to impacted canines can be easily resolved. The potential complications of canine impaction increase the need to use CBCT to understand the development of impaction and normal eruption. Several studies have investigated the possible predictors of canine impaction and orthodontic treatment choice in 2D radiographs.[133, 148] Therefore, the aim of this study is to compare 3D CBCT images of unilaterally impacted canines with the normal contralateral side, and to identify the radiographic factors that may be involved in maxillary canine impaction.

Materials and Methods

This investigation was based on the radiographic records of patients who were referred for CBCT investigation. All of the patients were non-syndromic and had a unilaterally impacted maxillary canine. The sample consisted of 65 patients, 43 females and 22 males, ranging in age from 9.6 to 13.8 yrs., with a mean age of 12.1 yrs and a median age of 12.2 yrs. (± SD, 1.23). 27 patients were selected from chapter 9 patients with unilateral impacted maxillary canine and 38 new patients (in the period from 1/04/2013 until 30/09/2013). Of the impacted maxillary canines, 32 were located on the right side (Tooth 13) and 33 on the left side (Tooth 23). The diagnosis of unilaterally impacted canine was determined from the patients' dental records to be a failure of the canine to erupt at its appropriate site in the dental arch in contrast to normal eruption of the contralateral side.

Radiographic follow-up assessment to identify unilateral impaction was performed for a period of 1 yr.

All of the patients were administered a CBCT scan with either 3D Accuitomo-XYZ Slice View Tomograph (J. Morita, Kyoto, Japan) or a Scanora® 3D CBCT (Soredex, Tuusula, Finland).

The Evaluation Protocol

The protocol included evaluation of the variables related to specific features obtained from radiographic records, which were analyzed by one investigator (A. Alqerban). The variables were categorized as:

Canine-related variables:

1. Crowding in the upper anterior region.
2. The primary maxillary canine was assigned to 1 of 3 categories: missing tooth, where the deciduous canine had been extracted; present without root resorption; or present with root resorption.
3. Canine development was assigned to 1 of 4 categories based on root development: complete development, 3/4 of the root developed, 1/2 of the root developed, and 1/4 of the root developed.
4. The canine apex: open, closed, or dilacerated.
5. Abnormalities, such as canine root resorption, mesiodens, peg-shaped lateral incisor, agenesis of permanent teeth, and impaction of other permanent teeth, were noted.
6. The canine rotation: either mesio-vestibular, disto-vestibular, mesio-palatal, or disto-palatal.
7. The canine position in relation to adjacent teeth was determined from CBCT images as being either palatal, buccal, or in the line of the arch.
8. Type of canine impaction was assigned to 1 of 3 categories: no impaction; vertical impaction, if the impacted canine was vertically

inclined and covered with soft and/or bony tissue; or horizontal impaction, if the impacted canine was horizontally inclined and covered with soft and/or bony tissue.

9. The roots of the first premolar were classified as: single root, separated root, or fused roots.
10. The anterior apical area was recorded as optimal, small, or severe.
11. The contact relationship between the canine and adjacent teeth was assigned to one of two categories as suggested by Ericson and Kurol[44]: contact, if the distance between the crown of the permanent maxillary canine and adjacent incisors was less than 1 mm; and no contact, if the distance between the crown of the permanent maxillary canine and adjacent incisors was more than 1 mm.

Linear measurement in millimeters:

1. The canine cusp tip to the midline was measured in the axial view.
2. The canine cusp tip to the occlusal plane was measured in the sagittal view. The occlusal plane was defined as the line from the mesio-buccal cusp of the maxillary first molar to the incisal edge of the maxillary central incisor in the sagittal view.
3. The canine apex to the midline was measured in the axial view.
4. The width of the canine crown bucco-lingually and mesio-distally was defined as the distance from the mesial contour to the distal contour of the maxillary canine.
5. The width of the lateral incisor bucco-lingually and mesio-distally at the cemento-enamel junction.
6. The length of the lateral incisor in mm from the incisal edge to the apex was measured in the sagittal view.

7. The mesio-distal space available for the canine between the lateral incisor and the first premolar at the occlusal and apical thirds was measured in the axial view.

Angular measurements:

1. The canine angulation to the midline, where the angle is formed by the long axis of the impacted canine and the midline of the maxilla in the coronal view.
2. The canine angulation to the lateral incisor, where an angle is formed by the long axis of the impacted canine and the long axis of the lateral incisor in the coronal view.
3. The canine angulation to the occlusal plane, where the angle in the sagittal view is formed by the long axis of the impacted canine and the occlusal plane.
4. The lateral incisor inclination to the maxillary plane, where the angle in the sagittal view is formed by the long axis of the lateral incisor and the maxillary plane.

Statistical Methodology

The data from the individuals with unilateral impaction were analyzed. Note that the aim of the study was to predict if a canine is impacted, not if an individual has an impacted canine. Therefore, in the statistical analysis, independent instead of dependent tests were used, i.e., Fisher's exact tests and Mann-Whitney U-tests were used to compare scores and measurements between impacted and non-impacted canines from individuals with unilateral impaction. The Area Under the Curve (AUC) (receiver operating) was recorded for each score and measurement to quantify the discriminative ability (0.5 = random prediction, 1 = perfect discrimination).

From these results, six variables were considered for a multivariable model, based on the AUC, clinical considerations, and the correlations between and among the variables. A backward selection procedure, with 0.157 as the critical level for the *P*-value, was applied to obtain a more parsimonious prediction model. This critical value corresponds to the use of the Akaike Information Criterion (AIC) for model selection. With the AIC, we required the increase in the model χ^2 to be larger than two times the degrees of freedom. A bootstrap re-sampling procedure was used to verify whether variables retained in the final multivariable model are "truly" independent predictors or "noise" variables.[11] In the applied modeling approach, the same data were used to develop and validate the model. Further, there was a clear risk of over-fitting due to the consideration of many predictors compared with the number of impactions and the application of an automated model selection procedure.[136] The resulting prediction model and its related AUC were, therefore, overoptimistic in the sense that the future performance in new patients was overestimated. Therefore, leave-one-out cross-validation was applied. Further, an optimism-corrected estimate of the performance (AUC) was obtained by a bootstrap re-sampling procedure. All of the analyses were performed with SAS software, Version 9.2 of the SAS System for Windows.

Results

Tables 10.1-3 present comparisons of impacted and non-impacted canines in terms of canine-related variables (scores), linear measurements, and angular measurements, respectively. Many significant and clinically relevant differences were found between impacted and non-impacted canines. The canine rotation, canine crown position, canine cusp tip to midline and to occlusal plane, canine angle to the midline, and canine angle to lateral incisor were used as variables in a multivariable prediction model for canine impaction.

The results from the multivariable logistic regression model for the 6 pre-selected predictors are shown in *Table 10.4*. The AUC of the pre-specified model for these 6 predictors equals 0.964 (95%CI: 0.934; 0.994) and 0.948 (0.909; 0.986) after cross-validation.

The results from the model obtained after application of a backward selection procedure are given in *Table 10.5*. The probability of true impaction P(I) can be obtained as follows:

$P(I) = \exp(\mu)/1+\exp(\mu)$, where

$\mu = -5.66 + 2.11*x1 +3.28*x2 + 0.27*x3 + 0.11*x4$,

with x1 = 1 if the canine crown position is buccally oriented and x1 = 0 if not; x2 = 1 if the canine crown position is palatally oriented and x2 = 0 if not; x3 is the linear measurements from canine cusp tip to the occlusal in the sagittal view (measured in mm), and x4 is the canine angle (°) to the lateral incisor in the coronal view (measured in degree).

The index of discrimination (AUC) of this final model equals 0.965 (95%CI: 0.936; 0.995). The optimism-corrected estimate of the AUC still equals 0.953.

Discussion

The position of impacted canines in the dental arch, the canine development, possible overlap with the roots of adjacent incisors, the presence of root resorption and anomalies, and the linear and angular measurements on radiographs have been discussed as predictors of canine eruption.[47, 50, 120, 137, 148] Dental development could be a predictor of a palatally impacted canine.[15] In a 2D study, if the canine is completely

Table 10.1: Comparison of canine-related variables (scores) in percentages between impacted and non-impacted canines of 65 individuals with unilateral canine impaction (P-value from Fisher's exact or Mann-Whitney U test, as appropriate)

	Variable	Not impacted (%)	Impacted (%)	*P*-value	AUC (95%CI)
Crowding	No crowding	75.3	76.9	N.S.	0.51 (0.43; 0.58)
	Crowding	24.7	23.1		
Primary canine	Missing tooth	78.5	52.3	0.007	0.64 (0.56; 0.72)
	No resorption	3	10.8		
	Resorbed root	18.5	36.9		
Canine development	Complete development	75.4	63	N.S.	
	3/4 of the root developed	20	30.8		
	1/2 of the root developed	4.6	6.2		
Open canine apex	Closed or dilacerated	41.5	29.2	N.S.	
	Open	58.5	70.8		
Abnormality	No abnormality	78.5	73.8	N.S.	0.52 (0.45; 0.60)
	Abnormality	21.5	26.2		
Rotation	No rotation	60	24.6	< 0.001	
	Mesio-vestibular rotation	16.9	20		
	Disto-vestibular rotation	16.9	20		
	Mesio-palatal rotation	3.1	23.1		
	Disto-palatal rotation	3.1	12.3		
Rotation	No rotation	60	24.6	< 0.001	0.68 (0.60; 0.76)
	Rotation	40	75.4		
Canine crown position	Palatally	4.6	47.7	< 0.001	0.86 (0.78; 0.91)
	Buccally	20	38.5		
	Line of the arch	75.4	13.8		
First premolar	Single root	21.5	18.5	N.S.	0.55 (0.46; 0.64)
	Separated root	52.3	46.1		
	Two roots	26.2	35.4		
Anterior apical area (axial)	Optimal	50.8	26.2	0.017	0.63 (0.54; 0.72)
	Small	32.3	47.7		
	Severe	16.9	26.1		
Contact relationship lateral	No contact	64.6	13.8	< 0.001	0.76 (0.68; 0.83)
	Contact	35.4	86.2		
Contact relationship lateral	No contact	100	83.1	< 0.001	0.59 (0.539; 0.631)
	Contact	0	16.9		
Contact relationship first premolar	No contact	98.5	90.8	N.S.	0.54 (0.50; 0.58)
	Contact	1.5	9.2		

developed, the canine angle to the midline and overlap with the lateral incisor are considered to be good indicators of canine impaction.[13] Radiographic parameters have also been correlated in the mixed dentition as predictors of the probability of spontaneous eruption or the success rate of the interceptive treatment outcome of the displaced permanent canine.[2, 49, 120, 137, 148] The study by Ericson and Kurol reported that the degree of mesial

Table 10.2: Comparison of linear measurements (in millimeters) between impacted and non-impacted canines of 65 individuals with unilateral canine impaction (P-value from Mann-Whitney U test)

Variable	Statistic	Not impacted	Impacted	*P*-value	AUC (95%CI)
Canine cusp tip to midline	Mean (SD) Median (range)	14.7 (2.6) 15.2 (5.6; 18.5)	10.0 (4.2) 9.6 (0.0; 24.0)	< 0.001	0.86 (0.79; 0.93)
Canine cusp tip to occlusal plane	Mean (SD) Median (range)	3.6 (4.1) 2.7 (0.0; 15.6)	10.6 (4.3) 10.6 (0.0; 22.5)	< 0.001	0.88 (0.82; 0.94)
Canine apex to midline	Mean (SD) Median (range)	12.8 (1.7) 12.5 (9.3; 17.0)	13.9 (2.41) 13.8 (5.8; 19.0)	0.003	0.65 (0.56; 0.75)
Mesio-distal width of canine crown	Mean (SD) Median (range)	7.6 (0.5) 7.6 (6.6; 8.6)	7.8 (0.5) 7.8 (6.7; 8.9)	N.S.	0.60 (0.50; 0.69)
Bucco-lingual width of canine crown	Mean (SD) Median (range)	8.0 (0.6) 7.9 (6.9; 9.2)	8.1 (0.5) 7.9 (7.4; 9.2)	N.S.	0.55 (0.45; 0.65)
Mesio-distal width of the lateral incisor	Mean (SD) Median (range)	6.3 (0.7) 6.3 (4.2; 8.5)	6.4 (0.8) 6.4 (3.9; 9.1)	N.S.	0.57 (0.47; 0.67)
Bucco-lingual width of the lateral incisor	Mean (SD) Median (range)	6.4 (0.8) 6.4 (3.1; 7.9)	6.4 (0.6) 6.4 (4.3; 7.8)	N.S.	0.50 (0.50; 0.50)
Length of the lateral incisor	Mean (SD) Median (range)	21.8 (2.5) 22.2 (13.6; 26.7)	21.0 (3.2) 21.4 (12.9; 27.9)	N.S.	0.59 (0.49; 0.69)
Mesio-distal space at occlusal level	Mean (SD) Median (range)	7.0 (1.9) 7.4 (0.8; 12.1)	5.0 (2.9) 5.8 (0.0; 11.4)	< 0.001	0.74 (0.66; 0.83)
Mesio-distal space at apex level	Mean (SD) Median (range)	9.1 (1.9) 8.9 (3.2; 13.2)	8.0 (2.5) 7.6 (2.9; 13.4)	0.005	0.64 (0.55; 0.74)

overlap of the maxillary canine relative to the adjacent lateral incisor plays a role in the severity of impaction and the probability of spontaneous eruption.[49] Warford et al. found that the degree of canine mesial overlap with an adjacent lateral incisor is a better predictor of impaction than angulations.[144] Power and Short found that, if canine angulation is more than 31° to the midline, their chances of eruption after deciduous extraction are decreased.[120] However, the position of impacted canines, linear measurements, and their angulations have been found by some authors to be invalid as indicators of the successful outcome of interceptive orthodontic

Table 10.3: Comparison of angular measurements between impacted and non-impacted canines of 65 individuals with unilateral canine impaction (P-value from Mann-Whitney U test)

Variable	Statistic	Not impacted	Impacted	*P*-value	AUC (95%CI)
Canine angle to midline, coronal view	Mean (SD) Median (range)	8.8 (6.5) 6.9 (0.6; 29.7)	20.7 (14.9) 17.0 (1.1; 62.7)	< 0.001	0.77 (0.69; 0.85)
Canine angle to the lateral incisor, coronal view	Mean (SD) Median (range)	10.5 (8.5) 8.0 (1.2; 38.9)	36.3 (18.1) 38.0 (5.7; 71.8)	< 0.001	0.90 (0.85; 0.95)
Canine angle to the occlusal plane, sagittal view	Mean (SD) Median (range)	63.0 (12.52) 65.4 (18.7; 86.3)	52.9 (17.19) 54.6 (1.3; 82.8)	< 0.001	0.69 (0.59; 0.78)
Lateral incisor inclination to the maxillary plane, sagittal view	Mean (SD) Median (range)	106.4 (14.5) 108.0 (11.8; 126.9)	104.2 (18.9) 105.8 (9.3; 139.0)	N.S.	0.56 (0.45; 0.66)

treatment, length of treatment, and periodontal status.[38, 61, 88, 148] In our study, canine crown position was used in the prediction model as a predictor and was not correlated with the specific factors in order to differentiate between either palatal or buccal position. We aimed to identify impaction vs non-impaction, regardless of their locations. We selected only unilateral impaction cases to avoid patient variations and misdiagnosis of impaction in bilateral cases.

In addition to the contradictory results of previous studies, those studies used 2D images and tested only one or two variables for canine impaction. Further, these studies showed the significant relation between impacted canines and radiographic factors to spontaneous eruption or the success rate of interceptive treatment without taking into account the correlations between variables. They also failed to verify whether the canines were truly impacted, whether those factors were independent predictors, or whether there was interaction between them. In this study,

Table 10.4: Results from multivariable logistic regression model with six pre-selected predictors [AUC of this model equals 0.964 (95% CI: 0.934; 0.994)]

Parameter	**Estimate**	**Odds ratio (95%CI)**	***P*-value**	**BIF (%)**
Intercept	-5.13			
Rotation	0.14	1.15 (0.28; 4.71)	0.8501	13
Canine crown position			0.0110	
Buccal	2.07	7.90 (1.60; 39.03)	0.0113	92
Palatal	3.04	20.82 (1.92; 225.86)	0.0126	
Line of the arch	#			
Canine cusp tip to midline (mm), axial view	-0.04	0.97 (0.74; 1.25)	0.7905	23
Canine cusp tip to occlusal (mm), sagittal view	0.26	1.29 (1.10; 1.52)	0.0023	97
Canine angle (°) to midline, coronal view	0.01	1.01 (0.91; 1.12)	0.8940	9
Canine angle (°) to the lateral incisor, coronal view	0.11	1.11 (1.04; 1.19)	0.0037	98

 # Reference category. BIF: Bootstrap importance frequency, i.e., the percentage of bootstrap samples in which the variable is retained in the final model after application of the backward selection procedure.

unilaterally impacted canines were selected and were determined to be truly impacted because the contralateral side was erupted and the ipsilateral side of all patients did not show any improvement in position after a follow up of 1 yr. However, the sample was considered representative of impacted canines regardless of whether the impaction was unilateral or bilateral. Likewise, the non-impacted canines were considered to be representative of non-impacted canines, whether the individual had unilateral impaction or not.

Table 10.5: Results from the final prediction model (obtained after the application of a backward selection procedure with 0.157 as the critical level for a p-value to remain in the model) and results from the bootstrap re-sampling procedure. The AUC = 0.965 (95%CI: 0.936; 0.995)

Variable	Estimate	Odds ratio (95%CI)	*P*-value
Intercept	-5.66		
Canine crown position			0.0014
Buccal	2.11	8.26 (1.77; 38.52)	0.0072
Palatal	3.28	26.45 (3.90; 179.51)	0.0008
Line of the arch	#		
Canine cusp tip to occlusal plane (mm), sagittal view	0.27	1.31 (1.12; 1.52)	0.0006
Canine angle (°) to the lateral incisor, coronal view	0.11	1.12 (1.04; 1.19)	0.0014

 # Reference category.

Several significant differences were found between impacted and non-impacted canines. From these results a selection of variables was made for constructing the final prediction model *(Table 10.4)*. These variables were selected because they were clinically relevant with a high AUC index and had no correlation between them. In this study, the contact relationship, the mesio-distal spaces at the occlusal level, and the apex levels were significantly different between impacted and non-impacted canines. However, they were not used in the selective predictors because the AUC indices were low (0.76, 0.74 and 0.64, respectively). A lack of mesio-distal space is the main cause of buccally impacted canines, while excessive space is correlated with palatally impacted canines.[70, 118] A CBCT study has reported that the root length and bucco-lingual and mesio-distal crown widths of the lateral incisors were smaller in a sample of palatally impacted canines.[94] Further, there is sexual dimorphism in the mesio-distal crown width between males and females.[34] Our samples included all kinds of impaction (buccal, palatal, and line-of-arch). Therefore, no difference was found between impacted and non-impacted canines in lengths or crown widths of the lateral incisors, which is consistent with results from a CBCT study of unilaterally impacted canines.[152] CBCT was found to be precise in measurements of the root length with a high level of reproducibility.[98] The linear and angular measurements in CBCT images were found to be accurate in canine impaction cases.[108] The measurement of each variable in this study was indicated. For instance, in the final prediction model the linear measurements from canine cusp tip to the occlusal plan measured in the sagittal view, and the canine angle to the lateral incisor measured in the coronal view. Because the measurement could be differently visualized, interpreted and assessed by clinicians.

The canine-to-lateral-incisor angle, rather than lateral incisor inclination, has been found to have a direct influence on canine impaction when CBCT was used.[14] This is in agreement with our findings. Incisor inclinations (labial root torque) in Angle Class II, Division 2 patients have been found to be risk factors for palatally impacted canines.[30, 97] However, in another study, incisor inclination in patients with buccally impacted canines showed no significant relation.[30] The present study showed no significant difference between impacted and non-impacted canines in lateral incisor inclination to the maxillary plane.

In 2009, the KPG index was developed which is a novel method to classify and estimate the difficulty of treatment of impacted maxillary canines using CBCT images, without having multiple measurements of angles and distances.[74] This index analyzed the canine's position, based on cusp and root tip deviations from the normal position, giving a scale from 0-5 along the sagittal, coronal, and axial planes. The difficulty of treatment were classified as easy, moderate, difficult and extremely difficult.[74] The reliability and the repeatability of this index have been proven by other studies to be an easy and efficient to classify the difficulty of treatment of impacted maxillary canines.[42, 126] However, the ability of estimating treatment time of impacted maxillary canines based on KPG is still unknown.[126]

It is of crucial importance to establish an easy validated prediction method for canine impaction. The index of discrimination (AUC) of this final model equals 0.965 (95%CI: 0.936; 0.995). The optimism-corrected estimate value of the AUC index still equals 0.953. Since the selection of the 6 included predictors was based on the data presented, the predictions obtained from the final multivariable model are expected to be too extreme, and the AUC obtained after internal validation is still likely to be overoptimistic. External validation is necessary to evaluate the true performance of this model in a new setting and its ability of canine prediction needs to be confirmed by prospective study.

Conclusions

The prediction of canine impaction based on CBCT was excellent. The final prediction model for canine impaction may help orthodontists identify the probability of impaction for optimally timing intervention. In the final prediction model, the canine crown position, the canine cusp tip to the occlusal plane, and the canine angulation to lateral incisor were identified as predictors.

Chapter 11

General discussion and conclusion

Radiographic analysis is an essential part of the diagnostic process in cases of maxillary canine impaction and associated lateral incisor root resorption. Clinical examination without radiographic confirmation is insufficient for making treatment decisions. No single 2D imaging technique is readily available for accurate, easily interpreted representations of all canine aspects and associated structures. Panoramic images were chosen to represent conventional radiographs because panoramic radiography is commonly used for the diagnosis and treatment planning of impacted canines. Nevertheless, we considered the constraints of panoramic imaging.

There is a great need for a more accurate diagnostic method for canine impaction and root resorption. CBCT is a promising alternative 3D imaging of dental structures. The diagnostic tasks for which these CBCT systems were mostly used in orthodontics included impacted teeth,[93, 147] temporomandibular joints, root proximity and resorption,[43, 89] tooth movement, cephalometric analysis, cleft lip and palate, planning for miniscrews, and orthodontic treatment planning.[35, 75] Previous studies addressing the issue of canine impaction-related root resorption date back more than 10 years. Meanwhile, CBCT has become commercially available and promises improved diagnosis of canine impaction as well as incisor root resorption. Over recent years, there have been many publications concerning the application of CBCT. Therefore, radiographic evaluation of CBCT and the potential influence of 3D information in vitro and vivo for diagnostic and preventive measures needs to be ascertained and requires validation through comparison with conventional methods.

Chapter 3 reported on the investigation carried out to compare the radiographic diagnostic accuracy between conventional 2D panoramic radiography and two CBCT systems in detecting simulated root cavities of different depths and locations in maxillary lateral incisors. Our approach using a pediatric skull (in Chapters 1 and 2) improved the simulation of canine overlap with high-density enamel that might compromise the detection of root resorption on the lateral incisor root surface. This resembles the resorption associated with impacted canines and thus better approaches the real clinical condition and allowed us to illustrate the difficulty in diagnosing root resorption. Simulation of real and complex mixed dentition was further enhanced by selecting teeth with varying morphologies and root profiles because it was presumed that root resorption occurs in all types of lateral incisors. The location of resorption did not affect diagnosis in our study. The resorption location was selected in the middle and apical thirds, since these are the most common sites for resorption with impacted canines. Other *in-vitro* studies simulated root resorption by repositioning teeth in the alveolar socket without tooth overlap over resorption lesions.[9, 24, 72, 107, 149] Moreover, those studies have shown that root resorption less than 0.60 mm in diameter and 0.30 mm in depth cannot be detected with 2D radiography.[9, 149] The results of Chapter 3 suggest that the CBCT technique could be a reliable diagnostic tool for detecting canine impaction and associated lateral incisor root resorption. Lesions as small as 0.20 mm could be easily diagnosed.

Even with the advantages of CBCT over the conventional methods, the challenges of detecting root resorption are due to the difficulty of distinguishing between mild root resorption and image artifacts. The diagnostic yield describes the balance between image quality and information gain. Image quality has been extensively discussed in the literature. The assessment of root resorption caused by an impacted canine to the adjacent teeth by using images of high quality is essential to provide for the best visualization of early resorption and to decrease misinterpretation caused by image noise. However, the general superiority of the various CBCT systems over conventional approaches has not yet been established. Although CBCT is expected to yield good results when detecting resorptions, its performance should was used in various systems to validate how much information is gained for patients with impacted canines or root resorption.

The study reported on in Chapter 4 established a link between image quality and the detection of simulated root resorption. Our null hypothesis was that 3D imaging with different CBCT systems is similar for detecting simulated root resorption. CBCT imaging was done with six systems to identify potential differences in detection thresholds based on machines and setting characteristics. The results of this study showed that the subjective image quality of the six CBCT systems was significantly different. However, all CBCT systems present high accuracy in the detection of root resorption. No significant difference among CBCT systems was found in the detection of the severity of root resorption. Therefore, the best option is to work with dose optimization and full justification to apply a low-dose CBCT technique that offers reasonable to excellent diagnostic accuracy.

Since much work was needed to demonstrate the added value of CBCT in routine orthodontic cases of canine impaction and root resorption, similar comparative studies were performed on patients with canine impaction to demonstrate the canine location and determine whether the accuracy of CBCT remains high. The data of the Chapter 5 clearly highlights that CBCT allowed validation of the impacted canine. The determination of canine location was highly significantly different between the panoramic and CBCT systems because CBCT images provide applicable diagnostic information for canine location in the sagittal, axial, and coronal planes without overlap. Moreover, CBCT imaging also increased the potential diagnostic efficiency and was more accurate than the conventional 2D panoramic radiograph in the different diagnostic tasks. The detection and severity of lateral incisor root resorption were significantly improved with CBCT. Therefore, CBCT has proven to be a reliable diagnostic method for the localization of impacted canines and detection of root resorption of adjacent incisors. Testing Research Hypothesis A was accepted based on the results of Chapters 3, 4, and 5.

Given the reliability and clear benefit of using CBCT in the diagnosis of impacted canines with 3D overviews of the dentomaxillofacial structures, it is essential to identify the effect on treatment planning, treatment approach, surgical planning and outcome expectations. Previous investigations have compared treatment planning differences between use of 2D images and CBCT images.[26, 63, 150] The results in two studies showed that there was a difference in treatment planning.[26, 63] However, it has been found that the treatment proposal for impacted canines did not differ whether based on 2D or 3D information. Therefore, the potential improvement in the surgical management of patients with the use of CBCT imaging warranted investigation. The study in Chapter 6 was carried out on patients who had both 2D panoramic and 3D CBCT images and focused on surgical treatment planning based on radiographic information and the factors that may affect surgical decisions.

Chapter 6 set out to quantify the value of CBCT scans and its impact on patient management. The focus was on surgical treatment planning and was unable to demonstrate a significant difference between the use of panoramic and CBCT radiographs for surgical treatment planning of impacted maxillary canine. A fundamental goal of this study was to understand the relative value of CBCT compared with panoramic radiographs and to aid in the justification of using CBCT for patients referred for surgical intervention. Pre-surgical treatment planning did not differ significantly between panoramic and CBCT modalities in terms of the type of treatment chosen, the surgical technique or the prediction of complications. However, CBCT images helped to increase the confidence level of the clinician regarding treatment planning, diagnosis of the canine location, contact with the adjacent teeth and the presence of root resorption.

Chapter 7 examined the treatment planning for patients with impacted canines. The results showed that the skeletal treatment, treatment methods, choice of teeth for extraction, and planning of surgical intervention did not differ significantly between the two modalities. If orthodontists have the information necessary for treatment planning from 2D images, there is no need for further CBCT radiation. In addition, surgical treatment planning was found in Chapter 6 not to be significantly different between those based on panoramic or CBCT images. In our study, the only significant difference was in the direction of canine traction in cases of surgical exposure. Thus, using CBCT in surgical cases to plan the direction of traction can be avoided. If the canine is surgically exposed, one can usually see the direction in which the orthodontist can move the impacted canine to the normal position. However, CBCT has been recommended for use in impacted canine cases if 2D radiographs cannot provide sufficient diagnostic information. Orthodontic patients for whom CBCT data were already acquired must not be subjected to further the radiation exposure of traditional panoramic images and lateral cephalograms. Additional conventional panoramic images and cephalograms are unnecessary, and additional X-ray exposure of the patient should be avoided. Moreover, clinicians' acceptance of and confidence in the use of 2D or 3D images should always be justified, rather than simply accepting high radiation doses or multiple images to increase confidence. Therefore, a balance should be struck between radiation dose and patient benefit, as well as diagnostic information.

In Chapter 8, the aim was to investigate the added value of using CBCT in the orthodontic treatment method of maxillary impacted canine and treatment outcome. The results of this retrospective study show that the choice of teeth for extraction, treatment methods, and successful treatment results did not differ significantly with or without CBCT images. There was also no indication for a difference in post-treatment outcome with regard to angle classifications.

Systematic differences between the two groups are to be expected because randomized clinical trial could not be performed. Yet, those differences in canine-related factors could be used to determine if it CBCT radiographs are indicated. In this study, significant differences between the two groups were found for canine-related variables, i.e. the type of canine impaction, the vertical canine crown height, the canine overlap of the adjacent teeth (sectors), the canine angulations to the lateral incisor, the midline, the occlusal plane, the presence of abnormalities, and the presence of root resorption. Thus, CBCT has been used in cases with more severe symptoms of maxillary canine impaction with no difference in the treatment methods used or in the treatment outcome.

Chapters 6, 7, and 8 demonstrated that more information is gained from CBCT than from panoramic images. A CBCT evaluation of the impacted canine improved the position assessment relative to adjacent teeth thus providing a greater degree of confidence in the treatment plan than with 2D images. As a result, Research Hypothesis B was rejected.

The presence or absence of root resorption may have a significant effect on tooth extraction strategies. The degree of resorption depends on the nature and strength of the pressure produced by the impacted canine; it often remains asymptomatic.[58] Root resorption is mostly found close to the maxillary canine and usually starts mildly in a specific area.[44] Yet in time, it can extend in all directions and invade the entire root, making the prognosis of the tooth poor. Therefore, early prediction is key for success, and the failure of early diagnosis of root resorption has been recognized as a problem.[49] When root resorption is diagnosed before orthodontic treatment begins, a decision must be made whether to extract the resorbed tooth, followed by orthodontic alignment of the impacted canine, space closure, and reshaping, or whether to move the impacted canine away from the resorbed tooth. For this purpose, CBCT has been recommended for use in impacted canine cases. However, ALARA principles and Sedentex CT guidelines state that CBCT examination should not be used indiscriminately but should only be used in selected orthodontic cases in which conventional radiography cannot supply sufficient diagnostic information.[54] The required information can be partially obtained from conventional two-dimensional radiographs. Conventional radiological imaging has been routinely used as the first step in examining the impacted canine. Therefore, CBCT should not be used routinely to obtain radiographs for orthodontic patients, but should be justified, with caution, for specific patients. More evidence-based research is necessary to define the justified use of CBCT. It would be useful if the information obtained from panoramic image can be transferred to a CBCT and vice versa. Therefore, in Chapter 9, we tried to identify a prediction model for predicting the possible presence of RR based on the initial panoramic image in order to be able to indicate more justified used of CBCT examination. The final prediction model for root resorption based on available panoramic radiographs could be a helpful tool in justifying the need for additional CBCT examination.

The etiology of impacted canines is multifactorial and still unclear. Several local factors have been hypothesized for maxillary canine impaction, such as the presence of a narrow maxillary arch or a Class II, Division 2 malocclusion.[30, 97] A possible genetic origin for palatally displaced canines has also been indicated.[20, 70] Palatally impacted canines are usually associated with other dental anomalies such as the congenital absence of the lateral incisors or of the second premolars, and peg-shaped lateral incisors.[1, 18, 18, 109, 118, 118] Moreover, maxillary canines have the longest and the most complicated eruption path of all teeth. Between the age of 5 and 15 years, the total eruption path extends over 22 mm,[37] which causes the maxillary canines to be prone to deviations from the normal path of eruption.[19, 22] Individuals with impacted canines are usually subjected to long treatment times, and successful orthodontic treatment and final treatment outcome of impacted canines are unpredictable.[55] It has been found that treating malocclusion with an impacted canine takes longer than for a similar malocclusion without impaction.[133, 135] This could be due to the application of different treatment methods in young patients according to the concept of 'try and wait'. The second reason could be a lack of defined impaction. The most important factor before treatment is undertaken is the confirmation of true impaction rather than a normal delay in eruption. The latter usually responds positively to any treatment applied. Therefore, identifying the presence of impaction is essential and requires an understanding of the differences between impacted and non-impacted canines in relation to adjacent structures.

We found no straightforward formula in the literature for the prediction of canine impactions based on CBCT. No guidance for the use of CBCT radiographs has been established to identify impaction. Therefore, the research reported in Chapter 10 was conducted to identify impactions based on the prediction formula derived from CBCT images of patients with unilaterally impacted maxillary canines. In this study, the analysis of CBCT images generated a number of radiographic factors. The significant differences between impacted and non-impacted canines are useful in the understanding of impaction, eruptions patterns, and the prediction of canine impaction. With our methodology, we attempted to differentiate impaction vs non-impaction using the prediction model with a high AUC value of 0.965, ranging from 0.936 to 0.995. Therefore, Research Hypothesis C was accepted.

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Summary

Maxillary canine impaction and root resorption of adjacent lateral incisors is a well-known and relatively common phenomenon in orthodontic practice. The risk of canine impaction and associated root resorption is relatively high in patients needing orthodontic treatment. Early diagnosis remains a critical problem, and there are no straightforward clinical clues concerning the treatment planning, prediction, or prevention as regards canine impaction and the associated root resorption of the adjacent lateral incisor. The introduction of CBCT in dentomaxillofacial radiology has created new diagnostic challenges, including some potential opportunities for evaluating the impacted canines. With this new technology, it was obligatory to investigate and determine if this new information provides another and better way of diagnostic approach, treatment planning, improved treatment outcome and early prediction. Consequently, the present thesis attempted to link the radiological observations to diagnostic, therapeutic and further preventive measures. The main objectives were to develop an improved diagnostic methodology that would enable optimal diagnosis, treatment, and early prediction.

The diagnostic accuracy for the detection of simulated canine-induced external root resorption lesions in maxillary lateral incisors was compared between conventional panoramic radiographic imaging and CBCT systems in vitro. The results show that the performance of CBCT imaging was significantly better than that of panoramic radiography. After the CBCT had been proven to perform better than conventional 2D panoramic images, the question to be answered remained whether there is a difference between CBCT machines. Therefore, the subjective image quality of the different CBCT systems in vitro was determined. The results suggest that the CBCT

radiographic method is more sensitive and that high image quality is important when trying to detect root resorption. There were no significant differences between the CBCT systems in the detection of root resorption. The findings of a previous in vitro study were confirmed in vivo: the results show that CBCT was a reliable diagnostic method for the localization of impacted canines and the detection of root resorption of adjacent lateral incisors.

The treatment of impacted canines usually requires a multidisciplinary approach and is associated with prolonged treatment times, increased costs, complexity, and a risk of failure and complications. The diagnostic consequences of using 2D or 3D radiography may have a significant impact on therapeutic interventions. Therefore, this aspect was investigated by comparing the orthodontic treatment planning between conventional and CBCT-based planning. Similarly, the influence on pre-surgical treatment planning was also studied. The findings of those studies show no statistically significant difference in treatment planning or in pre-surgical treatment planning between the use of conventional and CBCT sets. The only significant difference was related to the precise localization of impacted canine but had no effect in the treatment plans. However, a high confidence level was observed in CBCT treatment based planning. The influence of CBCT on the treatment methods used and treatment outcomes achieved for orthodontically treated patients was then investigated. No difference was found either in the number of treatment methods or treatment outcome.

In the last part of this thesis, a method for early prediction and prevention of canine impaction and root resorption was explored. Early prediction based on radiographic factors might clinically stimulate the application of preventive measures. Therefore, a prediction model for root resorption on panoramic radiographs was constructed. The early prediction of root resorption might reduce complications before, during and/or after treatment because additional clinical measure can be taken. The prediction of root resorption was carried out on the basis of available panoramic radiographs because they are routinely present in orthodontic records. Furthermore, the diagnosis of root resorption based on panoramic radiographs is difficult, and the final prediction model for root resorption could be a helpful tool in justifying the need for additional CBCT examination. The purpose was to reduce the need for additional radiation exposure, certainly in cases where the probability of the presence of root resorption is low. Finally, the prediction model for canine impaction was established on the basis of CBCT with a high level of accuracy, which may help orthodontists in identifying the probability of impaction, which, in turn, is helpful in defining the optimal intervention method.

Samenvatting

Impactie van de maxillaire hoektanden en wortelresorptie van naburige laterale snijtanden is een goed bekend en vrij waargenomen verschijnsel in de orthodontische praktijk. Het risico op cuspidaatimpactie en daarmee gepaard gaande wortelresorptie is vrij groot bij patiënten die een orthodontische behandeling vereisen. De vroegtijdige diagnose blijft een kritiek probleem, en er zijn geen duidelijke klinische aanknopingspunten voor de planning van de behandeling, prognose, of preventie met betrekking tot cuspidaatimpactie en de daarmee gepaard gaande wortelresorptie van de naburige laterale snijtand. De invoering van CBCT in dentomaxillofaciale radiologie heeft nieuwe diagnostische uitdagingen met zich meegebracht, maar ook mogelijkheden om cuspidaatimpacties te beoordelen. Met deze nieuwe technologie was het nodig om te onderzoeken en te bepalen of deze nieuwe informatie de aanpak voor de diagnose, planning van de behandeling, de gevolgen en de vroege prognose verandert of verbetert. Daarom wordt in deze thesis gepoogd om de radiologische observaties te koppelen aan diagnostische, therapeutische en verdere preventieve maatregelen. De hoofddoelstellingen waren om een betere diagnostische methodologie uit te werken waarmee de diagnose, behandeling, en vroege prognose geoptimaliseerd kunnen worden.

De diagnostische precisie van de conventionele panoramische radiografische beeldvorming en CBCT-systemen in vitro werd vergeleken voor de detectie van door de hoektanden veroorzaakte gesimuleerde externe wortelresorptieletsels bij maxillaire laterale snijtanden. De resultaten tonen dat de prestaties van beeldvorming door CBCT significant beter waren dan die van panoramische radiografie. Nadat gebleken was dat CBCT beter werkt dan conventionele panoramische beelden met 2D-beeldreconstructie, moest de vraag nog beantwoord worden of er een verschil is tussen CBCT-toestellen. Daarom werd de subjectieve beeldkwaliteit van de verschillende CBCT-systemen in vitro bepaald. De resultaten wijzen erop dat de radiografische CBCT-methode gevoeliger is en dat een hoge beeldkwaliteit belangrijk is om een wortelresorptie te detecteren. Er waren geen significante verschillen tussen de CBCT-systemen voor de detectie van wortelresorptie. De bevindingen van een eerder onderzoek in vitro werden in vivo bevestigd: de resultaten tonen dat CBCT een betrouwbare diagnostische methode was voor de opsporing van cuspidaatimpacties en de detectie van wortelresorptie van naburige laterale snijtanden.

De behandeling van cuspidaatimpacties vereist gewoonlijk een multidisciplinaire aanpak en gaat gepaard met een verlengde behandelingsduur, hogere kosten, hogere complexiteit en een hoger risico op falen en complicaties. De diagnostische gevolgen van het gebruik van 2D-beeldreconstructie of 3D-radiografie kunnen een grote weerslag hebben op de therapeutische ingrepen. Daarom werd dit aspect onderzocht door de vergelijking van de orthodontische behandelingsstrategie met conventionele methoden en met CBCT. De invloed op de preoperatieve behandelingsplanning werd ook bestudeerd. De bevindingen van deze onderzoeken tonen geen statistisch significant verschil tussen het gebruik van conventionele en CBCT-systemen voor de behandelingsplanning of de preoperatieve behandelingsplanning. Het enige significante verschil hield verband met de precieze lokalisatie van de ingesloten hoektand, maar had geen effect op de behandelingsschema's. Er werd echter een hoog betrouwbaarheidsniveau waargenomen bij de planning van de behandeling op basis van CBCT. Vervolgens werd de invloed van CBCT op de gebruikte behandelingsmethoden en de bereikte behandelingsresultaten voor orthodontisch behandeld patiënten onderzocht. Er werd geen verschil gevonden in het aantal behandelingsmethoden of de behandelingsresultaten.

In het laatste deel van deze thesis werd een methode voor vroege prognose en preventie van cuspidaatimpactie en wortelresorptie verkend. Vroege prognose op basis van radiografische factoren zou de klinische toepassing van preventieve maatregelen kunnen stimuleren. Daarom werd een voorspellingsmodel voor wortelresorptie op panoramische radiografieën opgezet. De vroege prognose van wortelresorptie zou complicaties vóór, tijdens en/of na de behandeling kunnen verminderen omdat er dan aanvullende klinische maatregelen getroffen kunnen worden. De voorspelling van wortelresorptie werd gedaan op basis van beschikbare panoramische radiografieën omdat ze routinematig aanwezig zijn in orthodontische dossiers. De diagnose van wortelresorptie op basis van panoramische radiografieën is overigens moeilijk, en het daaruit voortvloeiende voorspellingsmodel voor wortelresorptie zou een hulpmiddel kunnen zijn om de noodzaak van aanvullend CBCT-onderzoek te rechtvaardigen. Het doel was de noodzaak aan bijkomende blootstelling aan straling te verminderen, vooral in gevallen waar de kans op wortelresorptie laag is. Het voorspellingsmodel voor cuspidaatimpactie werd opgezet op basis van CBCT met hoge precisie. Deze kan orthodontisten helpen bij het bepalen van de kans op impactie, zodat ze de optimale interventiemethode kunnen kiezen.

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- Reviewer the Clinical Oral Investigations Journal.
- Reviewer Orthodontics & Craniofacial Research.
- Reviewer Angle Orthodontists Journal.
- Reviewer American Journal of Orthodontics and Dentofacial Orthopedics.
- Reviewer European Journal of Orthodontics.
- Reviewer Clinical Oral Investigations Journal.
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