Mestrado Integrado em Medicina Dentária
Faculdade de Medicina da Universidade de Coimbra

Análise comparativa de caninos superiores inclusos: Radiografia Panorâmica Vs Tomografia Computadorizada de Feixe Cónico

Catarina Luís Pico

Orientadora: Professora Doutora Sónia Alves
Co-Orientador: Professor Doutor Francisco do Vale

Coimbra, 2015

Integrated Masters in Dentistry
Faculty of Medicine, University of Coimbra

Comparative analysis of impacted upper canines:
Panoramic radiograph Vs Cone Beam Computed Tomography

Pico C[1], Vale F[2], Alves S[2]

[1] 5th Grade Student, Dentistry Area, Faculty of Medicine, University of Coimbra, Coimbra, Portugal.
[2] MS,DDS, PhD, Department of Orthodontics, Dentistry Area, Faculty of Medicine, University of Coimbra, Coimbra, Portugal .

Área de Medicina Dentária, FMUC, Coimbra - Portugal
Avenida Bissaya Barreto, Blocos de Celas
3000-075 Coimbra
Tel.: +351 239 484 183
Fax.: +351 239 402 910

Email: catarina_pico@hotmail.com

Index

Index of Figures

Index of Tables

Index of Annexes

Abbreviations List

CBCT: Cone Beam Computed Tomography

IMC: Impacted Maxillary Canine

CT: Computed Tomography

OPG: Orthopantomography

TMJ: Temporomandibular Joint

2D: Two-Dimensional

3D: Three-Dimensional

FOV: Field of View

mA: Milliamperage

kVp: Kilovoltage

AAOM: American Academy of Oral and Maxillofacial

ALARA: As Low As Reasonably Achievable

ROI: Region of Interest

DDFMUC: Department of Dentistry, Faculty of Medicine, University of Coimbra

DICOM: Digital Imaging and Communications in Medicine

JPEG: Joint Photographic Experts Group

M-D: Mesio-Distal

L-P: Labio-Palatal

Resumo

Introdução: A utilidade da Tomografia Computadorizada de Feixe Cónico (TCFC) está bem comprovada e documentada na literatura em diversas áreas da Medicina Dentária, incluindo na área da ortodontia. Vários estudos têm demonstrado a sua eficácia no diagnóstico e localização de caninos superiores inclusos, proporcionando um melhor tratamento cirúrgico e ortodôntico.

Objetivo: Comparar e concluir de que forma a opinião relativamente à localização de caninos superiores inclusos, reabsorção radicular dos dentes adjacentes, prognóstico, informação da imagem, plano de tratamento, duração de tratamento e grau de dificuldade do caso varia quando se observa uma imagem panorâmica em comparação com a observação de um conjunto de reconstruções de TCFC.

Materiais e Métodos: Vinte doentes (10 homens e 10 mulheres) com um total de 28 caninos inclusos foram identificados na base de dados da Área de Medicina Dentária, da Faculdade de Medicina da Universidade de Coimbra. Para cada canino foram disponibilizados dois diferentes tipos de imagens, uma imagem panorâmica e um conjunto de reconstruções da TCFC, sendo que a cada conjunto correspondeu um grupo. Depois de uma distribuição aleatória das imagens de ambos os grupos, nove médicos dentistas pós-graduados em ortodontia preencheram um questionário onde foram solicitados a avaliar, para cada caso, a posição do dente, a reabsorção radicular dos dentes adjacentes, o prognóstico, a informação da imagem, o plano de tratamento mais indicado e sua duração e a dificuldade do caso. A análise estatística foi realizada por meio de estatística de alfa de Cronbach para analisar a confiabilidade entre avaliadores para cada grupo (separadamente). A concordância intra-avaliador entre as duas modalidades de imagem foi medida utilizando a estatística de Kappa para as questões categóricas e o teste de McNemar para as questões dicotômicas, considerando $p < 0{,}05$ como estatisticamente significativo.

Resultados: Este estudo revelou existirem diferenças entre as duas imagens sobre a posição dos dentes. Quando analisada a posição mésio-distal do ápex, foi encontrada uma fraca concordância estatisticamente significativa entre os dois métodos. Também uma fraca concordância foi encontrada entre os dois métodos na análise da posição vestíbulo-palatina da cúspide e, na análise da reabsorção de dentes adjacentes, essa concordância foi muito fraca. Todas as restantes questões avaliadas obtiveram uma concordância entre as duas imagens variável entre moderada a forte. Quando questionado se consideravam a imagem suficiente para o diagnóstico ortodôntico, os examinadores concordaram que, na maioria dos casos, a imagem panorâmica foi insuficiente.

Conclusão: Os resultados deste estudo demonstram que a imagem panorâmica e reconstruções da TCFC fornecem informações diferentes sobre a posição do dente incluso (especialmente sobre a posição mésio-distal do ápex e a posição vestibulo-palatina da cúspide), mas também na avaliação da reabsorção radicular de dentes adjacentes.

Palavras-Chave: “Tomografia Computadorizada de Feixe Cónico”, “Ortodontia”, “Dente Incluso”, “Reabsorção Radicular”.

Abstract

Introduction: Cone-Beam Computed Tomography (CBCT) has proved its usefulness in different areas of dentistry, including the orthodontic field. Several studies have shown its efficiency in locating and diagnosing impacted maxillary canines, providing a better surgical and orthodontic treatment.

Aim: The aim of this study was to compare and conclude in what way the opinion regarding upper canine impaction location, adjacent tooth resorption, prognosis, image information, treatment plan and difficulty level differed when observing a panoramic image compared to the observation of a set of CBCT reconstructions.

Materials e Methods: Twenty patients (10 males and 10 females) with a total of 28 impacted maxillary canines were identified from the database of the Department of Dentistry, Faculty of Medicine, University of Coimbra. For each canine, two different kinds of images were available: a panoramic image and a set of CBCT reconstructions. After a random distribution of both group images, nine orthodontists completed a questionnaire where they were asked to evaluate each canine position, adjacent root resorption, prognosis, image information, treatment plan option and its duration and case difficulty. Statistic analysis was performed using Cronbach's alpha statistics to analyze inter-rater reliability for each group (separately). Intra-rater agreement between the two exam modalities was measured using Kappa statistics for categorical questions and McNemar test for dichotomous questions, considering $p < 0{,}05$ statistically significant.

Results: This study showed differences between the two images regarding tooth position. A statistical significant poor agreement was found between the two methods for the mesio-distal position of the apex. Also the analysis of the labio-palatal tip cusp position and the assessment of adjacent root resorption showed a poor and very poor agreement, respectively, between the two methods. Every other items were scored with an agreement between modalities ranging from moderate to strong. When asked if the image was enough for orthodontic diagnosis, the examiners agreed that in most of the cases the panoramic image was insufficient.

Conclusion: The results from this study demonstrate that panoramic image and CBCT images reconstructions provide different information regarding tooth position (especially concerning the mesio-distal apex position and the labio-palatal cusp position) but also in the assessment of root resorption.

Keywords: “Cone-Beam Computed Tomography”, “Orthodontics”, “Impacted Tooth”, “Root resorption”.

Introduction

Tooth eruption is a complex and dynamic process, defined as the emergence of a tooth from within its follicle in the alveolar process of the jaws into the oral cavity[1, 2]. In order to achieve its proper position in dental arch, fulfilling its function, a complexity of movements occurs around and within dental structures. Summarily, these movements are grouped in[3]:

- Pre-eruptive tooth movement: described as the movements made by deciduous and permanent tooth germs inside jaws tissues, before they began to erupt;
- Eruptive tooth movement: described as the axial movement of teeth from their development position inside jaws tissue to their functional position in occlusal plane;
- Post-eruptive tooth movement: described as the movements made by the tooth after its functional position has been established.

Though there are several hypotheses to explain it, the exact mechanisms behind these movements are still not fully understood. A literature review from 2014 by Kjær *et al*[2], showed that root growth, bone remodelling, dental follicle, periodontal ligament formation, vascular pressure, contractile collagen and hormonal signals have been some of the theories used to explain mechanisms behind tooth eruption. But only two of these hypotheses are supported by literature: the importance of dental follicle, supported by animal studies and the necessity of the existence of bone tissue surrounding the tooth. The author recognizes that there is still a lack of information regarding what leads to tooth movement from its development location in the jaw, into its final position in oral cavity, and justifies it with methodological difficulties. Yet, he proposes and tests a new hypothesis, defending that tooth eruption depends on three principles: 1) Space in the eruption path: "The crown follicle destroys overlying bone tissue creating the necessary space in the eruption path"; 2) Lift or pressure from below: "The innervation in the root membrane" causes "an overpressure that supplants to the root surface, periodontal membrane, and pulp tissue, causing the tooth to elevate in the eruption direction"; 3) Adaptability in the periodontal membrane. Therefore, the three structures involved in the eruption process are: the crown follicle, the membrane covering the apical part of the tooth root and the periodontal membrane.

Once accepted the complexity of tooth eruption and the number of structures with it involved, it's easy to understand that a small change in one of them may lead to deviations of the eruptive movement that might ultimately result in tooth impactions[4, 5].

An impacted tooth might be defined as a tooth that has failed its eruptive movement, from its development location in the alveolar process into its proper location in dental arch within the normal period of growth and development, and that it won't apparently full erupt based on clinical or radiographic assessment[6-8]. This failure can be related with both systemic factors[9] and local factors[7, 9-12] shown in Annex 1.

Estimation of the normal period of growth and development mentioned above might be done using charts of the developing dentition and specific crown/root formation stages. Schour and Massler's chart (originally presented in 1941 and revised in 1944), one of the most well known and studied, consider that at the age of 11years±9months it's expected that upper canine emerge in dental arch and at the age of 12years±6months it's in its correct position in the dental arch[13]. Ubelaker's dental chart, first presented in 1978 and revised in 1989, was an attempt to overcome some of the Schour and Massler's errors and limitations[13]. Ubelaker considered that at the age of 11years±30months upper canine should emerge in dental arch and at the age of 12years±30months it's expected its full eruption and its correct position in the dental arc[14].

More recently in 2010, AlQahtani *et al*[15] developed the London Atlas of Development and Eruption, an evidence based atlas that uses both tooth development and its eruption for 31 age categories. They concluded that: upper canine alveolar eruption occurs at the age of 11,5years (being this age a midpoint of 1 year and an average for combined gender, both males and females); clinical emergence in dental arch in males is at the age of 12,1years and in females is at the age of 10,6years (based on Haavikko studies, 1970); full eruption on oral cavity occurs at the age of 12,5years (once again this age is considered a midpoint of 1 year and an average for combined gender). A comparative study preformed in 2014 showed that London Atlas is a more accurate method of dental age estimation from developing teeth than Schour and Massler's and Ubelaker's[13].

In this study we considered a upper canine as an impacted maxillary canine (IMC) when, after the age of 13,00 years (according to the London Altlas, 12,99years is considered the maximum interval in which is expected upper canine full eruption in oral cavity, being out of the normal time of eruption above the age of 13,00years), the canine was still in the alveolar process prevented from erupting into its correct position in the oral cavity and its full eruption wasn't predictable.

IMC is a relatively common pathology, having the third highest incidence ranging from 1% to 3%[10, 12, 16]. Mandibular third molars have the highest incidence (82,5%) followed by maxillary third molars (15,6%), whereas the incidence of impacted mandibular canine is one of the lowest (0,35%)[7, 16, 17].

Relatively to tooth localization, IMC generally occupies a palatal position (85%) instead of a vestibular position (15%)[10, 12, 16, 18]. These impactions are more commonly found in female patients (1,17%) than in male ones (0,51%) with a 2:1 ratio[12, 19]. Among all patients with IMC, only 8% have bilateral impactions. As for prevalence ratings, IMC ranges from 0.92% to 4.3%[19].

Permanent maxillary canine take a crucial role regarding masticatory function, dento-facial aesthetic and harmony and dental occlusion and stability[10]. Therefore, it is important that clinicians are aware of this condition in order to detect the impaction and prevent some of the possible complications associated with its occurrence and treatment such as adjacent root resorption (the most common complication), swelling, bleeding or hematoma of the soft tissues around the operation site, post-surgical pain, purulent exudate, breakage of ligature wire, de-bonding of the attachment and inability to bond the attachment during surgery[20].

Beside avoiding the complications mentioned above, an early detection of tooth inclusion may allow a conscious and correct diagnosis and treatment planning, which often requires a multidisciplinary approach[8, 10]. Park *et al*[8] summarily describes IMC management, dividing the treatment plan in two phases:

1st: <u>Preventive and interceptive treatment</u> (preformed when it's likely that impaction will occur): the main goal in this stage is to eliminate obstacles from the eruption path and to provide enough space for the IMC to erupt with i.e. deciduous canine extraction; deciduous canine extraction associated to rapid maxillary expansion; or both deciduous canine and deciduous first molar extraction;

2nd: <u>Corrective treatment</u> (preformed when preventive and interceptive treatment fails or when patient is beyond the age of these treatments): treatment plan depends on the IMC location. When it's located labially, gingivectomy, apically positioned flap and closed eruption technique might be preformed. For exposing palatal impactions might be done a surgical exposure followed by orthodontic traction. Even though it's rare, permanent impacted tooth extraction might be considered if the impacted canine is ankylosed, resorpted or if its reposition in correct place it's not possible.

In order to perform a correct diagnosis and to choose the most appropriate treatment plan, some orthodontic records are needed. Though it's not defined a minimum of record set necessary for this purpose, several exams are usually required. Dental casts, intra and extra oral photographs, clinical measurements and different radiographic images are traditionally utilized[21].

In this last category are included: orthopantomography (OPG), lateral cephalograms, hand-wrist radiographs and intra oral radiographs[10, 21, 22]. Summarily, OPG allows a general view of both upper and lower dental arch, temporomandibular joints (TMJ) and adjacent structures[10, 23]; lateral cephalograms enables cephalometric analysis, TMJ and tonsillar and lymphoid tissues evaluation[24]; hand-wrist radiograph examines the ossification centers allowing determination of patient's skeletal maturity; and intra and extra oral radiographs show the relation between deciduous and definitive dentition[21].

When diagnosing an impacted upper canine, several radiographic projections might be needed in order to determine its exact position. OPG and periapical radiographs allow information regarding canine mesio-distal and vertical location among adjacent structures. Accessing its labio-palatal position might be difficult due to superimposition within the image of the impacted teeth and other teeth or structures. Though its precise position determination is not possible, some authors believe that an estimation might be done with two or more periapical radiographs with different horizontal angles of the x-ray beam (using Clark's rule) or with a normal occlusal radiography. Also cephalograms (frontal and lateral) help clarify the proximity to other anatomical structures, i.e. maxillary sinus[16, 25, 26].

Adding to the fact that IMC is located at the most curved area of the maxillary arch, distortion, superimposition of anatomical structures, the occurrence of radiographic artifacts and the difficulty in obtain information of its exact location are some of the main concerns regarding these radiographs that might not allow a correct reading and interpretation of its information. Even though with Computed Tomography (CT) the exact location of the tooth it's possible, the high radiation exposure, high costs and limited access to CT imaging services do not make it a viable alternative. Supported by this idea, some authors believe that the canine impaction study based on these exams it isn't the most correct[6, 16, 25, 27].

In the late 90's, Professor Mozzo from Verona University, Italy, discovered Cone Beam Computed Tomography (CBCT). Its capacity in reproducing high resolution images from craniofacial structures, compared to traditional radiographs associated with lower dose radiation exposure, compared to CT, turned it into an interesting and revolutionary diagnostic method. The growing use of CBCT in Dentistry is well known and documented in literature[28].

The use of CBCT in orthodontics has recently been growing, improving diagnosis and treatment planning[29]. CBCT has been described in the study of: impacted teeth, root resorption, roots fractures, orthodontic implants placement, asymmetry assessment, TMJ, airway paths, cleft lip and palate, cephalograms (reconstructed from CBCT), orthognathic surgery, rapid maxillary expansion, space analysis in mixed dentition, superimposition and digitized dental casts[10, 21, 30-32].

CBCT system uses an x-ray source and detector unit designed to rotate around patient's head. The x-ray source emits a coneshaped beam of ionizing radiation through patient's head that is then received by detector. This unit rotates only once around the patient's head in full 360º or less (partial arcs) and while rotating, on every degree it rotates (usually 1º) the x-ray source emits radiation allowing the detector to acquire multiple "basis" projection radiographs, very similar to two-dimensional (2D) ones. The resulting volumetric data is cylindrical shaped and this cylinder is made of cuboids' structures – voxels – representing a specific degree of the x-ray beam. Once the scan is done, the multiple 2D projections are reconstructed, with the help of a computer software program that uses an algorithm, into a three-dimensional (3D) volume, allowing patient's study in three orthogonal planes: sagittal, coronal and axial(16, 23, 29, 30, 33, 34).

CBCT advantages are well known. When compared to conventional 2D radiographs, CBCT provides information on the location of the structures in the three orthogonal planes and respective relations with adjacent structures(16), enables sub millimeter spatial resolution of craniofacial structures(35), can accurately assess linear, angular and 3D measures from craniofacial complex(6, 35-39), and has a greater accuracy because the projection is orthogonal, meaning that x-ray beams are emitted parallel to each other and the distance between x-ray source and detector unit is very short. This explains the almost absence of projection and magnification effects in CBCT, resulting in undistorted 1:1 measurements(16). As mentioned before, when compared with CT the main advantage is the lower dose radiation exposure, besides the obvious lower exam cost. A more detailed comparison between CBCT, CT and 2D radiographs is presented in Annex 2.

Even though these advantages, one should never forget that effective dose radiation (that it is still obviously present) is related to the risk of radiation-induced cancer, and this relation might triplicate in children and young people, which are the target groups for orthodontic treatment. Hence, it's extremely important a conscious weighing either or not this exam is sorely needed. If clinicians decide that it is, some adjustments might be done before scanning in order to lower the radiation dose exposure(26). The regulation of voxel size, field of View (FOV) and exposure settings (milliamperage (mA), kilovoltage (kVp) and time exposure) to the clinical condition in study, associated with protective shields are some of the recommendations provided by the American Academy of Oral and Maxillofacial (AAOM) to minimize the patient's radiation exposure without compromising the diagnostic information, respecting ALARA - As Low as Reasonably Achievable - principle(32).

Regarding tooth impactions, what the current literature suggests is that smaller voxel sizes should only be requested when it's necessary to study very small structures (i.e. tooth fractures). When analyzing other structures, voxel sizes of 0.3 mm and 0.4 mm should be preferred(40). Also FOV can be adjusted to allow only the visualization of ROI (Region of Interest), which in this case is the maxilla, eliminating other structures that aren't important and decreasing radiation dose. The AAOM defines that a small FOV ($\leq$100mm) should be required when the ROI is limited to “a few teeth, a quadrant and up to two dental arches” as it is the case of this study[(32)].

The use of CBCT applied to the study of IMC is not new. One of the first publications go back a decade. In 2005 Nakajima *et al*[(34)] described three cases, one of them included tooth impactions, in which he proved the usefulness of 3D images in providing information for orthodontic diagnosis and treatment planning. From then on several more studies with different methodologies have proved CBCT value and nowadays we know that it is a powerful tool in location, diagnosis and treatment planning of IMC, providing better surgical and orthodontic treatment[(6, 10, 16, 25, 26)].

The aim of this study was to compare and conclude in what way the opinion regarding upper canine impaction location, adjacent tooth resorption, prognosis, image information, treatment plan and difficulty level could vary when observing a panoramic image compared to the observation of a set of CBCT reconstructions.

Material and Methods

The study sample was based on the analysis of CBCT exams from the database of the Department of Dentistry, Faculty of Medicine, University of Coimbra (DDFMUC).

The selected patients had already been submitted to CBCT exam due to previous clinical indication for 3D evaluation. None of them went through CBCT exam only to be included in this study.

Therefore, from an initial database of over 700 CBCT exams, the flowing inclusion criteria were applied: pre-existing CBCT from DDFMUC's database; upper canine impaction (left or right, uni or bilateral); age over 13 years; 0,3mm voxel size of CBCT exam and FOV of 100mm. The exclusion criteria were: syndromic patients or with craniofacial or dental anomalies that could affect tooth eruption and development; previous or current orthodontic treatment when CBCT scan was performed and artifacts that unable the CBCT analysis.

Once applied this criteria, 20 patients (10 males and 10 females) were included in the study, aged between 13 and 73 years old. A total number of 28 upper impacted canines were examined.

The initial study design meant to evaluate the difference between OPG and CBCT images. However, only 7 of these patients had an available OPG image. OPG was not performed in this study to the other patients once CBCT exam already existed and to avoid further radiation exposure. Instead, we decided to use the correspondent CBCT panoramic reconstruction image.

Patients were scanned using the iCAT scanner machine (*Imaging Sciences International, Hatfield PA, USA*) available in hospital, set at 0,3mm voxel size, 120 kV tube voltage, 5mA current, 100 FOV, 4s of time scanning and with a slice thickness interval of 1,20mm. The DDFMUC follows a high quality protocol when obtaining radiological images.

The CBCT images were then exported in format of Digital Imaging and Communications in Medicine (DICOM) and imported into iCATVision software (*Imaging Sciences International, Hatfield PA, USA*) for analysis. Several projections were reconstructed having two groups of images available for each impacted canine:

- Group A: a CBCT panoramic reconstruction image (Figure 1-A). This image was automatically reconstructed by the software based on anatomic landmarks;
- Group B: a set of 7 reconstructions under different planes (Figure 2). It allows tooth analysis under the three orthogonal planes: a frontal cephalometric, an axial/transversal view, a sagittal view, a coronal/frontal, and two 3D reconstructions,

the first one with a high level of bone density, and the second one with less to allow a more accurate view of the teeth.

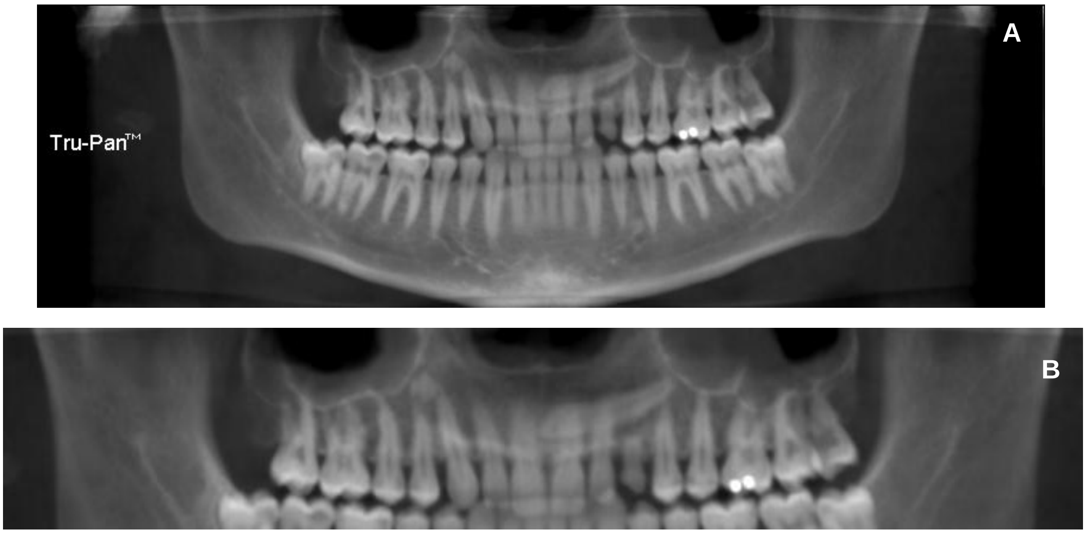

Figure 1: Example of panoramic reconstruction obtained from iCATVision. A: original CBCT panoramic reconstruction image; B: the same image cropped to show only the ROI.

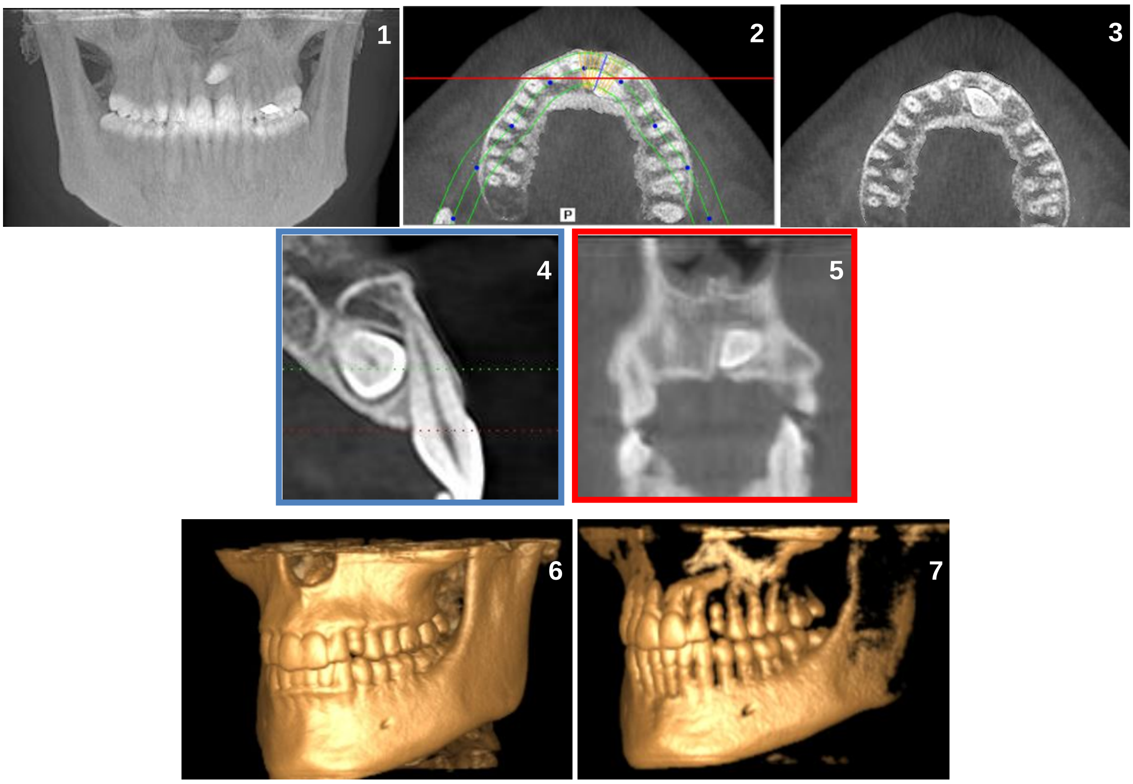

Figure 2: Example of images data set obtained from iCATVision software: (1) frontal cephalometric projection, (2) axial/transversal view showing the cuts used to reconstruct the sagittal view (represented by the blue line) and the coronal/frontal view (represented by the red line), (3) the same axial/transversal view without the lines, (4) sagittal view, (5) coronal view, (6) 3D reconstruction with a high level of bone density, and (7) the same 3D reconstruction with less bone density.

One operator performed these segmentations for every case. Then each image was extracted from the software and saved as a JPEG file.

Images from Group A were cropped to show only the ROI which in this case was the superior dental arch and related structures (Figure 1-B), and printed with a dimension of 23,5cm x 5,5cm. Images from Group B were printed with a size of 7,5cm x 4,5cm, with exception from sagittal and coronal view, which had a size of 5cm x 4cm. For every case, both gender and age was indicated.

The images were printed in a high quality paper (Inapa Techno, Hamburg, Germany) and using Ricoh MP C4500 (Ricoh Americas Corporation, Malvern PA, USA) laser printer, indicated for high resolution images.

A questionnaire (Annex 3) was distributed to nine orthodontists, where they were asked to analyze tooth position, adjacent tooth resorption, image information, prognosis, treatment plan and its duration and difficulty of the case. The exact same questions were applied to both groups A and B, after a random distribution of both groups' images using an online sorter (https://www.random.org/) so that images from group A did not necessarily correspond to those from group B. The questionnaire was divided in two parts:

Part A – the observers were asked about their academic record;

Part B – after some initial considerations regarding the questionnaire fill, the observers were asked to orderly answer to the questions on the "Answer Sheet".

The data set was conducted using the SPSS software (version 22, SPSS Inc., USA).

Cronbach's alpha statistics was used to determine inter-rater reliability for both questions from group A and group B (separately). Intra-rater agreement between groups A and B was measured using Kappa statistics for categorical questions and McNemar test for dichotomous questions.

For all comparisons, a *P* value of less than 0.05 was considered statistically significant.

Results

The number of patients included in this study were 20, 50% (n=10) were males and 50% (n=10) were females, with a ratio 1:1. A total of 28 impacted upper canines were found: 40% (n=8) were bilateral impactions, 30% (n=6) were unilateral right impactions and 30% (n=6) were unilateral left impactions.

As shown on the figure bellow (Figure 3), male patients presented 5 cases of upper bilateral impaction, 1 case of unilateral upper right impaction and 4 cases of unilateral upper left impaction. Female patients presented 3 cases of upper bilateral impaction, 5 cases of unilateral upper right impaction and 2 cases of unilateral upper left impaction.

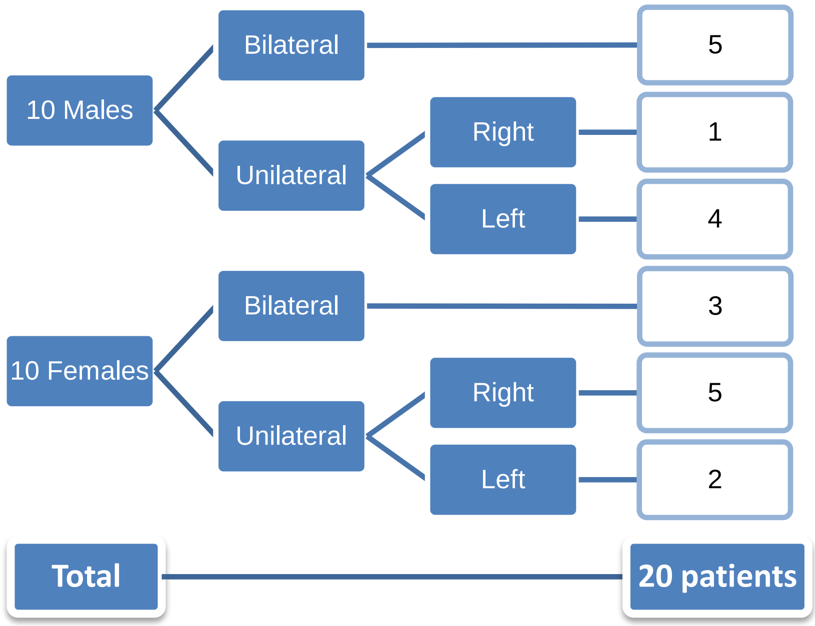

Figure 3: Study sample distribution according to gender.

Patients included in the study were aged between 13,00years (<13,00years was considered within the normal time of eruption) and 73,08years old, with a mean age of 26,83years and a standard deviation of 16,43years. As illustrated on Figure 4, 32,14% were aged between 13 to 15 years, 21,43% were aged between 15 to 20 years, 14,29% were aged between 20-25 years and 32,14% were above 30 years. There was no patient aged between 25 to 30 years in our sample.

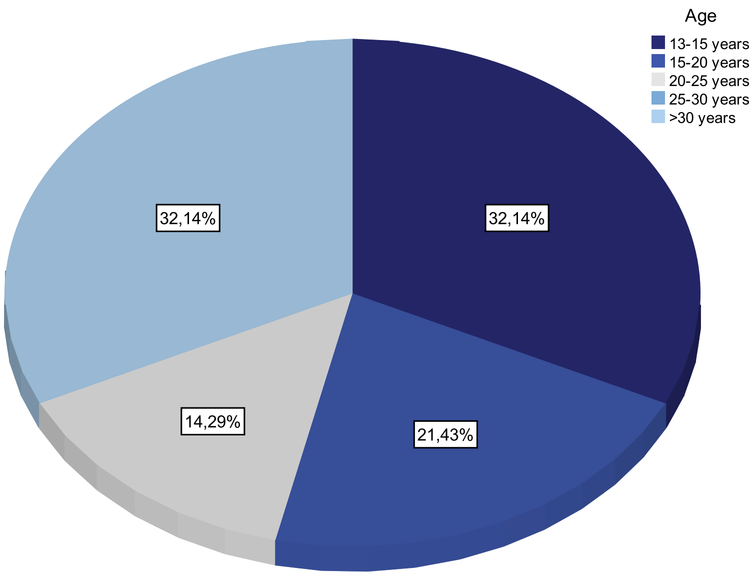

Figure 4: Patients age distribution.

The nine observers were aged between 30 and 47 years with a mean age of 39,5years with a standard deviation of 5,93years. They were all postgraduates in orthodontics and had been practising (as postgraduate) at a mean of 9,33years with a standard deviation of 4,95years.

Considering that there were nine observers and 28 canines to compare with both panoramic and CBCT images, the total number of data set was 252.

The results obtained from the questionnaires are summarized in Tables II – were values obtained from the Cronbach's Alpha test ($\alpha_{cronbach}$) are presented – and Table III – showing the agreement percentage found between the two methods, kappa values (k) and the significance level (p). The range of values and its meanings used in our study are shown in the table bellow (Table I).

Table I: Range of values considered for Cronbach's alpha statistics and Kappa statistics.

Meaning	**Value**
Perfect	1
Very Strong	0,8-0,99
Strong	0,6-0,8
Moderate	0,4-0,6
Poor	0,2-0,4
Very Poor	0,0-0,2

Inter-rater reliability ranged in every question from moderate to very strong, with exception of question number 2 for group B and question number 8 for group A (Table II). These findings will be explained bellow.

Table II: Summary of the results of the inter-rater reliability between panoramic (Group A) and CBCT (Group B) images separately.

		Group A $\alpha_{cronbach}$	Group B $\alpha_{cronbach}$
1	M-D tip cusp position in relation to the long axis of the lateral incisor	0,704	0,564
2	M-D apex position in relation to the long axis of the first premolar	0,834	0,373
3	Vertical tip cusp position in relation to the long axis of the lateral incisor	0,648	-
4	L-P position in relation to lateral incisor	0,976	0,649
5	Adjacent tooth resorption	0,963	0,765
6	Image information	0,913	0,987
7	Prognosis	0,772	0,784
8	Treatment Plan	0,249	0,468
9	Treatment Duration	0,794	0,726
10	Difficulty of the case	0,891	0,906

Table III: Summary of the results of the agreement between panoramic and CBCT images. First column shows the percentage of agreement; second column indicates the kappa value; $\boldsymbol{p}$ level it's indicated on the third column.

		% Agreement	k statistics	p
1	M-D tip cusp position in relation to the long axis of the lateral incisor	69,8%	$k = 0.577$	$p < 0{,}001$
2	M-D apex position in relation to the long axis of the first premolar	57,4%	$k = 0.388$	$p < 0{,}001$
3	Vertical tip cusp position in relation to the long axis of the lateral incisor	85,9%	$k = 0.035$	$p = 0{,}114$
4	L-P position in relation to lateral incisor	42,2%	$k = 0.271$	$p < 0{,}001$
5	Adjacent tooth resorption	55,3%	$k = 0.105$	$p = 0{,}015$
6	Image information	32,6%	$k = 0.061$	$p = 0{,}008$
7	Prognosis	70,6%	$k = 0.546$	$p < 0{,}001$
8	Treatment Plan	77,6%	$k = 0.603$	$p < 0{,}001$
9	Treatment Duration	71,7%	$k = 0.482$	$p < 0{,}001$
10	Difficulty of the case	66,0%	$k = 0.479$	$p < 0{,}001$

1) Canine localization in three orthogonal planes

Differences were found in the location of the IMC position between the two radiographic modalities. When asked to access the mesio-distal (M-D) tip cusp position in relation to the long axis of the lateral incisor a 69,8% (n= 169) of agreement between the two images was found between raters. With the analysis of CBCT images, IMC were less classified as “overllaped”. Only 9,9% (n=24) of the “overllaped” answers were maintained after analyzing group B images (Table IV).

Table IV: Crosstabulation for the M-D tip cusp position.
Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B				Total
			Mesial	Overllaped	Distal	NA	
Group A	Mesial	Count	65	6	1	2	74
		% of Total	26,9%	2,5%	0,4%	0,8%	30,6%
	Overllaped	Count	28	24	26	1	79
		% of Total	11,6%	9,9%	10,7%	0,4%	32,6%
	Distal	Count	2	7	63	0	72
		% of Total	0,8%	2,9%	26,0%	0,0%	29,8%
	NA	Count	0	0	0	17	17
		% of Total	0,0%	0,0%	0,0%	7,0%	7,0%
Total		Count	95	37	90	20	242
		% of Total	39,3%	15,3%	37,2%	8,3%	100,0%

The mesio-distal apex position had an intra-rater agreement between panoramic and CBCT images of 57,4% (n=139). More than a third of the sample (n=98), were classified as “distal” with the panoramic image, whereas with CBCT images there was a significant change of answers to a more “mesial” or “overllaped” position, with basically half of the cases being maintained as “distal” (n=44) and another half being changed (n=22+30=52) to “mesial” or “overllaped” (Table V). The poor inter-rater reliability found can be associated with the fact that a larger spread of answers was observed with the CBCT images.

Table V: Crosstabulation for the M-D apex position.

Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B				Total
			Mesial	Overllaped	Distal	NA	
Group A	Mesial	Count	40	13	2	0	55
		% of Total	16,5%	5,4%	0,8%	0,0%	22,7%
	Overllaped	Count	18	53	8	0	79
		% of Total	7,4%	21,9%	3,3%	0,0%	32,6%
	Distal	Count	22	30	44	2	98
		% of Total	9,1%	12,4%	18,2%	0,8%	40,5%
	NA	Count	6	1	1	2	10
		% of Total	2,5%	0,4%	0,4%	0,8%	4,1%
Total		Count	86	97	55	4	242
		% of Total	35,5%	40,1%	22,7%	1,7%	100,0%

Vertical cusp position had a high intra-rater agreement (85,9%). Most of the IMC classified as above the apex of the central incisor with the panoramic image were classified as bellow apex with the CBCT data set. There were zero cases scored as “NA” for both images from goups A and B (Table VI). Though inter-rater reliability for vertical cusp position of CBCT images couldn’t be calculated (Table II), Figure 5 shows a bar chart with the percentage of answers given by the observers for each case of group B images. There, is possible to see that, with the exception of three cases where one of the examiners disagreed, every other case had an agreement of 100%.

Table VI: Crosstabulation for the vertical cusp tip position

Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B			Total
			Above apex	Bellow apex	NA	
Group A	Above apex	Count	1	27	0	28
		% of Total	0,4%	11,2%	0,0%	11,6%
	Bellow apex	Count	2	207	0	209
		% of Total	0,8%	85,5%	0,0%	86,4%
	NA	Count	0	5	0	5
		% of Total	0,0%	2,1%	0,0%	2,1%
Total		Count	3	239	0	242
		% of Total	1,2%	98,8%	0,0%	100,0%

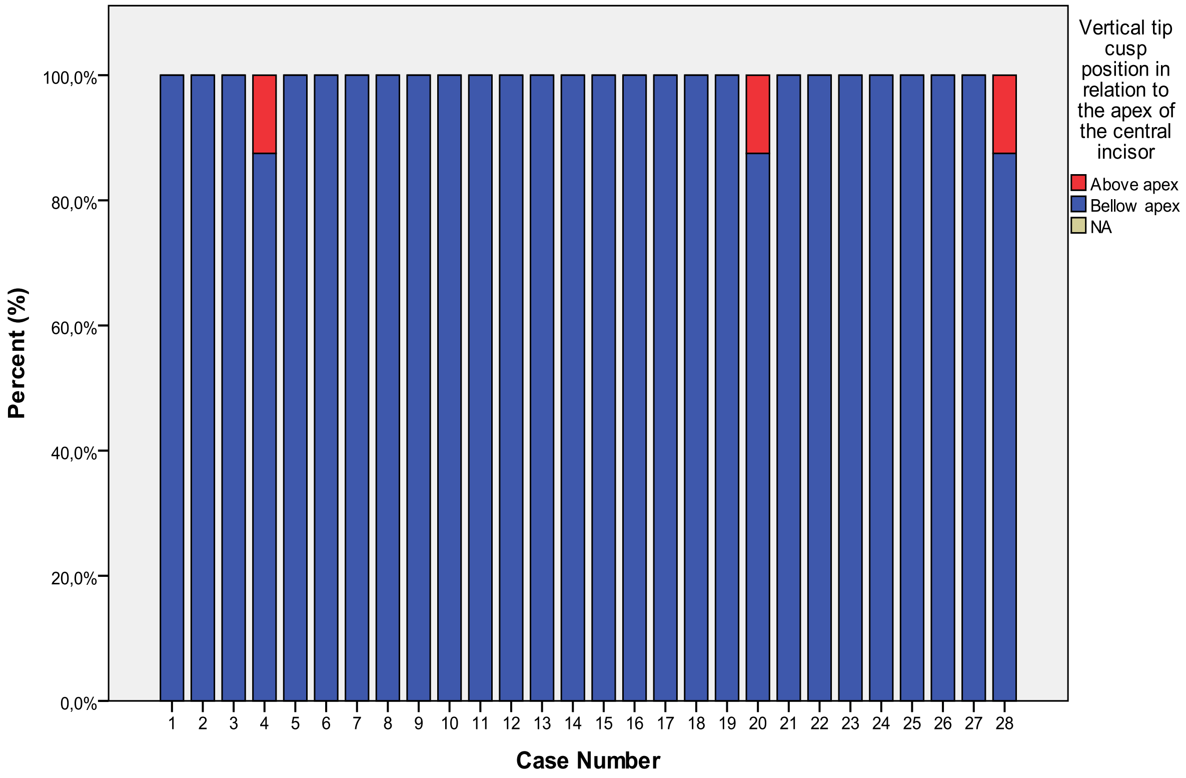

Figure 5: Answers given by observers about the vertical tip cusp position in relation to the long axis of the lateral incisor to each case of group B images.

Labio-Palatal (L-P) position had a significant poor intra-rater agreement ($k = 0.271; p < 0{,}001$) with an agreement percentage of only 42,2%. With the panoramic image in 36,8% of the cases (n=89) wasn't possible to determine the IMC L-P position. This evaluation decreased significantly with the CBCT data set to only 17 cases. Also a higher "Labial" classification was found with the CBCT data set (Table VII).

These findings can also explain why a higher Cronbach's Alpha value was found for the panoramic images group, because here the answers were basically divided in "Palatal" and "NA" options, while a larger spread of answers was observed with the CBCT group images, leading to a decrease of inter-rater reliability.

Table VII: Crosstabulation for the L-P cusp position.

Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B				Total
			Labial	Palatal	Midalveolus	NA	
Group A	Labial	Count	20	13	1	0	34
		% of Total	8,3%	5,4%	0,4%	0,0%	14,0%
	Palatal	Count	18	62	18	5	103
		% of Total	7,4%	25,6%	7,4%	2,1%	42,6%
	Midalveolus	Count	5	3	8	0	16
		% of Total	2,1%	1,2%	3,3%	0,0%	6,6%
	NA	Count	25	25	27	12	89
		% of Total	10,3%	10,3%	11,2%	5,0%	36,8%
Total		Count	68	103	54	17	242
		% of Total	28,1%	42,6%	22,3%	7,0%	100,0%

2) Adjacent tooth resorption

Observers were asked either if root resorption was present or not. The kappa statistics show a very poor agreement between the two groups ($k = 0.105; p = 0,015$).

CBCT analysis demonstrated a lower classification of root resorption. From the 23,6% (n=57) of "yes" answers from group A, 15,3% (n=37) were changed to "no" when 3D data was analysed. Also "NA" answers decrease from 47 cases with the panoramic image to only 6 cases with CBCT analysis (Table VIII).

Table VIII: Crosstabulation for adjacent tooth resorption.

Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B			Total
			Yes	No	NA	
Group A	Yes	Count	18	37	2	57
		% of Total	7,4%	15,3%	0,8%	23,6%
	No	Count	22	114	2	138
		% of Total	9,1%	47,1%	0,8%	57,0%
	NA	Count	3	42	2	47
		% of Total	1,2%	17,4%	0,8%	19,4%
Total		Count	43	193	6	242
		% of Total	17,8%	79,8%	2,5%	100,0%

3) Image information

The examiners were asked if the images were enough for orthodontic diagnosis. Both groups A and B obtained a very good inter-rater reliability individually ($\alpha_{cronbach} = 0{,}913$ and $\alpha_{cronbach} = 0{,}987$ respectively). The panoramic images were mostly assessed as not enough for orthodontic diagnosis, while more than 200 images analysed with the CBCT images were classified as enough (Figure 6).

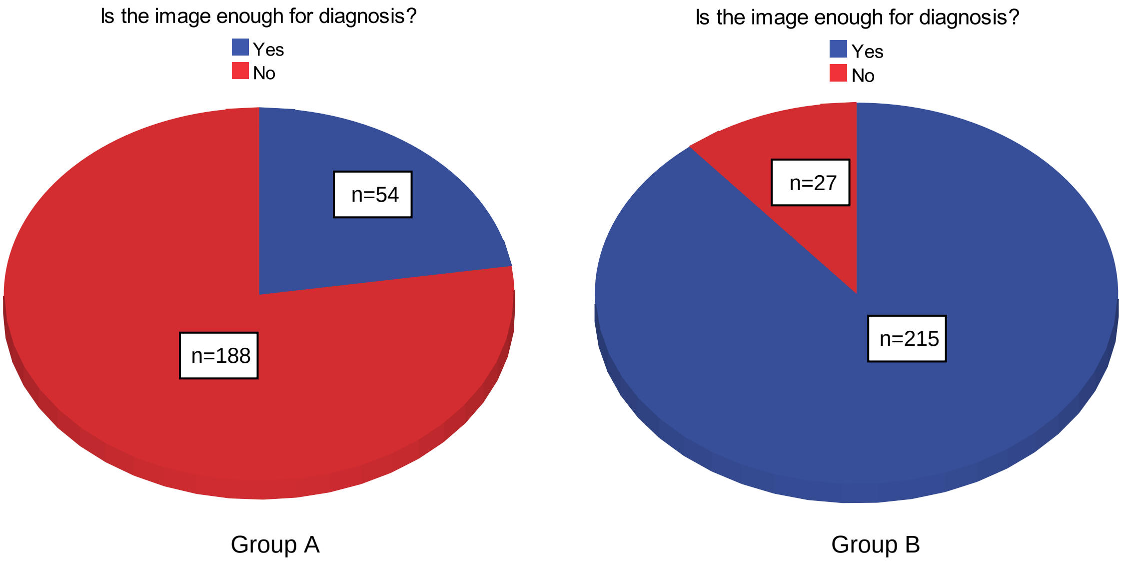

Figure 6: Pie chart indicating the answers obtained for the image information for group A (left) and group B (right).

Comparing the two images, a very poor intra-rater agreement was found ($k = 0.061; p = 0{,}008$). McNemar's test show that there is a statistically significant change of answers between groups (60,7% CI95% [56,3%; 61,5%]; $p = 0{,}001$). Of all cases, 162 cases scored as not enough for diagnosis with the panoramic image were changed when CBCT data set was available (Table IX).

Table IX: Crosstabulation for the image information.
Ten missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=242).

			Group B		Total
			Yes	No	
Group A	Yes	Count	53	1	54
		% of Total	21,9%	0,4%	22,3%
	No	Count	162	26	188
		% of Total	66,9%	10,7%	77,7%
Total		Count	215	27	242
		% of Total	88,8%	11,2%	100,0%

4) Prognosis

When asked to classify cases prognosis a statistically significant moderate agreement was found between the two methods ($k = 0.546; p < 0{,}001$). Both total percentages and total cases count were very similar in both methods (Table X).

Table X: Crosstabulation for prognosis.
Eleven missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=241).

			Group B			Total
			Good	Reasonable	Weak	
Group A	Good	Count	53	19	7	79
		% of Total	22,0%	7,9%	2,9%	32,8%
	Reasonable	Count	20	73	10	103
		% of Total	8,3%	30,3%	4,1%	42,7%
	Weak	Count	1	14	44	59
		% of Total	0,4%	5,8%	18,3%	24,5%
	Total	Count	74	106	61	241
		% of Total	30,7%	44,0%	25,3%	100,0%

5) Treatment Plan

The orthodontists were given 4 treatment options: either to extract the deciduous canine, to perform orthodontic treatment with permanent canine traction, to extract permanent canine or not to treat. Inter-rater reliability was poor with the panoramic image $\alpha_{cronbach} = 0{,}249$ whereas with the CBCT views was moderate $\alpha_{cronbach} = 0{,}468$. The total percentages of answers were similar between the two groups. An agreement of $76{,}4\%$ was found with a strong kappa agreement $k = 0.603; p < 0{,}001$. For both groups of diagnostic images, the most frequent response was “orthodontic treatment with permanent canine traction”. Eleven of the thirty-five cases (nearly a third) indicated for “permanent canine extraction” with the panoramic image were assessed to perform “traction” with CBCT data set (Table XI).

Table XI: Crosstabulation for treatment plan.

Eleven missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=241).

Legend: dCE - Deciduous canine extraction; OTPCT - Orthodontic treatment with permanent canine traction; PCE - Permanent canine extraction; NT - No treatment (only supervise).

			Group B				Total
			dCE	OTPCT	PCE	NT	
Group A	dCE	Count	19	11	0	1	31
		% of Total	7,9%	4,6%	0,0%	0,4%	12,9%
	OTPCT	Count	6	127	8	8	149
		% of Total	2,5%	52,7%	3,3%	3,3%	61,8%
	PCE	Count	0	11	22	2	35
		% of Total	0,0%	4,6%	9,1%	0,8%	14,5%
	NT	Count	2	2	3	19	26
		% of Total	0,8%	0,8%	1,2%	7,9%	10,8%
	Total	Count	27	151	33	30	241
		% of Total	11,2%	62,7%	13,7%	12,4%	100,0%

6) Orthodontic Treatment Duration

When asked about the orthodontic treatment duration, 38,2% and 37,3% (Table XII) answered “NA” to both groups A and B, respectively, a percentage that correspond to the sum of every treatment plan proposed minus the “Orthodontic treatment with permanent canine traction” option. In table XV is shown the percentages of answers obtained for this topic, after excluding the “NA” option. An agreement of 71,7% was found between the two methods, with a kappa value showing a moderate agreement (Table XIII). In group B images, a slight longer treatment was scored than in group A.

Table XII: Crosstabulation for treatment duration.

Eleven missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=241).

			Group B			Total
			Normal	Long	NA	
Group A	Normal	Count	32	23	10	65
		% of Total	13,3%	9,5%	4,1%	27,0%
	Long	Count	13	59	12	84
		% of Total	5,4%	24,5%	5,0%	34,9%
	NA	Count	9	15	68	92
		% of Total	3,7%	6,2%	28,2%	38,2%
Total		Count	54	97	90	241
		% of Total	22,4%	40,2%	37,3%	100,0%

Table XIII: Crosstabulation for treatment duration (excluding the “NA” answers).

125 missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=127).

			Group B		Total
			Normal	Long	
Group A	Normal	Count	32	23	55
		% of Total	25,2%	18,1%	43,3%
	Long	Count	13	59	72
		% of Total	10,2%	46,5%	56,7%
Total		Count	45	82	127
		% of Total	35,4%	64,6%	100,0%

7) Difficulty of the case

Lastly, the observers were asked to classify the case difficulty as: easy, moderate or difficult. A statistically significant moderate agreement was found between the two methods ($k = 0.479; p < 0{,}001$), with a 66,0% (n=159) percentage of agreement. A slightly lower score of “difficult” was obtained with the panoramic image compared with the CBCT data set (59 cases to 70 cases, respectively) but the majority of the answers were for both groups “moderate” (Table XIV).

Table XIV: Crosstabulation for difficulty of the case.

Eleven missing cases were observed and the percentage shown is considering as 100% the valid number of cases (n=241).

			Group B			Total
			Easy	Moderate	Difficult	
Group A	Easy	Count	45	20	9	74
		% of Total	18,7%	8,3%	3,7%	30,7%
	Moderate	Count	23	69	16	108
		% of Total	9,5%	28,6%	6,6%	44,8%
	Difficult	Count	4	10	45	59
		% of Total	1,7%	4,1%	18,7%	24,5%
Total		Count	72	99	70	241
		% of Total	29,9%	41,1%	29,0%	100,0%

Discussion

The number of male and female patients included in this study was the same, resulting in a ratio of 1:1, differing from what's described in literature. Also the frequency of unilateral and bilateral impactions found in this study (60% and 40% respectively) differed from the ones found in other studies (92% and 8%, respectively)[12, 19]. These differences might be justified by the reduced sample size.

Regarding M-D cusp and apex position, a reduction of "overllaped" classification was verified when CBCT data was analyzed, what might be justified due to superimposition associated to the panoramic image. Haney *et al*[16] found in their study a 79% of agreement for the M-D tip position when comparing 2D radiograph and 3D CBCT volumetric views, a percentage similar to the one found in ours.

The results obtained for the M-D position of the apex were different than the ones described by Botticelli *et al*[25]. Though the author also found a significant lack of agreement between the two methods, our results show a higher tendency to score the apex tooth in a more distal area with the panoramic data. Also a very small number of cases were classified as "NA" for both panoramic and CBCT images in our study, whereas in the study of Wriedt *et al*[10], in more than 25% of the cases, canine apex was not identified in the OPG. This can be justified with the reduction of the horizontal distortion provided by the panoramic CBCT reconstruction used in this study[41, 42].

Understanding the vertical position of the IMC is important to plan and predict the treatment[8, 25, 43]. CBCT scored almost every cases in a lower vertical position, whereas some of the cases were classified in a higher position with the panoramic exam, suggesting that the vertical level of the crown is classified in a higher position when analysing a panoramic radiography, which is in agreement with a previous study[25]. The agreement percentage found was higher than the 50% of agreement described in prior a research by Haney *et al*[16]. In this question, for both panoramic image and CBCT reconstructions, there were zero cases classified as "NA", suggesting that both exams allow the determination of the vertical cusp position.

The superimposition associated to 2D images often lead to a misinterpretation of the L-P tip cusp position. Knowing the exact L-P position of the IMC is one of the most important questions either for the surgical exposure and to define the vector of traction [10, 16, 25]. A statistically significant lack of agreement was found between the two sets of images. A superior score for labial cusp location was verified with CBCT images. Also a significant decrease of “NA” classification was observed with CBCT data set compared to panoramic images, suggesting that this data provides a better assessment of L-P cusp position.

The most common complication of canine impaction is resorption of the maxillary lateral incisor. Even though radiographic diagnosis in an early stage is possible, clinical root resorption identification is difficult mainly because it often remains asymptomatic, even in cases of pulp involvement. Clinical diagnosis generally occurs at an advanced stage, which may result in a more difficult treatment and may lead to extraction of the affected tooth(42). In this study the examiners weren’t asked to classify root resorption, but to name if adjacent tooth resorption was present or not. Once again, a decrease of the “NA” answers was verified with CBCT, compared to panoramic image. Tough the majority of the cases were assorted as having no root resorption, for both groups A and B, previous studies showed that 3D images are more sensitive and provide a better detection of root resorption than conventional 2D exams(10, 44) and also that OPG is inadequate for the characterization of resorption lesions(42).

When the observers were asked about the image quality, a very high inter-rater reliability for both sets of images was found, just like a previous report(25). A great majority said that the panoramic image wasn’t enough for orthodontic diagnosis, whereas almost 90% classified the CBCT reconstructions as sufficient for the same purpose.

There are several treatment techniques described in literature to prevent, intercept or actively treat IMC and bring the IMC into its proper position in the dental arch(45, 46). In this study, four treatment plans were proposed. Similarly to Alqerban *et al*(44) research, a strong agreement was found between the two groups for the treatment plan option, meaning that the treatment plan proposal didn’t differed much based on the panoramic and the CBCT data set. For both methods orthodontic treatment with permanent canine traction was the preferred treatment plan, chosen for more than half of the cases. Some other studies found treatment plans to be different when analyzing 2D and 3D images(10, 16, 25). Botticelli *et al*(25) found a more frequent choice of an observational–interceptive approach based on the 2D evaluation, while a more active intervention was recommended based on the 3D examination.

The position of the impacted tooth and the inclination of its long axis strongly influence the prognosis, treatment duration and the difficulty of the case. A poor prognosis, a longer and more difficult treatment is expected if the tooth is more dislocated from its correct location, or is placed deeper in bone structures or if the horizontal inclination of its axis it’s bigger(8, 25, 43). In our study, the prognosis, treatment duration and difficulty of the case didn’t differ much between the two groups, what might be explained by the agreement found between the two groups for the treatment plan. A statistically significant moderate agreement was found for these three topics evaluated with only a slightly longer and more difficult treatment being scored with the CBCT images. A previous study[25] found that the difficulty of the case differed significantly comparing 2D and 3D images, with a higher degree of difficulty obtained with the 3D image set. An interesting conclusion from *Alqerban et al*[44] study was that the level of improvement in diagnosis and chances of success in more difficult cases with CBCT was similar to the one observed in simpler cases treated with 2D information.

Summarily, the literature regarding IMC location with CBCT shows different results among all of these topics evaluated, what is very likely related with the lack of standardized methodologies. The results found in this study indicate that the greater differences between the two exams modalities are related with the mesio-distal apex position, the labio-palatal cusp position and with adjacent tooth resorption assessment, what might be explained with the superimposition and lack of 3D information of the panoramic image, suggesting CBCT examination when these issues are doubtful.

Further investigation, using precise protocols, should be done in order to evaluate in what cases CBCT exam has a clear advantage over conventional 2D exams, justifying its use.

Conclusion

CBCT system is a very useful tool in diagnosing IMC, once it allows information in the sagittal, axial, and coronal planes without overlap.

The comparison realized in this study of IMC based on panoramic image and CBCT images showed some differences between the two diagnostic methods. The results demonstrate that major differences between these two exams were about tooth position, especially concerning mesio-distal apex position and labio-palatal cusp position an also regarding the assessment of root resorption.

A very conscious weighted of pros and cons associated with CBCT exam must be done for each case, once a statistical significant moderate to strong agreement was found for all of the topics evaluated (with exception of the above mentioned where CBCT might have a clinical indication), in order to limit patients dose exposure.

Further investigation should be done to increase both study sample and the number of examiners and to assess the accuracy of these diagnostic images and compare it with the results obtained in this study.

Acknowledgements

“Agora que chega a hora
Surge a memória
Do que vivi aqui.
Coimbra, ai quem me dera
Parar o tempo e ficar...” (Grupo de Fado In Illo Tempore)

Cinco anos voltados carecem de vários agradecimentos a todos aqueles que constantemente demonstraram o seu apoio durante o meu percurso académico. Apesar da limitação de espaço não me permitir agradecer como gostaria, deixo aqui uma homenagem àqueles que mais contribuíram na concretização desta etapa.

Agradeço à minha orientadora, Professora Sónia Alves, pela confiança, total disponibilidade, ajuda e colaboração neste trabalho. Sem o seu apoio, recetividade, conhecimentos e motivação a concretização do mesmo não seria possível.

Agradeço também ao meu co-orientador, Professor Francisco do Vale por todos os ensinamentos transmitidos ao longo destes anos e pelo constante apoio, disponibilidade e ajuda que sempre demonstrou.

Agradeço ao Professor Francisco Caramelo, por toda a paciência, ensinamentos e ajuda com a análise estatística, determinantes na conclusão deste trabalho.

Aos meus espetaculares colegas e grandes amigos, por todo o apoio, por todos os desafios vencidos, por todas as aventuras vividas, por todas as alegrias convosco partilhadas e por todas as gargalhadas, um sincero obrigada.

À minha tuna, Tuna Feminina de Medicina da Universidade de Coimbra, um gigante obrigada por tantas vezes serem o meu escape às dificuldades subjacentes a este curso, por sempre me ajudarem a relativizar e ultrapassar situações menos simpáticas. Acima de tudo, obrigada pelos infindáveis momentos de pura diversão, alegria e felicidade que me proporcionaram. Para vocês, um grande F-R-A!

Por fim, e não sabendo bem como o fazer, pois tamanha entrega tornam escassas as palavras, agradeço do fundo do coração à minha família. Mãe, Pai, Irmão, Avós, Tios, Primos, Afilhadas…Obrigada por toda a formação pessoal e académica que me proporcionaram desde sempre, por toda a confiança, motivação, paciência, carinho, alegria e apoio incondicional que demonstraram ao longo de todos estes anos. Graças a vocês cheguei até aqui. Obrigada “famelga”!

Mais uma vez, a todos vocês, muito obrigada!

Bibliography

1. Boucher CO, Zwemer TJ. Boucher's clinical dental terminology: a glossary of accepted terms in all disciplines of dentistry: C.V. Mosby Co.; 1982.

2. Kjaer I. Mechanism of human tooth eruption: review article including a new theory for future studies on the eruption process. Scientifica. 2014;2014:341905.

3. Textbook of Dental and Oral Histology and Embryology with MCQs: Jaypee Brothers,Medical Publishers,India; 2004.

4. Purkait SK. Essentials of Oral Pathology: Jaypee Brothers,Medical Publishers Pvt. Limited; 2011.

5. Becker A. Orthodontic Treatment of Impacted Teeth: Wiley; 2012.

6. Almuhtaseb E, Mao J, Mahony D, Bader R, Zhang ZX. Three-dimensional localization of impacted canines and root resorption assessment using cone beam computed tomography. Journal of Huazhong University of Science and Technology Medical sciences = Hua zhong ke ji da xue xue bao Yi xue Ying De wen ban = Huazhong keji daxue xuebao Yixue Yingdewen ban. 2014;34(3):425-30.

7. Yadiki JV, Kategari YB, Chada P, Vallakatla V. Can Milk Teeth be Impacted? Why Not: A Case of Six Impacted Primary Teeth. International journal of clinical pediatric dentistry. 2014;7(3):220-2.

8. Park JH, Srisurapol T, Tai K. Impacted maxillary canines: diagnosis and management. Dentistry today. 2012;31(9):62, 4-6; quiz 8-9.

9. Litsas G, Acar A. A review of early displaced maxillary canines: etiology, diagnosis and interceptive treatment. The open dentistry journal. 2011;5:39-47.

10. Wriedt S, Jaklin J, Al-Nawas B, Wehrbein H. Impacted upper canines: examination and treatment proposal based on 3D versus 2D diagnosis. Journal of orofacial orthopedics = Fortschritte der Kieferorthopadie : Organ/official journal Deutsche Gesellschaft fur Kieferorthopadie. 2012;73(1):28-40.

11. Aruna U, Annamalai PR, Nayar S, Bhuminathan S. Primary failure of eruption- a case report with cone beam computerized tomographic imaging. Journal of clinical and diagnostic research : JCDR. 2014;8(4):ZD14-6.

12. Fu PS, Wang JC, Wu YM, Huang TK, Chen WC, Tseng YC, et al. Unilaterally impacted maxillary central incisor and canine with ipsilateral transposed canine-lateral incisor. The Angle orthodontist. 2013;83(5):920-6.

13. AlQahtani SJ, Hector MP, Liversidge HM. Accuracy of dental age estimation charts: Schour and Massler, Ubelaker and the London Atlas. American journal of physical anthropology. 2014;154(1):70-8.

14. Senn DR, Weems RA. Manual of Forensic Odontology, Fifth Edition: Taylor & Francis; 2013.

15. AlQahtani SJ, Hector MP, Liversidge HM. Brief communication: The London atlas of human tooth development and eruption. American journal of physical anthropology. 2010;142(3):481-90.

16. Haney E, Gansky SA, Lee JS, Johnson E, Maki K, Miller AJ, et al. Comparative analysis of traditional radiographs and cone-beam computed tomography volumetric images in the diagnosis and treatment planning of maxillary impacted canines. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2010;137(5):590-7.

17. Dalessandri D, Migliorati M, Visconti L, Contardo L, Kau CH, Martin C. KPG index versus OPG measurements: a comparison between 3D and 2D methods in predicting treatment duration and difficulty level for patients with impacted maxillary canines. BioMed research international. 2014;2014:537620.

18. Syrynska M, Budzynska A. [The incidence of uni- and bilateral impacted maxillary canines and their position in dental arch depending on gender and age]. Annales Academiae Medicae Stetinensis. 2008;54(2):132-7.

19. Kumar S, Mehrotra P, Bhagchandani J, Singh A, Garg A, Kumar S, et al. Localization of impacted canines. Journal of clinical and diagnostic research : JCDR. 2015;9(1):Ze11-4.

20. Sajnani AK, King NM. Complications associated with the occurrence and treatment of impacted maxillary canines. Singapore dental journal. 2014;35:53-7.

21. Rischen RJ, Breuning KH, Bronkhorst EM, Kuijpers-Jagtman AM. Records needed for orthodontic diagnosis and treatment planning: a systematic review. PloS one. 2013;8(11):e74186.

22. Dalessandri D, Migliorati M, Rubiano R, Visconti L, Contardo L, Di Lenarda R, et al. Reliability of a novel CBCT-based 3D classification system for maxillary canine impactions in orthodontics: the KPG index. TheScientificWorldJournal. 2013;2013:921234.

23. Suomalainen A, Pakbaznejad Esmaeili E, Robinson S. Dentomaxillofacial imaging with panoramic views and cone beam CT. Insights into imaging. 2015;6(1):1-16.

24. Gribel BF, Gribel MN, Frazao DC, McNamara JA, Jr., Manzi FR. Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. The Angle orthodontist. 2011;81(1):26-35.

25. Botticelli S, Verna C, Cattaneo PM, Heidmann J, Melsen B. Two- versus three-dimensional imaging in subjects with unerupted maxillary canines. European journal of orthodontics. 2011;33(4):344-9.

26. Becker A, Chaushu S, Casap-Caspi N. Cone-beam computed tomography and the orthosurgical management of impacted teeth. Journal of the American Dental Association. 2010;141 Suppl 3:14S-8S.

27. Hong WH, Radfar R, Chung CH. Relationship between the maxillary transverse dimension and palatally displaced canines: A cone-beam computed tomographic study. The Angle orthodontist. 2014.

28. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. European radiology. 1998;8(9):1558-64.

29. Seth V, Kamath P, Vaidya N. Cone beam computed tomography: third eye in diagnosis and treatment planning. International journal of orthodontics. 2012;23(2):17-22.

30. Agrawal JM, Agrawal MS, Nanjannawar LG, Parushetti AD. CBCT in orthodontics: the wave of future. The journal of contemporary dental practice. 2013;14(1):153-7.

31. Noar JH, Pabari S. Cone beam computed tomography--current understanding and evidence for its orthodontic applications? Journal of orthodontics. 2013;40(1):5-13.

32. American Academy of O, Maxillofacial R. Clinical recommendations regarding use of cone beam computed tomography in orthodontics. [corrected]. Position statement by the American Academy of Oral and Maxillofacial Radiology. Oral surgery, oral medicine, oral pathology and oral radiology. 2013;116(2):238-57.

33. Hodges RJ, Atchison KA, White SC. Impact of cone-beam computed tomography on orthodontic diagnosis and treatment planning. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2013;143(5):665-74.

34. Nakajima A, Sameshima GT, Arai Y, Homme Y, Shimizu N, Dougherty H, Sr. Two- and three-dimensional orthodontic imaging using limited cone beam-computed tomography. The Angle orthodontist. 2005;75(6):895-903.

35. Moshfeghi M, Tavakoli MA, Hosseini ET, Hosseini AT, Hosseini IT. Analysis of linear measurement accuracy obtained by cone beam computed tomography (CBCT-NewTom VG). Dental research journal. 2012;9(Suppl 1):S57-62.

36. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2009;136(1):19-25; discussion -8.

37. Nguyen E, Boychuk D, Orellana M. Accuracy of cone-beam computed tomography in predicting the diameter of unerupted teeth. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2011;140(2):e59-66.

38. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. The Angle orthodontist. 2008;78(3):387-95.

39. Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dento maxillo facial radiology. 2008;37(2):80-93.

40. Spin-Neto R, Gotfredsen E, Wenzel A. Impact of voxel size variation on CBCT-based diagnostic outcome in dentistry: a systematic review. Journal of digital imaging. 2013;26(4):813-20.

41. Flores-Mir C, Rosenblatt MR, Major PW, Carey JP, Heo G. Measurement accuracy and reliability of tooth length on conventional and CBCT reconstructed panoramic radiographs. Dental press journal of orthodontics. 2014;19(5):45-53.

42. Alqerban A, Jacobs R, Fieuws S, Willems G. Comparison of two cone beam computed tomographic systems versus panoramic imaging for localization of impacted maxillary canines and detection of root resorption. European journal of orthodontics. 2011;33(1):93-102.

43. Laffranchi L, Dalessandri D, Fontana P, Visconti L, Sapelli P. Cone beam computed tomography role in diagnosis and treatment of impacted canine patient's: a case report. Minerva stomatologica. 2010;59(6):363-76.

44. Alqerban A, Jacobs R, van Keirsbilck PJ, Aly M, Swinnen S, Fieuws S, et al. The effect of using CBCT in the diagnosis of canine impaction and its impact on the orthodontic treatment outcome. Journal of orthodontic science. 2014;3(2):34-40.

45. San Martin DE, English JD, Kau CH, Gallerano RL, McGrory KR, Salas AM, et al. The KPG index--a novel 3D classification system for maxillary canine impactions. Texas dental journal. 2012;129(3):265-74.

46. Koutzoglou SI, Kostaki A. Effect of surgical exposure technique, age, and grade of impaction on ankylosis of an impacted canine, and the effect of rapid palatal expansion on eruption: A prospective clinical study. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2013;143(3):342-52.

47. Farman AG. Panoramic Radiology: Seminars on Maxillofacial Imaging and Interpretation: Springer Berlin Heidelberg; 2007:96-97.

48. Oberoi S, Gill P, Chigurupati R, Hoffman WY, Hatcher DC, Vargervik K. Three-dimensional assessment of the eruption path of the canine in individuals with bone-grafted alveolar clefts using cone beam computed tomography. The Cleft palate-craniofacial journal : official publication of the American Cleft Palate-Craniofacial Association. 2010;47(5):507-12.

49. Garib DG, Raymundo Jr. R, Raymundo MV, Raymundo DV, Ferreira SN. Tomografia computadorizada de feixe cônico (Cone beam): entendendo este novo método de diagnóstico por imagem com promissora aplicabilidade na Ortodontia. Revista Dental Press de Ortodontia e Ortopedia Facial. 2007;12:139-56.

Annex

Annex 1 (Table 1): Systemic and local conditions leading to tooth impaction[6, 7, 9-12, 47, 48].

	Systemic Conditions	Local Conditions

Impacted Tooth	- Cleidocranial Dysplasia;
	- Osteomatosis Intestinal Polyposis Syndrome (Gardner Syndrome);
	- Amelogenesis imperfect;
	- Syndromes associated with enamel defects
		- Misposition of tooth germen;
		- Micrognatia/Crowding;
		- Supranumemary tooth;
		- Early loss of deciduous antecedent or its agenesis;
		- Small, peg-shaped or agenesis of maxillary lateral incisor;
		- Retained deciduous teeth (or its roots) with or without ankylosis due to:
		    - Pulp inflammation
		    - Periapical lesion
		    - Pulpar treatment (pulpotomy/ pulpectomy)
		- Folicular cysts;
		- Association with tumor, i.e.:
		    - Adenomatoid Odontogenic Tumor;
		    - Ameloblastoma;
		    - Ameloblastic Fibroma/ Fibroodontoma;
		    - Odontogenic Myxoma;
		- Cementifying-ossifying Fibroma
		- Cherubism;
		- Fibrous Dysplasia;
		- Gingival Fibromatosis;
		- Cleft lip and palate;
		- Trauma during eruption movement
		- Lack of eruptive potential

Annex 2 (Table 2): Comparison between CBCT, CT and traditional radiographs. CBCT: Cone Beam Computed Tomography; CT: Computed Tomography; 2D: Two-Dimensional; 3D: Three-Dimensional; s: seconds; FOV: Field of View (Adapted from Garib *et al*[49], Becker *et al*[26], American Academy of Oral and Maxillofacial Radiology[32] and Suomalainen *et al* [23]).

	CBCT	**CT**	**Radiograph**
Machine dimenison	- Smaller - Only head and neck examination	- Big - Full body examination	- Smallest - Only mouth examination
Image aquisition	- Only one rotation around patient's head - Preliminary image similar to 2D ones	- Several rotations around patient's body - Axial slices	- Static patient and machine - 2D image
Images obtained	- 2D reconstructions - 3D reconstruction	- 3D reconstruction	- 2D reconstruction
Image quality	- Accurate - Clear - Low contrast	- Clear - High contrast	- Magnefied - With distorption - Superimposition with adjacent structures
Scaning time	- 10s to 70s - 3s to 6s of radiation exposure	- 1s *per* slice	- Immediate (except orthopantomography: 10s to 20s)
Radiation exposure	- Lower than CT . Small FOV ≈ 28-652 μSv . Large FOV ≈ 68-1073 μSv	- High .Dental scans ≈ 534-1000 μSv	- Low . Panoramic ≈ 24 μSv . Periapical ≈1 μSv . Oclusal ≈ 4 μSv . Cephalograms ≈ 6-11 μSv . Status ≈ 85 μSv
Costs	- Low	- High	- Low

Annex 3 - Questionnarie: Part of the questionnaire distributed to the observers, showing the two parts and the "Sheet Answer" with questions and hypothisis analysed.

Part 1

Academic Data

Please mark and complete below with the most appropriate answer.

Age:

Academic degree:

Graduate: _____
Institution:
Conclusion year:

Master: _____
Institution:
Conclusion year:

Doctoral: _____
Institution:
Conclusion year:

Number of years practicing as orthodontic postgraduate: ________

Part 2

Comparative analysis between two images

This part is divided in two groups: Group A composed by panoramic images and group B composed by CBCT reconstructions. In both groups, images are randomly distributed, so that images from each group do not necessarily match.

Carefully analyse the images presented and answer orderly and with a cross to the following questions in the *Answer Sheet*. Trough your analysis, consider that:

- There is no right or wrong answers;
- Signalize only one hypothesis for each question;
- Whenever the hypotheses do not apply, mark the hypothesis "NA" (Not applicable).
- All patients are cooperative and healthy (without any syndrome, craniofacial anomaly or dental trauma that could interfere with the normal tooth development and eruption);
- No patient received any orthodontic treatment;
- Patient's age and gender (during the examination) are provided at the top of each image;
- The impacted tooth is asymptomatic;
- The item "prognosis", "treatment duration" and "difficulty of the case" should be evaluated only considering the impacted tooth;
- In group A panoramic images were cropped to show only the region of interest - the upper jaw;
- In group B sections are shown as follows (from left to right):

1st Line: frontal cephalometric projection

2nd Line: axial/transversal view showing the cuts used to reconstruct the sagittal view (represented by the blue line) and the coronal/frontal view (represented by the red line);

the same axial/transversal view without the lines,

3rd Line: sagittal view;

coronal view

4th Line: 3D reconstruction

same 3D reconstruction with less bone density.

Please do not scratch any of the images.
Thank You.

Evaluation	Case	1	2	3	4	5	(...)
M-D tip cusp position in relation to the long axis of the lateral incisor	Mesial						
	Overllaped						
	Distal						
	NA						
M-D apex position in relation to the long axis of the first premolar	Mesial						
	Overllaped						
	Distal						
	NA						
Vertical tip cusp position in relation to the apex of the central incisor	Above apex						
	Bellow apex						
	NA						
L-P cusp position in relation to lateral incisor	Labial						
	Palatal						
	Midalveolus						
	NA						
Presence of adjacent tooth resorption	Yes						
	No						
	NA						
Is the image enough for diagnosis?	Yes						
	No						
Prognosis	Good						
	Reasonable						
	Weak						
Which seems to be the most appropriate treatment? *(OT: Orthodontic Treatment)*	Deciduous canine extraction						
	OT with permanent canine traction						
	Permanent canine extraction						
	No treatment (only supervise)						
Orthodontic Treatment Duration	Normal (22m-26m)						
	Long (>26m)						
	NA						
Difficulty of the case	Easy						
	Moderate						
	Difficult						