OPEN ACCESS

Scientific Letters

Review

Three-dimensional evaluation of impacted maxillary canines and repercussions on adjacent teeth

Rita Leitão [1], Ana Sofia Rocha [1], Ana Catarina Oliveira [1], Ana Luísa Peres [1] and Teresa Pinho [1,*]

[1] UNIPRO, Oral Pathology and Rehabilitation Research Unit, University Institute of Health Sciences-CESPU (IUCS-CESPU), 4585-116 Gandra, Portugal; a27460@alunos.cespu.pt (RL); a27132@alunos.cespu.pt (ASR); a26895@alunos.cespu.pt (ACO); a26921@alunos.cespu.pt (ALP)

* Correspondence: teresa.pinho@iucs.cespu.pt

Abstract: Maxillary canines have very important roles in aesthetics and function. They are the second most frequently impacted teeth. One of the most severe complications associated with impacted maxillary canines is root resorption of adjacent teeth. Cone-beam computed tomography (CBCT) provides three-dimensional multiplanar images and detailed information on dentofacial structures. The aim of this systematic review is to analyze impacted maxillary canines from three dimensions and analyze root resorption of the adjacent teeth caused by the impaction, based on CBCT only. The PRISMA methodology was applied, and a literature search of the last 11 years was carried out in PubMed and Scielo using the keywords “cone-beam computed tomography”, “maxilla”, “cuspid”, “root resorption”, “tooth, impacted”. This search was conducted through inclusion and exclusion criteria. The clinical relevance of this study consists of the need for adequate assessment of the location of impacted canines and degree of root resorption of adjacent teeth for surgeons and orthodontists to create an appropriate diagnosis and collaborative treatment plan. Lateral incisors were more affected by root resorption, especially when the widths of the crown, root length and volume were decreased. Female gender predominates; however, this is controversial. Some authors stated that the most common position of impacted maxillary canines is palatal. A statistically significant connection between bilaterally impacted maxillary canines and a greater number of teeth resorption was found; notwithstanding, the degree of root resorption is not consistent among authors. Their most frequent locations are palatal, mesial, and horizontal. Adjacent teeth located beyond the mesial surface, in contact with palatally impacted canines whose cusp tip is at the apical third of their roots, were likely to suffer root resorption.

Keywords: cone-beam computed tomography; maxilla; cuspid; root resorption; tooth; impacted

Received: 17 May 2024; Accepted: 19 July 2024; Published: 04 September 2024

Introduction

A permanent maxillary canine establishes the overall harmonious impression of the face, is highly stable, and is vital in oral care. Nonetheless, its development is frequently disrupted over its long physiological eruption course [1-3].

Maxillary canines (MC) are the second most frequently impacted teeth, and the prevalence of their impaction is of 1-3% in the general population. Impacted maxillary canines (IMC) are more common in females than in males, and there is significant variance across different racial communities [4,5].

The cause of IMC is unknown, but it appears to be complex. Canine impaction is caused by two main theories: guidance and genetics. Over-retained primary canines, pegged or absent lateral incisors (LI), spaced dentition, aberrant tooth bud eruption, or abnormal eruption rate are all possible guidance factors. Genetic factors can also be found in a variety of forms [1,4,6,7].

Considering that canines may be palpated buccally around 1.5 years before they erupt into the oral cavity, it is advised that the vestibular and palatal areas to the deciduous canines are clinically examined in children aged 7 to 10 years. However, if the permanent canine appears to be retained, an X-ray of the area should be performed at the age of ten [3].

IMC may result in arch length shortening, migration of neighboring teeth, aesthetic consequences, cystic development, or canine ankylosis. Furthermore, root resorption (RR) of neighboring teeth is one of the most serious problems. As a result, the longevity of neighboring teeth is compromised. Early detection and prevention would reduce the need for canine exposure and simplify orthodontic treatment [2,4,6,8].

RR can be difficult to detect with two-dimensional (2D) radiography, especially if the canine is in direct palatal or facial position to the LI roots [1,2,4,6,9,10].

Until recently, conventional 2D radiographic imaging was extensively employed for canine localization, treatment planning, and post-treatment assessment. Nevertheless, it is limited because the diagnostic information acquired suffers from a variety of flaws, including distortion, magnification, artefacts, and structural superimposition. The clinician's ability to visualize specific structures is hampered by the superimposition of structures [1-4,8,9,11-13].

Cone-beam computed tomography (CBCT) is currently the most detailed and efficient imaging method for diagnosing and planning impacted tooth treatment. The magnitude, location, and prospective implications of this eruptive anomaly may be analyzed more effectively than with 2D images [7,14,15].

CBCT provides enhanced localization of impacted teeth, identifies pertinent disease, and has a high ability and reliability in diagnosing RR by removing overlap of dental structures, when compared to panoramic radiography [16]. Furthermore, as compared to computed tomography (CT), CBCT has reduced the cost and radiation dosage by reducing the cone-shaped X-ray beam, scanner size, and scanning duration. On the other hand, as low as reasonably achievable (ALARA) principles and SEDENTEXCT recommendations suggested that CBCT examination should be utilized sparingly and only in selected orthodontic instances, when conventional radiographs cannot offer adequate diagnostic information [1,4,8,15].

To fully utilize the information obtained from CBCT, volumetric pictures must be interpreted on a three-dimensional (3D) scale. Clinicians would be able to describe and assess diseases, malformations, and impactions with greater clarity and precision using such an approach [2,17,18]. Early diagnosis of IMC is crucial [7,19,20].

Thus, this review aims to localize the IMC from 3D using CBCT, and analyze RR of the adjacent teeth caused by the impaction of MC, based on CBCT only. The hypotheses of the study are that CBCT allows an accurate 3D assessment of IMC and reveals a significant association between their impaction and RR of adjacent teeth.

Materials and Methods

This systematic review was elaborated in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. The study protocol was submitted to the PROSPERO database [CRD42023430751].

Eligibility criteria

The population, intervention, comparison and outcomes (PICO) strategy was used to define the focused question to which this review will respond, as shown in Table 1.

Table 1. PICO strategy.

Population	Patients with IMC with CBCT registration
Intervention	3D measurements (CBCT) of IMC and adjacent teeth
Comparison	Patients with erupted MC and no repercussions on adjacent teeth
Outcomes	IMC may cause resorption in adjacent teeth. Effectiveness of 3D radiographic methods (CBCT) in IMC measurement

3D: three-dimensional; CBCT: cone-beam computed tomography; IMC: impacted maxillary canines; MC: maxillary canines

As a result, the following focused questions of this systematic review were established: "What is the most common location of IMC?", "Is CBCT the most viable tool for the localization of IMC?", and "What are the repercussions caused by maxillary canine impaction on adjacent teeth?". To answer these questions, the admission criteria for this systematic review were defined.

Inclusion criteria:
- Articles published between January 2012 and January 2023;
- Articles written in English or Spanish;
- Articles on the subject whose full text is available;
- Studies performed in human beings;
- Articles with patients with IMC, CBCT registration;
- Retrospective clinical studies, case controls and cross-sectional studies.

Exclusion criteria:
- Articles whose abstract did not fit the subject;
- Articles that only made reference to 2D radiographic imaging;
- Full reading did not provide revealing information: patients without IMC, CBCT; patients with craniofacial syndromes, tumors or odontogenic cysts, cleft lip, cleft palate and systemic diseases;
- Case reports, systematic review articles, theses and dissertations;
- Articles whose full text was not available in the database.

Search strategy

A thorough search was conducted to identify any relevant studies based on various keyword combinations. PubMed and Scielo were the databases explored. These electronic databases were searched for articles published between January 2012 and January 2023, using the keywords specified in Table 2.

Table 2. Search strategy.

Database	Keywords	No. of articles found
PubMed	((("Cone-Beam Computed Tomography"[Mesh]) AND "Cuspid"[Mesh]) AND "Tooth, Impacted"[Mesh]) AND "Maxilla"[Mesh]	112
	(((("Tooth, Impacted"[Mesh]) AND "Cuspid"[Mesh]) AND "Maxilla"[Mesh]) AND "Cone-Beam Computed Tomography/methods"[Mesh]) AND "Root Resorption"[Mesh]	20
Scielo	(cone-beam computed tomography) AND (impacted maxillary canine)	2
	((cone-beam computed tomography) AND (impacted maxillary canine)) AND (root resorption)	2

Selection of articles and data collection

The search terms were used to perform an advanced search. Duplicates were removed using Mendeley. The titles and abstracts of the potentially relevant articles underwent a preliminary analysis to determine whether they met the purposes of the study. The articles that met the inclusion criteria were completely reviewed and their eligibility was evaluated. The rejected studies were registered separately, elucidating the reasons for rejection. Then, the reference lists of all retrieved full-text articles were thoroughly searched for relevant articles. Finally, articles that did not answer the research questions were excluded. Data was extracted from the full-text articles and organized chronologically in Table 3.

Quality assessment of data

The quality of the selected articles was assessed by three authors (RL, ASR, ALP), using a “star system” in which studies are judged from three broad perspectives: study group selection, group comparability, and ascertainment of either the exposure or outcome of interest for case-control or cohort studies, respectively. This systematic review was graded using the Newcastle-Ottawa Scale (NOS), which assessed the risk of bias in the selected studies (Table 4). Parameters as the size of the sample, accurate description of the sample, use of valid methods, proper statistical analysis, presence of confusing variables, and blind measurements were also used.

The complete data on the methodological quality assessment is presented in Table 5. In terms of methodological quality, the NOS Quality Assessment Tool was utilized to categorize the studies examined:
- Three studies were categorized as 5* – good quality;
- Six studies were categorized as 4* – fair quality;
- One study was categorized as 3* – poor quality.

Due to blinding and to the lack of a control group in some of the articles, most of the studies included had a fair overall grade.

Results

Selection of articles

136 articles were found in the electronic literature. After removing duplicates, there were 127 articles left. Titles and abstracts were evaluated, and 52 articles were selected. 75 articles were excluded because they did not match the inclusion and exclusion criteria (70 articles) or were not available (5 articles). 30 articles were chosen for further review by ALP. These studies were individually read and analyzed, by RL and ASR, for eligibility, and 10 articles were selected and included in this systematic review.
Fig. 1 depicts the selection procedure. In addition to the articles chosen through this procedure, a manual search was conducted in the bibliographies of the included studies to identify and retrieve articles that were not found through the electronic search.

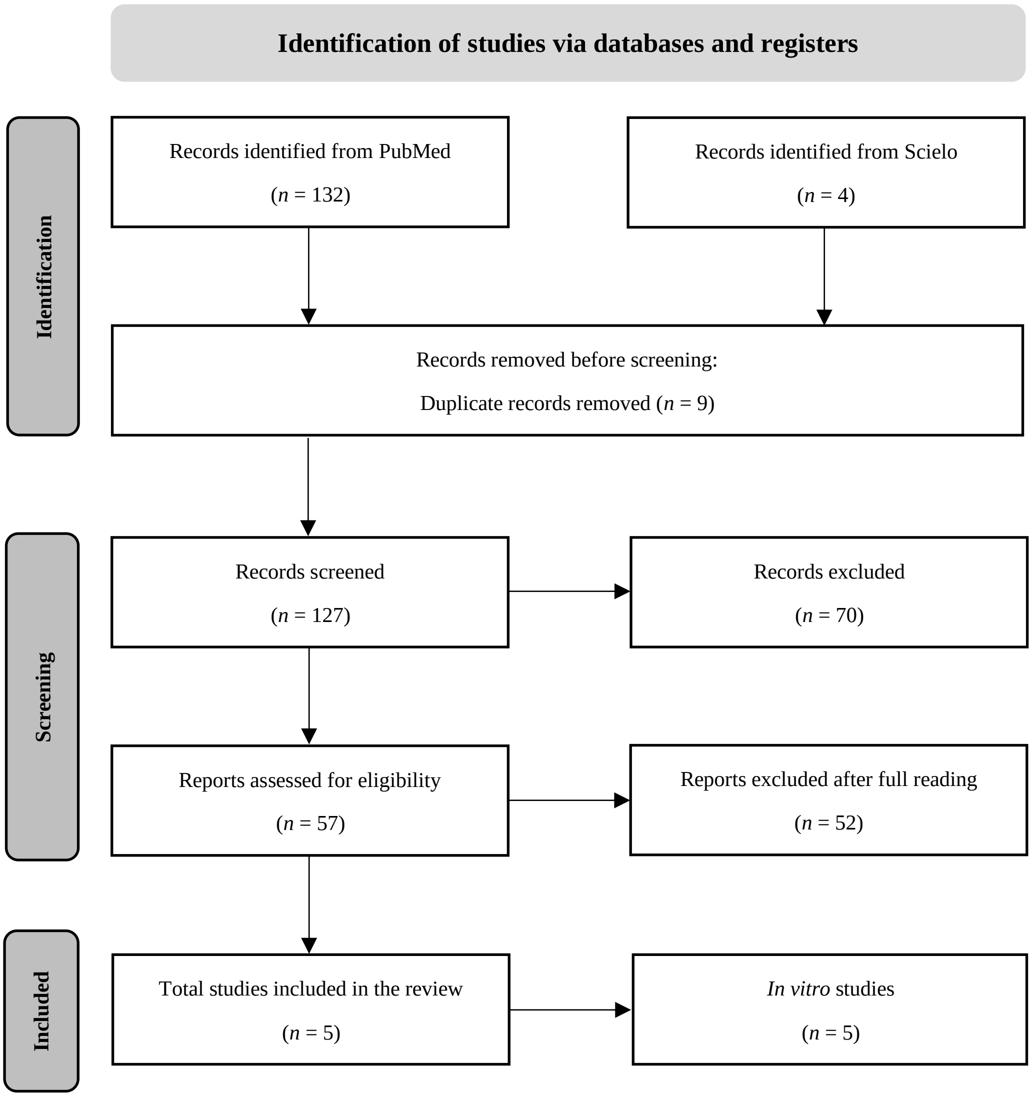

Figure 1. PRISMA flow diagram with research data.

Profile of the studies reviewed

Data from the included studies was organized and systematized in Table 3.
The information is organized as follows: authors' names and year of publication, study design and population, measurements, results, and conclusions.

Table 3. Data from articles. Significant results regarding the location of the IMC and RR of the adjacent teeth using CBCT measurements.

Author and year of publication	Study Design, Population	Measurements	Results	Outcomes
Oberoi S *et al.* (2012) [1]	Retrospective study; 29 patients with IC undergoing orthodontic treatment	• The MLI's distal line angle and the 1st PM's mesial line angle were projected onto the occlusal plane • Reference cusp tip position: ○ Axial, sagittal, and coronal planes	• Female (76%) • Mesial impaction 93% • Distal impaction 7% • Palatal impaction 60% • Buccal impaction 40%	• Females were more affected • PIC was more common • MLI was more affected, namely with slight RR
		• No RR: intact root surfaces • Slight RR: up to ½ the dentine thickness to pulp • Moderate RR: ≥ ½ to the pulp • Severe RR: pulp exposed	• No RR (40.4%) • RR of MLI: ○ Slight (35.7%) ○ Moderate (14.2%) ○ Severe (4.0%)	
Liuk IW *et al.* (2013) [2]	Case-control study; EG: 46 PIC CG: 60 canines	• Length of the MLI on the sagittal plane • BL and MD root widths (LI) on the axial plane	• In PIC: ○ The mean length of the MLI was shorter ○ The mean root diameters were smaller, BL dimension ○ Higher palatal position IMC	• In patients with PIC, the mean tooth lengths and mean root widths of the MLI were shorter
Lai CS *et al.* (2013) [21]	Retrospective study; 92 unilateral IMC 21 bilateral IMC	• SMC localization • VMC localization • Location of RR • Degree of RR	• Higher vertical location on cervical 1/3 of root MLI • Higher RR in middle 1/3 root • MLI more affected by RR • Higher severe RR (MLI) • Higher RR in females	• MLI was more affected, namely with severe RR • Palatal impaction was more common
Almuhtaseb E *et al.* (2014) [17]	Retrospective study; 46 patients with IC undergoing orthodontic treatment	• Sella; Nasion, right and left portion • Upper and lower incisor and 1st molar profile • Maxillary and symphysis profile • Cusp tip and apex tip of the IC • Midsagittal, occlusal, and frontal planes	• Female crowding (79.3%) • Male (88.25%) • Buccal (40.2%), palatal (37.6%) and midalveolus (22.2%) IMC	• The majority of the impactions were buccal and midalveolus • MLI had the highest degree of RR, namely mild RR
		• RR: ○ No intact root surfaces ○ Mild: ≥ ½ to the pulp ○ Moderate: pulp exposed ○ Severe: pulp exposed	• RR: ○ Absent 67.39% ○ Mild 17.39% ○ Moderate 10.87% ○ Severe 4.35% • In the MLI 23.9% • In the MCI 8.69%	
Doğramaci EJ *et al.* (2015) [6]	Retrospective cross-sectional study; 183 patients with IMC	• Resorption location related to the root level and to the affected surface • Severity of RR: slight, moderate or severe resorption	• RR: ○ In MLI 64.2% ○ Moderate 20% ○ Severe 30% • Palatal surface ≥ 50% resorbed • Apical root 1/3 more affected	• MLI were the most common to resorb in the presence of IMC • Palatal surface and apical 1/3 frequently involved
Kim Y *et al.* (2017) [22]	Retrospective study; EG: 10 IMC, 10 CI, 10 LI CG: 10 MC, 10 CI, 10 LI	• MD width of the crown (mm) • Anatomic height of the crown (mm) • Volume of the crown (mm^3) • Length of the root (mm) • Volume of the root (mm^3)	• Smaller MD dimension of the MLI with IMC • The root of MLI was shorter and smaller on the impaction side • The MCI was larger on the impaction side	• Strong connection between: ○ IMC and smaller MLI root sizes ○ MC and larger crown sizes
Ucar FI *et al.* (2017) [12]	Cross-sectional study; EG: impacted canine side CG: non-impacted canine side	• Volume of root resorption MLI (mm^3) • Lateral root volume (mm^3) • Canine angulation (°)	• No gender differences in MLI's RR or canine angulation (p>0.05) • MLI volume was < on the impacted side • p > 0.05 in differences in RR of the lateral volume • IMC angulation > on the labial side	• Canine angulation was lower in PIC than in LIC • p > 0.05: RR on MLI between labially and palatally IMC
Dağsuyu IM *et al.* (2018) [23]	Retrospective study; 102 patients with 140 IMC	• Occlusal plane distances to IMC cusp tip and apex • Midline distances to IMC crown tip and apex • Angulations of IMC to midline, MLI and occlusal plane	• 57.9% of IMC are female • Palatal (54.3%), central (27.8%) and buccal (17.8%) impactions • Right IMC had > midline angulation than left IMC, while left IMC had > occlusal plane angulation than right IMC	• Women were more likely to have IMC than men • Palatal impaction was nearly 3 times more common than buccal

		• RR: ○ None ○ Slight, up to ½ the dentine thickness ○ Moderate, ≥ ½ to the pulp ○ Severe, with pulp exposed	• MLI were more affected with slight RR • 10 MLI and 4 1st PM showed severe RR	
Leonardi R *et al.* (2018) [24]	Cross-sectional study; EG: 28 patients with IMC CG: 25 patients with 3rd molar impaction	• Root length of MCI, MLI, IMC and 1st PM • Volume of MCI, MLI, MC and 1st PM	• LI adjacent to PIC were 1 mm shorter to the MLI on the NS • Volume of the MLI adjacent to PIC was smaller to the NS	• MLI adjacent to PIC have shorter roots and smaller volume
Koral S *et al.* (2021) [25]	Retrospective study; 52 patients with unilateral IMC	• MLI, IMC: ○ Volume ○ Root and total length • Midline, midsagittal, occlusal, axial, and coronal plane • Central axis of canine • MD and BL widths of the LI crown • Angles between the central axis of the LI and the midline • Angles between the LI and the occlusal plane	• On the impacted side: ○ BL and MD widths of the MLI crown were smaller ○ Root and total length of the MLI were shorter ○ The mean MLI volume was lower ○ The angle between the MLI and the IMC axis was greater • The angle between the MLI axis and the midline was > on the NS	• MLI adjacent to IMC have shorter length and reduced volume

BL: buccolingual; CG: control group; CI: central incisor; EG: experimental group; IC: impacted canines; IMC: impacted maxillary canine; LI: lateral incisor; MC: maxillary canine; MCI: maxillary canine impaction; MD: mesiodistal; MLI: maxillary lateral incisor; NS: nonimpacted side; PIC: palatally impacted canine; PM: premolar; RR: root resorption; SMC localization: sagittal MC localization (labial, median, or palatal); VMC localization: vertical MC localization (coronal, cervical 1/3 of the root, middle 1/3 of the root, apical 1/3 of the root, or apical to the root tip); Resorption location to the root level: apical 1/3, apical and middle 1/3, middle 1/3, middle and cervical 1/3, cervical 1/3 or apical, middle and cervical 1/3; Resorption location to the affected surface: mesial, distal, buccal, palatal, mesio-palatal, disto-palatal, mesio-buccal, disto-buccal; Root length: most apical point of the cemento-enamel junction (CEJ), two points respectively 4 mm and 8 mm apical to the CEJ level and a point at the apical foramen.

Table 4. Scale of the results of the methodological quality assessment (included studies).

Newcastle-Ottawa Quality Assessment Scale		
Study	**Number of stars**	**Scale**
Oberoi S *et al.* (2012) [1]	4*	Fair quality
Liuk IW *et al.* (2013) [2]	5*	Good quality
Lai CS *et al.* (2013) [21]	4*	Fair quality
Almuhtaseb E *et al.* (2014) [17]	4*	Fair quality
Doğramaci EJ *et al.* (2012) [6]	6*	Excellent quality
Kim Y *et al.* (2013) [22]	4*	Fair quality
Ucar FI *et al.* (2013) [12]	5*	Good quality
Dağsuyu IM *et al.* (2014) [23]	4*	Fair quality
Leonardi R *et al.* (2018) [24]	5*	Good quality
Koral S *et al.* (2021) [25]	4*	Fair quality

Table 5. Quality assessment data for clinical trials, using the Quality Assessment Tool, Newcastle-Ottawa Scale (NOS).

	Author/Year		Oberoi S *et al.* (2012) [1]	Liuk IW *et al.* (2013) [2]	Lai CS *et al.* (2013) [21]	Almuhtaseb E *et al.* (2014) [17]
Selection	Representativeness of the sample	a) Truly representative of the average in the target population ✶ (all subjects or random sampling) b) Somewhat representative of the average in the target population (non-random sampling) c) Selected group of users d) No description of the sampling strategy	NA	A*	NA	NA
	Selection of the non-exposed cohort	a) Drawn from the same community as the exposed cohort * b) Drawn from a different source c) No description of the derivation of the non-exposed cohort	A*	B	A*	A*
	Ascertainment of exposure	a) Secure record ✶ b) Structured interview c) Written self-report d) No description	A*	A*	A*	A*
	Demonstration that outcome of interest was not present at the start of the study	a) Yes✶ b) No	A*	A*	A*	A*
Comparability	Comparability of cohorts on the basis of the design or analysis	a) Study controls for localization of IMC and RR of adjacent teeth * b) Study controls for any additional factor *	NA	A*	NA	NA
Outcome	Assessment of outcome	a) Independent blind assessment✶ b) Record linkage✶ c) Self-report d) No description e) Other	B*	B*	B*	B*
	Was follow-up long enough for outcomes to occur?	a) Yes✶ b) No	B	B	B	B
	Adequacy of follow-up of cohorts	a) Complete follow-up – all subjects accounted for ✶ b) Subjects lost to follow-up unlikely to introduce bias – small number lost – > ____ % ✶ c) Follow-up rate < ____% d) No statement	D	D	D	D
Results			****	*****	****	****

		Author/Year	**Doğramaci EJ *et al.* (2012) [6]**	**Kim Y *et al.* (2013) [22]**	**Ucar FI *et al.* (2013) [12]**	**Dağsuyu IM *et al.* (2014) [23]**
Selection	Representativeness of the sample	a) Truly representative of the average in the target population ✶ (all subjects or random sampling) b) Somewhat representative of the average in the target population (non-random sampling) c) Selected group of users d) No description of the sampling strategy	NA	A*	A*	NA
	Selection of the non-exposed cohort	a) Drawn from the same community as the exposed cohort * b) Drawn from a different source c) No description of the derivation of the non-exposed cohort	A*	B	B	A*
	Ascertainment of exposure	a) Secure record ✶ b) Structured interview c) Written self-report d) No description	A*	A*	A*	A*
	Demonstration that outcome of interest was not present at the start of the study	a) Yes✶ b) No	A*	B	A*	A*
Comparability	Comparability of cohorts on the basis of the design or analysis	a) Study controls for localization of IMC and RR of adjacent teeth * b) Study controls for any additional factor *	NA	A*	A*	NA
Outcome	Assessment of outcome	a) Independent blind assessment ✶ b) Record linkage ✶ c) Self-report d) No description e) Other	B*	B*	B*	B*
	Was follow-up long enough for outcomes to occur?	a) Yes✶ b) No	A*	B	B	B
	Adequacy of follow-up of cohorts	a) Complete follow-up – all subjects accounted for ✶ b) Subjects lost to follow-up unlikely to introduce bias – small number lost – > ____ % ✶ c) Follow-up rate < ____% d) No statement	A*	D	D	D
Results			******	****	*****	****

	Author/Year		Leonardi R *et al.* (2018) [24]	Koral S *et al.* (2021) [25]
Selection	Representativeness of the sample	a) Truly representative of the average in the target population ✶ (all subjects or random sampling) b) Somewhat representative of the average in the target population (non-random sampling) c) Selected group of users d) No description of the sampling strategy	A*	NA
	Selection of the non-exposed cohort	a) Drawn from the same community as the exposed cohort * b) Drawn from a different source c) No description of the derivation of the non-exposed cohort	B	A*
	Ascertainment of exposure	a) Secure record ✶ b) Structured interview c) Written self-report d) No description	A*	A*
	Demonstration that outcome of interest was not present at the start of the study	a) Yes✶ b) No	A*	A*
Comparability	Comparability of cohorts on the basis of the design or analysis	a) Study controls for localization of IMC and RR of adjacent teeth * b) Study controls for any additional factor *	A*	NA
Outcome	Assessment of outcome	a) Independent blind assessment✶ b) Record linkage✶ c) Self-report d) No description e) Other	B*	B*
	Was follow-up long enough for outcomes to occur?	a) Yes ✶ b) No	B	B
	Adequacy of follow-up of cohorts	a) Complete follow-up – all subjects accounted for ✶ b) Subjects lost to follow-up unlikely to introduce bias – small number lost –> ____ % ✶ c) Follow-up rate < ____% d) No statement	D	D
Results			*****	****

IMC: impacted maxillary canines; NA: not applicable; RR: root resorption

Discussion

The hypotheses established in this study were accepted: CBCT is an effective tool for the detailed assessment of IMC and there is a measurable relationship between canine impaction and RR in the adjacent teeth.

When a canine is not visible in the dental arch and its root growth is complete or progressed, it may be said to be impacted.

The limitations of traditional radiographs include overlaps, overlaid projection, confusion between teeth buccal and palatal locations, magnification, horizontal distortion, and deformation. On the other hand, CBCT pictures accurately localize the labiolingual region and measure the impacted canines (IC) [22-24]. Also, the orthodontist can get the diagnostic data from any type of intraoral radiograph, panoramic and cephalometric radiographs, and temporomandibular joint series images with the help of CBCT technology [1,17,23]. Therefore, a more accurate diagnosis and treatment plan could be made possible by 3D volumetric imaging, which would ultimately lead to better treatment outcomes and patient care [1,12,17,21,25]. Fig. 2 represents an example of an IMC perfectly visible through 3D imaging.

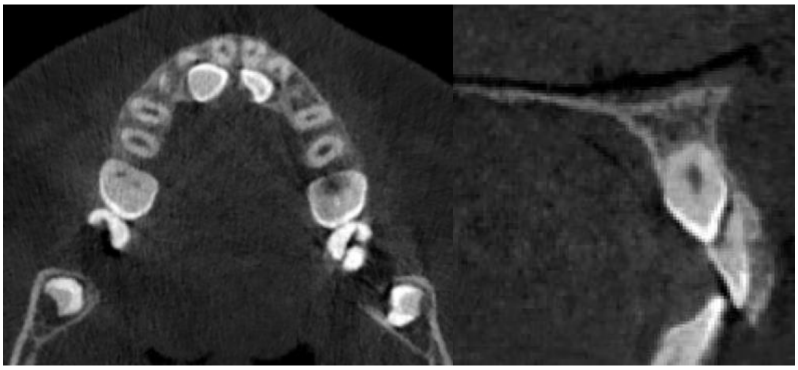

Figure 2. Impacted maxillary canine easily visualized through CBCT images.

Over the years, various authors concluded that IMC are more prevalent in females than in males; however, opinions differ from author to author according to substantial variance across ethnic communities. According to Oberoi *et al.* and Dağsuyu *et al.*, female individuals appear to be more affected by IMC than males [1,23]. However, Almuhtaseb *et al.* refers that crowding affected 88.25% of the males, compared to a little lower percentage of 79.3% among females [17]. Other authors refer no information regarding gender prevalence [2,22,25].

The ratio of palatal-to-buccal impaction differed among authors, with the majority reporting that palatal impaction was the most common [1,2,21,23].

Previous research has demonstrated that buccal and palatal impaction of IMC are two distinct events. Buccal impaction is frequently caused by insufficient dental arch space, whereas palatally impacted canine (PIC) causes of impaction can be classified as either local – delayed eruptive routes, and absent or abnormal lateral incisors – or genetic [21,23-25].

The genetic theory and the absence of guidance theories are now the two most widely accepted hypotheses published in the literature. Both contend that specific genetic traits are linked to the impaction of the IMC [21,23]. The guidance theory, which postulates that the root of the maxillary lateral incisor (MLI) plays a crucial role in the eruption of the IMC, has been observed as the most appealing explanation among the processes put forward [21,23-25].

As shown by the study by Oberoi *et al.*, IMC most common positions are palatal (60%) and mesial (93%) [1]. A high prevalence of palatal impaction (51.49%) is also mentioned by Lai *et al.*, who states that discrepancies in prevalence and location of IMC between studies may potentially be attributed to discrepancies in patient selection [21]. Dağsuyu *et al.* corroborate this information, with a palatal impaction of 54.3% [23]. Contrary to these authors, Almuhtaseb *et al.* reported that most of the IMC were located buccally in 40.2% of the patients, palatally in 37.6%, and midalveolus in 22.2% [17]. Regarding patients with bilateral impaction of IMC, Dağsuyu *et al.* reached the conclusion that right IMC had significantly higher midline angulation than left IMC – therefore, in a more horizontal position –, while left IMC had higher occlusal plane angulation than right IMC – therefore being in a more vertical position [23]. This could be due to asymmetries in the maxillary structure or differing eruption paths on each side. Furthermore, the variability in the vertical positioning of IC could also be associated with differences in dental and skeletal development between the two sides of the maxilla. Such discrepancies can result in different eruption angles and positions for the right and left canines [23,24].

Previous research found that MLI anomalies were associated with IMC. Furthermore, patients with IMC have a significant decrease in the mesiodistal (MD) dimension of their maxillary teeth, including their maxillary incisors [2,22,24,25].

According to the findings of Kim *et al.*, people with smaller MLI roots are more likely to have canine eruption problems. These findings suggest that normal eruption may be hampered in patients with larger

MC crowns due to a lack of space, which is consistent with previous research suggesting that IMC may result from a lack of space for eruption [20,22].

Regarding palatal impaction, it was found to be linked with MLI anomalies, such as smaller MLI, peg-shaped MLI, and missing MLI [2]. Without 3D imaging, measuring the widths of MLI roots was previously not practically viable, especially in the buccolingual (BL) dimension. The development of CBCT imaging has made this possible. It was proposed that the smaller MD crown width of MLI associated with PIC could simply reflect the shorter root length, and that it was a more critical influencing factor. Liuk *et al.* found that not only was the LI's length shorter, but so was its root width [2].

The findings of Leonardi *et al.* and Koral *et al.* appear to support those of Kim *et al.* and Liuk *et al.* – shorter root lengths and reduced volumes of MLI are involved in PIC, as they can have a strong local influence [2,24,25]. In terms of volume, the MLI on the PIC side had a statistically significant smaller volume than the MLI on the non-PIC side and MLI from the control sample [24].

The BL and MD widths of the MLI crown were substantially decreased, apart from the fact that the MLI root length on the impacted side (13.1 mm) was shorter than on the non-impacted side and the mean MLI volume was also considerably lower (376 mm^3). Koral *et al.* also concluded that the angle between the MLI and the IMC axis was greater on the impacted side [25].

This suggests that people with shorter MLI roots and morphological differences in the MLI and canines (crowns and roots) are more susceptible to canine eruption problems [24,25].

Regarding the localization of the IMC, traditionally it was assessed in 2D, which did not allow the operator to localize the canine properly; for an accurate localization, the measurement should be made tri-dimensionally [1,6,12].

As stated by Almuhtaseb *et al.*, CBCT images provide the oral surgeons with clear simulation images of the location of the IC, resulting in less invasive surgery as they work to expose or extract them. CBCT is currently the best method for diagnosing and localizing IMC and their potential complications [17].

The amount of information obtained through 3D radiography was much higher than that obtained from standard periapical and panoramic pictures. CBCT gave exceptionally detailed 3D imaging, as well as more advantageous viewpoints. Furthermore, picture superimpositions could be avoided, and scanned anatomical features, such as tooth roots, may be recreated in several planes, allowing for the optimum treatment plan for the patient [25].

CBCT provides visualization of the roots in all projections and is expected to provide a more accurate evaluation than 2D imaging [1,16]. Nonetheless, differing CBCT device voxel sizes may alter the detectability of early or mild RR. There is unquestionably a need to assess the impact of various CBCT operating circumstances on the diagnosis and severity categorization of RR [21].

2D radiographs make it more difficult to identify RR when the hard tissue has been resorbed from the buccal or palatal root side. Furthermore, because the resorptive process is sterile, 2D radiography is unlikely to show radiolucent areas, which would be expected if the resorption was infectious in nature [6]. CBCT is currently the preferred imaging technique for assessing the extent and depth of RR in neighboring teeth. The use of CBCT imaging can enhance the likelihood of detecting resorption in teeth next to IMC. 2D radiographs were also shown to be insufficient for imaging the buccal and palatal resorption zones [23].

Lai *et al.* concluded that incisor RR associated with IMC is more common in female patients [21]. Although the reasons for this are unknown, genetic or hormonal etiologic factors, as well as female's earlier skeletal growth spurt, earlier eruption of canines, and overall earlier dental development, jaw discrepancies, and root and crown sexual dimorphism, may all play important roles [21]. This information is corroborated by the study by Chaushu *et al.* [8].

According to the results of the studies of Doğramaci *et al.* and Ucar *et al.*, there was no association between gender and number, location, or severity of RR [6,12].

The etiology of RR caused by a neighboring erupting tooth is still unknown. According to some authors, the erupting tooth applies physical pressure. Others believe the pressure is caused by the dental follicle rather than by the tooth itself [21,26,27].

When it comes to IMC, the MLI are the most commonly affected teeth, with other teeth resorption being rare [1,6,17,21,23,25].

The location of resorption can be described using the affected root surface and level. The majority of lesions are found in the root's apical third, with the cervical third being the least frequently involved, according to Doğramaci *et al.* [6,26].

In this study, there was a statistically significant link between bilaterally IMC and a greater number of teeth affected by resorption. 18.8% of the study participants had bilaterally IMC, which resulted in multiple RR [6]. Another study stated that, in patients with bilateral IMC, the left IMC presented severe RR, but the right one showed slight RR [1]. Unlike these authors, Dağsuyu *et al.* reported that the maxillary right and left MLI presented similar RR degrees and common levels of slight resorption. Severe resorption was found in less than fifteen teeth, including MLI and premolars (PM) [23].

Adjacent maxillary teeth that cross the mesial surface, have contact with PIC and the cusp tip of the canine is at the apical third of the roots of adjacent teeth were likely to suffer RR, according to Lai *et al.* [21].

According to the study of Ucar *et al.*, IMC were significantly associated with RR of the adjacent MLI; however, the amount of resorption was unaffected by the IMC's position or angulation. There was no significant difference in the amount of lateral RR between the sectors where the canines were located and in the amount of RR on MLI between labially and palatally IMC [12]. Therefore, the correlation between IMC position and degree of RR is non-existent, in contrast to the studies of Lai *et al.* [12,21].

Even at an early stage, etiologic factors such as the morphological and angular characteristics of LI can be detected. As a result, these findings may support orthodontists in the diagnosis, prevention, and treatment planning of IMC [25].

Depending on the presence of resorption in the neighboring teeth, the angle and location of the IMC, the patient's age, their malocclusion, and any pathologies in the tissues around them, a variety of orthodontic treatment options, such as extraction, prevention, or active therapy, have been taken into consideration for IMC. To deliver fixed orthodontic treatments in such cases, CBCT imaging analysis of the IMC's angulation, position, and surrounding tissues is particularly helpful [23].

As there are few articles on the main subject, these were chosen between January 2012 and January 2023 (a larger timeframe – eleven years) in order to focus our purpose on discovering more current evidence on the more prevalent location of IMC applying CBCT measurement and its implications on the adjacent teeth.

The absence of articles on the requested topic was due to the prevalence of those which compare 2D conventional imaging with 3D imaging. In this review, the main objective was based on CBCT measurements and their effectiveness only.

CBCT has been applied to assess the position of IMC in 3D, improving accuracy and allowing for more precise surgical and orthodontic management. It is currently the preferred imaging technique for assessing the extent and depth of RR in neighboring teeth, proving its reliability.

The impacted and non-impacted sides have different lateral morphology and angular features. Based on CBCT images, smaller MD crown width of MLI, associated with PIC, could simply reflect the shorter root length and reduced volumes of MLI, which suggests that patients with shorter MLI roots and morphological differences in the MLI and canines (crowns and roots) are more prone to canine eruption issues. Normally, the IMC location is palatal, mesial and in a horizontal position.

Patients with IMC present a high frequency of adjacent teeth RR. Those located beyond the mesial surface, in contact with PIC and in which the cusp tip of the canine is at the apical third of their roots were likely to suffer adjacent RR. The degree of RR is still a controversial subject but differs mainly according to the position of the IMC and the root of the adjacent teeth.

Appropriate localization of IMC, as well as the assessment of the existence, location, and degree of RR of adjacent teeth, is required for surgeons and orthodontists to create an appropriate diagnosis and collaborative treatment plan.

Acknowledgments

This work was funded by Cooperativa de Ensino Superior Politécnico e Universitário (CESPU): project AlignAgen-GI2-CESPU-2022.

Author Contributions

RL planned the overall design and conception of the work, acquired, analyzed, and interpreted the data, and drafted the present manuscript. ASR substantially revised the manuscript. ACO revised the manuscript. ALP verified the quality assessment. TP conceived and designed the work, drafted, and substantially revised the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

The authors declare no competing interests.

References

1. Oberoi, S.; Knueppel, S. Three-dimensional assessment of impacted canines and root resorption using cone beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol* **2012**, *113*, 260-267, doi:10.1016/j.tripleo.2011.03.035.
2. Liuk, I.W.; Olive, R.J.; Griffin, M.; Monsour, P. Maxillary lateral incisor morphology and palatally displaced canines: a case-controlled cone-beam volumetric tomography study. *Am J Orthod Dentofacial Orthop* **2013**, *143*, 522-526, doi:10.1016/j.ajodo.2012.11.023.
3. Alqerban, A.; Jacobs, R.; Fieuws, S.; Willems, G. Radiographic predictors for maxillary canine impaction. *Am J Orthod Dentofacial Orthop* **2015**, *147*, 345-354, doi:10.1016/j.ajodo.2014.11.018.
4. Wriedt, S.; Jaklin, J.; Al-Nawas, B.; Wehrbein, H. Impacted upper canines: examination and treatment proposal based on 3D versus 2D diagnosis. *J Orofac Orthop* **2012**, *73*, 28-40, doi:10.1007/s00056-011-0058-8.
5. Dachi, S.F.; Howell, F.V. A survey of 3,874 routine full-mouth radiographs. I. A study of retained roots and teeth. *Oral Surg Oral Med Oral Pathol* **1961**, *14*, 916-924, doi:10.1016/0030-4220(61)90003-2.

6. Dogramaci, E.J.; Sherriff, M.; Rossi-Fedele, G.; McDonald, F. Location and severity of root resorption related to impacted maxillary canines: a cone beam computed tomography (CBCT) evaluation. *Aust Orthod J* **2015**, *31*, 49-58.
7. Hettiarachchi, P.V.; Olive, R.J.; Monsour, P. Morphology of palatally impacted canines: A case-controlled cone-beam volumetric tomography study. *Am J Orthod Dentofacial Orthop* **2017**, *151*, 357-362, doi:10.1016/j.ajodo.2016.06.044.
8. Chaushu, S.; Kaczor-Urbanowicz, K.; Zadurska, M.; Becker, A. Predisposing factors for severe incisor root resorption associated with impacted maxillary canines. *Am J Orthod Dentofacial Orthop* **2015**, *147*, 52-60, doi:10.1016/j.ajodo.2014.09.012.
9. Schindel, R.H.; Sheinis, M.R. Prediction of maxillary lateral-incisor root resorption using sector analysis of potentially impacted canines. *J Clin Orthod* **2013**, *47*, 490-493.
10. Schroder, A.G.D.; Guariza-Filho, O.; de Araujo, C.M.; Ruellas, A.C.; Tanaka, O.M.; Porporatti, A.L. To what extent are impacted canines associated with root resorption of the adjacent tooth?: A systematic review with meta-analysis. *J Am Dent Assoc* **2018**, *149*, 765-777 e768, doi:10.1016/j.adaj.2018.05.012.
11. Miresmaeili, A.; Farhadian, N.; Mollabashi, V.; Yousefi, F. Web-based evaluation of experts' opinions on impacted maxillary canines forced eruption using CBCT. *Dental Press J Orthod* **2015**, *20*, 90-99, doi:10.1590/2176-9451.20.2.090-099.oar.
12. Ucar, F.I.; Celebi, A.A.; Tan, E.; Topcuoglu, T.; Sekerci, A.E. Effects of impacted maxillary canines on root resorption of lateral incisors : A cone beam computed tomography study. *J Orofac Orthop* **2017**, *78*, 233-240, doi:10.1007/s00056-016-0077-6.
13. Hajeer, M.Y.; Al-Homsi, H.K.; Alfailany, D.T.; Murad, R.M.T. Evaluation of the diagnostic accuracy of CBCT-based interpretations of maxillary impacted canines compared to those of conventional radiography: An in vitro study. *Int Orthod* **2022**, *20*, 100639, doi:10.1016/j.ortho.2022.100639.
14. Mitsea, A.; Palikaraki, G.; Karamesinis, K.; Vastardis, H.; Gizani, S.; Sifakakis, I. Evaluation of Lateral Incisor Resorption Caused by Impacted Maxillary Canines Based on CBCT: A Systematic Review and Meta-Analysis. *Children (Basel)* **2022**, *9*, doi:10.3390/children9071006.
15. Pauwels, R.; Araki, K.; Siewerdsen, J.H.; Thongvigitmanee, S.S. Technical aspects of dental CBCT: state of the art. *Dentomaxillofac Radiol* **2015**, *44*, 20140224, doi:10.1259/dmfr.20140224.
16. Tsolakis, A.I.; Kalavritinos, M.; Bitsanis, E.; Sanoudos, M.; Benetou, V.; Alexiou, K.; Tsiklakis, K. Reliability of different radiographic methods for the localization of displaced maxillary canines. *Am J Orthod Dentofacial Orthop* **2018**, *153*, 308-314, doi:10.1016/j.ajodo.2017.06.026.
17. Almuhtaseb, E.; Mao, J.; Mahony, D.; Bader, R.; Zhang, Z.X. Three-dimensional localization of impacted canines and root resorption assessment using cone beam computed tomography. *J Huazhong Univ Sci Technolog Med Sci* **2014**, *34*, 425-430, doi:10.1007/s11596-014-1295-z.
18. Al-Kyssi, H.A.; Al-Mogahed, N.M.; Altawili, Z.M.; Dahan, F.N.; Almashraqi, A.A.; Aldhorae, K.; Alhammadi, M.S. Predictive factors associated with adjacent teeth root resorption of palatally impacted canines in Arabian population: a cone-beam computed tomography analysis. *BMC Oral Health* **2022**, *22*, 220, doi:10.1186/s12903-022-02249-4.
19. Grybiene, V.; Juozenaite, D.; Kubiliute, K. Diagnostic methods and treatment strategies of impacted maxillary canines: A literature review. *Stomatologija* **2019**, *21*, 3-12.
20. Arboleda-Ariza, N.; Schilling, J.; Arriola-Guillen, L.E.; Ruiz-Mora, G.A.; Rodriguez-Cardenas, Y.A.; Aliaga-Del Castillo, A. Maxillary transverse dimensions in subjects with and without impacted canines: A comparative cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop* **2018**, *154*, 495-503, doi:10.1016/j.ajodo.2017.12.017.
21. Lai, C.S.; Bornstein, M.M.; Mock, L.; Heuberger, B.M.; Dietrich, T.; Katsaros, C. Impacted maxillary canines and root resorptions of neighbouring teeth: a radiographic analysis using cone-beam computed tomography. *Eur J Orthod* **2013**, *35*, 529-538, doi:10.1093/ejo/cjs037.
22. Kim, Y.; Hyun, H.K.; Jang, K.T. Morphological relationship analysis of impacted maxillary canines and the adjacent teeth on 3-dimensional reconstructed CT images. *Angle Orthod* **2017**, *87*, 590-597, doi:10.2319/071516-554.1.
23. Dagsuyu, I.M.; Kahraman, F.; Oksayan, R. Three-dimensional evaluation of angular, linear, and resorption features of maxillary impacted canines on cone-beam computed tomography. *Oral Radiol* **2018**, *34*, 66-72, doi:10.1007/s11282-017-0289-5.

24. Leonardi, R.; Muraglie, S.; Crimi, S.; Pirroni, M.; Musumeci, G.; Perrotta, R. Morphology of palatally displaced canines and adjacent teeth, a 3-D evaluation from cone-beam computed tomographic images. *BMC Oral Health* **2018**, *18*, 156, doi:10.1186/s12903-018-0617-0.
25. Koral, S.; Arman Ozcirpici, A.; Tuncer, N.I. Association Between Impacted Maxillary Canines and Adjacent Lateral Incisors: A Retrospective Study With Cone Beam Computed Tomography. *Turk J Orthod* **2021**, *34*, 207-213, doi:10.5152/TurkJOrthod.2021.20148.
26. Wang, H.; Li, T.; Lv, C.; Huang, L.; Zhang, C.; Tao, G.; Li, X.; Zou, S.; Duan, P. Risk factors for maxillary impacted canine-linked severe lateral incisor root resorption: A cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop* **2020**, *158*, 410-419, doi:10.1016/j.ajodo.2019.09.015.
27. Muñoz-Domon, M.; Arraya-Valdés, D.; Castro-Catalán, D.; Vergara-Núñez, C. Impactación Canina Maxilar y Reabsorción Radicular de Dientes Adyacentes: Un Análisis a Través de Tomografía Computarizada Cone-Beam. *Int J Odontostomat* **2020**, *14*, 27-34, doi:10.4067/S0718-381X2020000100027.