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ORIGINAL ARTICLE

The prevalence of root resorption of maxillary incisors caused by impacted maxillary canines

Georg D. Strbac · Andrea Foltin · André Gahleitner · Hans-Peter Bantleon · Georg Watzek · Thomas Bernhart

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Abstract
Objectives The aim of this study was to evaluate the prevalence of root resorption of maxillary incisors caused by impacted maxillary canines using low-dose dental computed tomography and to gain additional knowledge of the underlying aetiology and the progression of root resorption.

Materials and methods A total of 440 patients (mean age, 24.7 years) with 557 impacted maxillary canines were examined regarding their location and the occurrence of root resorption of maxillary incisors.
Results The frequency of root resorption was 2 % of central and 7.7 % of lateral maxillary incisors. The location of the 557 impacted canines within the dental arch was palatal in 67.5 %, buccal in 15.4 % and central in 17.1 %. No significant differences could be shown with respect to the width and the shape of the dental follicle of the impacted maxillary canines and the presence of root resorption of incisors. The presence of root resorption of central ($p<0.0001$) and lateral ($p<0.023$) maxillary incisors was significantly correlated with an existing contact relationship of the impacted maxillary canines.
Conclusions Our investigation confirms the theory of prior reports comprising a much larger patient population, hypothesising that the dental follicle of impacted maxillary canines does not cause resorption of adjacent maxillary incisors per se.
Clinical relevance Root resorption of maxillary incisors is correlated with effects of contact of the impacted maxillary canines, and these findings should be considered in treatment planning. Our findings are consistent with other reports and may develop new treatment approaches for the treatment of this sequela.

G. D. Strbac (✉) · G. Watzek · T. Bernhart
Department of Oral Surgery, Bernhard Gottlieb University Clinic of Dentistry, Medical University of Vienna,
Sensengasse 2a,
1090 Vienna, Austria
e-mail: georg.strbac@meduniwien.ac.at
URL: www.bgzmk.at

G. Watzek
e-mail: georg.watzek@meduniwien.ac.at
URL: www.bgzmk.at

T. Bernhart
e-mail: thomas.bernhart@meduniwien.ac.at
URL: www.bgzmk.at

A. Foltin · H.-P. Bantleon
Department of Orthodontics, Bernhard Gottlieb University Clinic of Dentistry, Medical University of Vienna,
Sensengasse 2a,
1090 Vienna, Austria

A. Foltin
e-mail: andrea.foltin@meduniwien.ac.at
URL: www.bgzmk.at

H.-P. Bantleon
e-mail: hans-peter.bantleon@meduniwien.ac.at
URL: www.bgzmk.at

A. Gahleitner
Department of Radiology, Bernhard Gottlieb University Clinic of Dentistry, Medical University of Vienna,
Sensengasse 2a,
1090 Vienna, Austria
e-mail: andre.gahleitner@meduniwien.ac.at
URL: www.bgzmk.at

Keywords Root resorption · Tooth impaction · Dental follicle · Maxillary canine · Maxillary incisor · Computed tomography

Abbreviations

2D	Two dimensional
3D	Three dimensional
CT	Computed tomography

CBCT Cone beam computed tomography
MRI Magnetic resonance imaging

Introduction

Impaction of teeth is defined as a failure of eruption at its appropriate site within its normal period of growth [1]. Impacted permanent maxillary canines (average eruption age, 11–12 years) rank second in frequency of impacted teeth exceeded only by impacted maxillary and mandibular third molars (average eruption age, 17–21 years) [1–3]. However, in contrast to third molars, maxillary canines are located in highly demanding functional and aesthetic areas [4]. The incidence of impacted maxillary canines ranges from 0.8 to 3.3 % depending on the population examined [1, 5–8]. The impaction is more frequently seen in palatal location (85 %) and unilaterally (92 %) and is more common in females than in males (ratio, 2:1) depending on ethnic populations studied [4, 9–13]. The aetiology of impacted maxillary canines has not yet been fully defined and is controversial, possibly due to a multifactorial predisposition; two main theories may explain the occurrence of palatally impacted canines: the 'guidance theory' and the 'genetic theory' [1]. The majority of impacted canines may remain asymptomatic over decades; however, some of them may increase the risk of infections, cystic follicular lesions and external root resorption of adjacent teeth, especially root resorption of maxillary incisors [1, 14]. Root resorption of teeth is defined as a complication associated with the activity of tooth resorbing cells, which may result in the loss of cementum and/or dentine [1]. The prevalence of root resorption of the permanent maxillary incisors caused by ectopically erupting maxillary canines is approximately 12 %, but even normally erupting maxillary canines may induce root resorption [15]. Root resorption is more common in unilateral location and at the roots of lateral maxillary incisors, even though the roots of central incisors may also be affected. Root resorption of maxillary incisors is more common in females than in males with a female/male ratio varying between 2:1, 3:1, 4:1 and 10:1 in different surveys. However, no gender differences have been described for severity and location of root resorption [1, 16]. Aetiology and biological mechanisms of root resorption of maxillary incisors caused by impacted maxillary canines have not yet been fully clarified. It has been proposed that an enlarged or active dental follicle and the pressure caused by erupting maxillary canines may be responsible for the root resorption of maxillary incisors. Even though the size and the shape of the dental follicle of erupting maxillary canines vary between individuals and experimental animal studies demonstrated that the dental follicle, but not the crown of erupting teeth, is involved in bone resorption and formation of an eruption pathway, the underlying mechanisms of root resorption have not yet been defined [15, 17–19].

Although the aetiology is still unknown, root resorption is very difficult to treat and generally requires extraction of the maxillary incisor [1]. As a consequence, the resulting condition requires surgical and prosthodontic and/or prolonged orthodontic treatment [16]. For avoiding this serious complication in a highly demanding functional and aesthetical area, early clinical and radiological diagnosis of inaccurately erupting maxillary canines is crucial. As clinical evaluation with palpation and intraoral signs of impacted maxillary canines might be indicative, additional radiological investigation is required in patients older than 10 years [1, 20].

Intraoral and panoramic two-dimensional (2D) radiographs are the most common primary diagnostic radiographs for evaluation and treatment planning; however, these conventional standard radiographic imaging procedures are of limited use for the accurate localisation of impacted canines and adjacent structures. Compared with 2D radiographs, three-dimensional (3D) imaging techniques, such as dental computed tomography (CT), cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) are required for an accurate diagnosis of impacted canines and root resorption of incisors [1, 3, 4, 20].

The purpose of this retrospective study was to evaluate the prevalence of root resorption of the maxillary incisors caused by maxillary canines using low-dose CT and to gain additional basic knowledge of the underlying aetiology and the progression of root resorption of maxillary incisors for the purpose of developing new treatment approaches for the treatment of this sequela.

Materials and methods

Patient assessment

This retrospective study was conducted at the Bernhard Gottlieb University Clinic of Dentistry, Medical University of Vienna, Austria. All patients with clinically diagnosed impacted maxillary canines referred for further 3D radiographic assessment within a period of five years (2005–2010) were included in the investigation. The entire patient collective comprised 440 subjects with 557 impacted maxillary canines. The patients' age ranged between 9 and 76 years, the mean age was 24.7 years. The study protocol was approved by the Ethics Committee of the Medical University of Vienna, Austria (EK1093/2011).

Radiographic assessment

The 3D radiographic examination was performed by CT (Tomoscan SR-6000, Philips Medical Systems, Eindhoven, Netherlands) using a standard low-dose CT protocol (1.5 mm slice thickness, 1 mm table feed, 120 kV, ≤25–50 mA/s, 2 s scan time/slice, 512 matrix, native and bone window). The stored DICOM files of the axial images, parallel to the hard palate, were transferred to a working station for image reconstruction. Multiplanar reconstructions were generated using the standard dental software package (Easy Vision workstation, Dental software package 2.1, Philips, Best, Netherlands) [21].

Radiographic evaluation of images

Root resorption of the maxillary central and lateral incisors, localisation and eruption pathway of the maxillary canine, shape and width of the dental follicle of the canine, alveolar process and morphology of the deciduous canine were evaluated based on 3D images.

Root resorption of the maxillary permanent incisors The root resorption status of each central and lateral incisor was graded into one of the following four categories (Figs. 1, 2 and 3) [1, 15, 22–26]:

- No resorption: intact root surface, cementum may be lost
- Slight resorption: root resorption extending up to half of the dentine thickness toward the pulp
- Moderate resorption: root resorption extending half the distance to the pulp or more, with the pulp lining being unbroken
- Severe resorption: root resorption with the pulp being exposed

Periodontal contours of the permanent maxillary incisors The periodontal contours of the central and lateral incisors were evaluated and graded with the following three categories (Fig. 4) [15]:

- Unbroken intact alveolus contours: the lamina dura of the alveolus and periodontal ligament space were intact
- Broken alveolus contours: the lamina dura of the alveolus was destroyed, but without root resorption of the permanent maxillary incisors
- Broken periodontal contours and resorption of the root (s) of the central and/or lateral incisors adjacent to the erupting maxillary impacted canine

Contact relationship between the canines and incisors The contact relationship between the impacted maxillary canines and the incisors was assessed and categorised as follows (Fig. 4) [15, 22]:

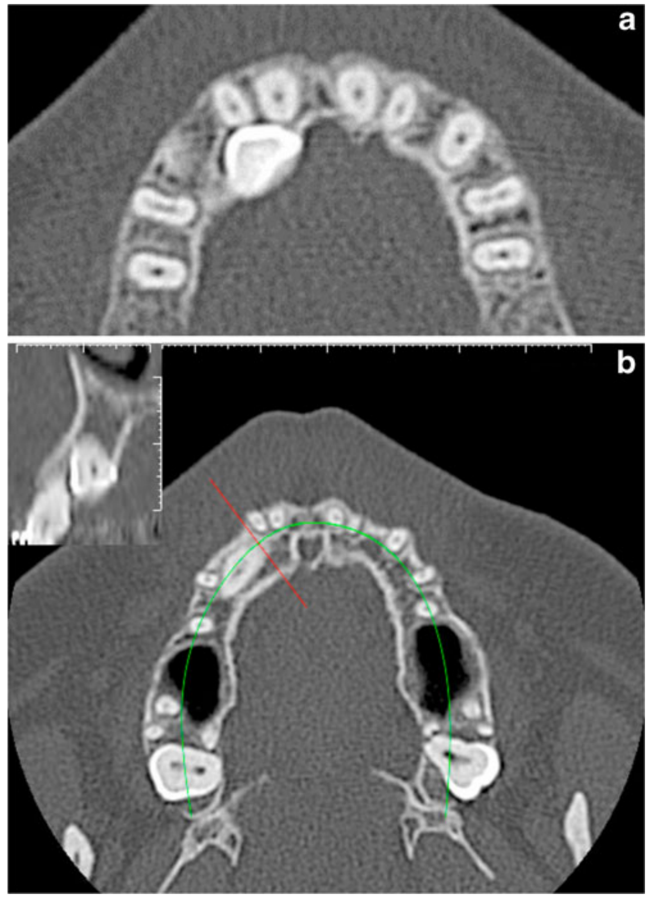

Fig. 1 CT scans of an impacted maxillary right canine and slight resorption of the lateral maxillary incisor: **a** axial scan and **b** multiplanar reconstruction

- No contact: the distance between the crown of the impacted canine and the adjacent incisor was more than 1 mm
- Contact: the distance between the crown of the impacted canine and the adjacent incisor was less than 1 mm

Localisation of the impacted canine The position of the impacted canine within the dental arch (palatally/buccally/centrally in line with the arch) and its inclination following the path of eruption in terms of inclination to the midline was defined (normally erupting canine/ectopically erupting canine) [1, 15, 22, 27].

Shape of the dental follicle of the canine Based on the morphology, the shape of the dental follicle was graded in the following two categories (Figs. 5 and 6) [15, 28]:

- Symmetric extension: rounded or spherical shape with the crown of the impacted canine in the centre
- Asymmetric extension: irregular shape buccal, mesial, distal, palatal or in combination to the crown of the impacted canine

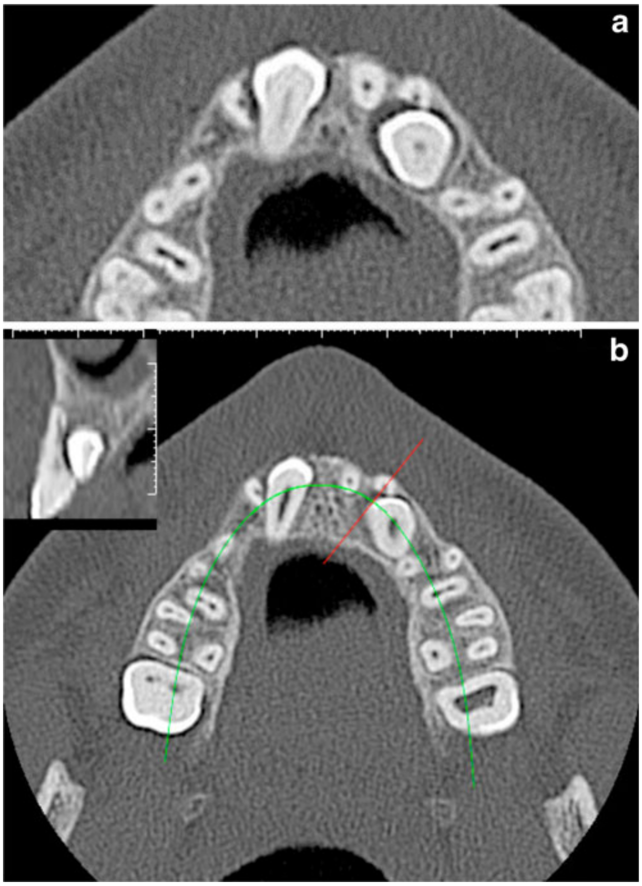

Fig. 2 CT views of impacted maxillary canines, resorbed central right incisor and bilateral moderate resorption of the lateral maxillary incisors: **a** axial scan and **b** multiplanar reconstruction

Width of the dental follicle of the canine The width of each dental follicle was defined as the largest distance from the crown of the impacted canine to the periphery of the follicle and the distance was measured in the transverse plane on axial scans to the nearest 0.5 mm accuracy (Fig. 6) [8, 15, 22, 28].

Fig. 3 Axial CT scan of bilateral impacted maxillary canines with severe resorption of the lateral maxillary right incisor and slight resorption of the lateral maxillary left incisor

Fig. 4 CT view of impacted maxillary right canine with broken alveolus contours of the central and lateral maxillary incisors. Existing contact relationship of the lateral right incisor without root resorption and no contact relationship of the central right incisor

Stage of eruption The impacted maxillary canine eruption path with respect to the cortical lining of the alveolar bone was categorised as follows [28]:

– Impacted canine does not emerge through the cortical bone plate of the alveolus, follicle present and surrounded by a lining of intact compact bone

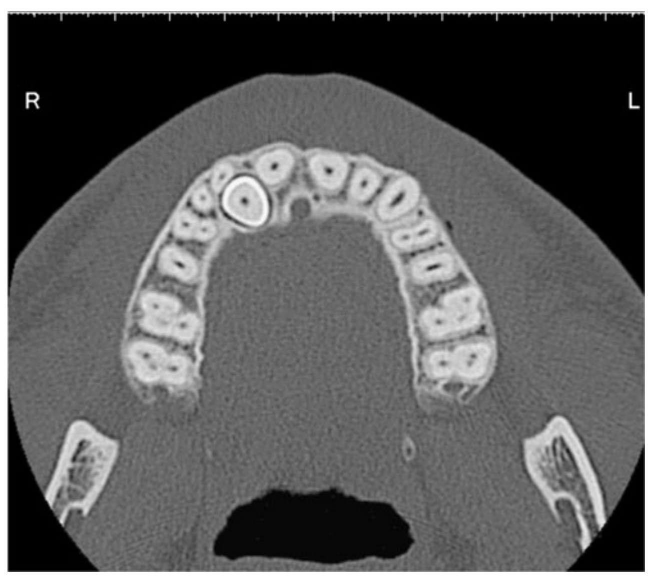

Fig. 5 Axial CT image of impacted maxillary right canine symmetric morphology of the dental follicle

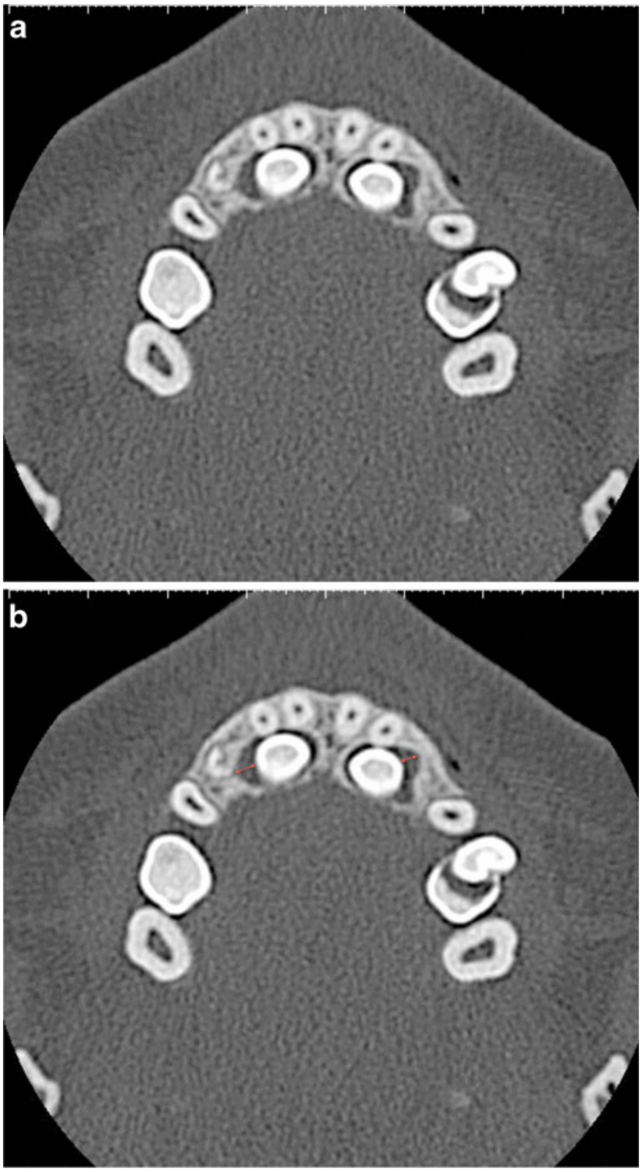

Fig. 6 CT scan of bilateral impacted maxillary canines: **a** asymmetrically enlarged dental follicles with irregular shape and **b** measurements of the widths of the dental follicles from the periphery to the crowns of the canines (*arrows*)

– Impacted canine emerges through the cortical bone plate of the alveolus, follicle present, but not completely covered by compact bone

Deciduous maxillary canines The status and resorption of the deciduous maxillary canines was classified in the following five categories (Fig. 7) [15, 22]:

– Missing deciduous maxillary canine
– No root resorption of the deciduous maxillary canines, without contact between the follicle of the permanent and deciduous maxillary canines
– No root resorption of the deciduous maxillary canines, with contact between the follicle of the permanent and deciduous maxillary canines
– Root resorption of the deciduous maxillary canines, without contact between the follicle of the permanent and deciduous maxillary canines
– Root resorption of the deciduous maxillary canines, with contact between the follicle of the permanent and deciduous maxillary canines

Statistical assessment

All statistical analyses were performed using statistical software SPSS (Version 14.0.0, SPSS© Inc., Chicago, IL, USA) and SAS (Version 9.2, SAS© Institute Inc., Cary, NC, USA). Data were described with frequencies and percentages for categorical data and with median, minimum, maximum and lower and upper quartiles for continuous data. Associations between two categorical covariates were tested by chi-square test or with Fisher's exact test in case of sparse data. Associations between a continuous and a dichotomous or multinomial categorical covariate were assessed using Wilcoxon rank-sum test for two-group comparisons or the Kruskal–Wallis tests in case of more groups, associations between two continuous covariates were assessed by the non-parametric Spearman's correlation coefficient. In case of multiple pairwise comparisons, a Bonferroni–Holm correction was performed. All tests performed were two-sided and a p value of ≤0.05 was considered significant.

Results

Patient assessment

The study collective presented 557 (281 left canines, 50.45 %; 276 right canines, 49.55 %) impacted maxillary canines (n=440 patients; 152 male, 34.55 %; 288 female, 65.45 %), referred for 3D radiographic assessment; 323 subjects had unilateral and 117 bilateral ectopic maxillary canines. The patients' age ranged between 9 and 76 years, the mean age was 24.7 years (SD=±13.9; median=19.8).

Radiographic assessment

Root resorption of the maxillary permanent incisors

In the radiographic assessment of the impacted maxillary canines (n=557), root resorption of the central incisors (n=549) was observed in 2 % (n=11) and root resorption of the lateral incisors (n=523) in 7.7 % (n=43) (Table 1). Occurrence and extent of the root resorption showed slight

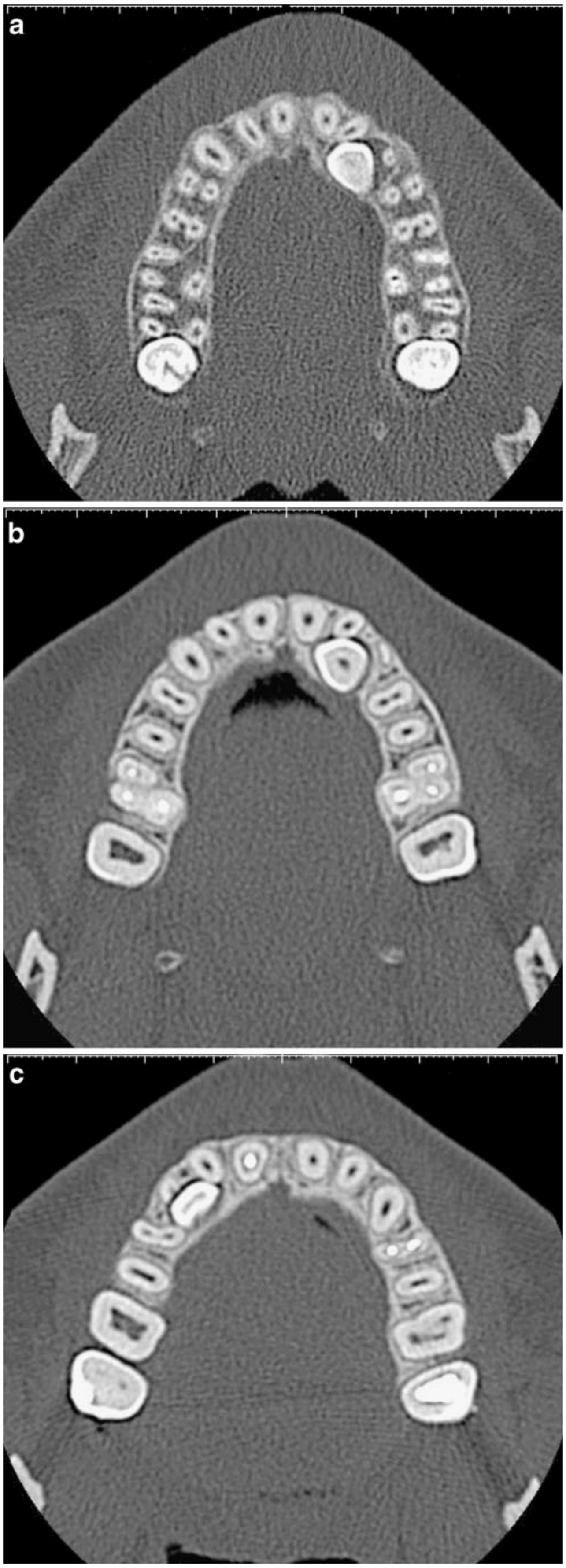

Fig. 7 CT illustrations of deciduous maxillary canines and impacted canines: **a** no root resorption with present contact of the follicle of the maxillary canine, **b** root resorption without contact of the follicle and **c** contact between the follicle of the permanent canine and the deciduous maxillary canine with root resorption

resorption in 0.9 % (*n*=5), moderate resorption in 0.4 % (*n*=2) and severe resorption of the central maxillary incisors in 0.7 % (*n*=4) and slight resorption of the lateral maxillary incisors in 3.1 % (*n*=16), moderate resorption in 1.3 % (*n*=7) and severe resorption in 3.8 % (*n*=20) (Table 2). Male patients showed root resorption in 3.3 % (*n*=6) of the central incisors and in 9.7 % (*n*=17) of the lateral incisors, while female patients showed root resorption in 1.4 % (*n*=5) of the central incisors and in 7.5 % (*n*=26) of the lateral incisors. No significant differences were seen for the occurrence of root resorption with regard to the relationship between gender and age.

Periodontal contours of the permanent maxillary incisors

An unbroken intact alveolus contour with an intact lamina dura and periodontal ligament was observed in 57 % (*n*=313) of the central incisors and in 12.1 % (*n*=63) of the lateral incisors. A broken alveolus contour without root resorption of the permanent maxillary incisors was seen in 41 % (*n*=225) of the central incisors and in 79.7 % (*n*=417) of the lateral incisors. Root resorption with broken alveolus contour of the permanent maxillary incisors was found in 2 % (*n*=11) of the central incisors and in 8.2 % (*n*=43) of the lateral incisors (Table 3).

Contact relationship between the canines and incisors

Evaluation concerning the contact relationship between the maxillary canines and the maxillary incisors showed no contact of the crowns of the impacted canines and no root resorption in 71 % (*n*=390) of central maxillary incisors and in 13.6 % (*n*=71) of lateral maxillary incisors. Contact between the crowns of the impacted canines with no root resorption was observed in 27 % (*n*=148) of the central maxillary incisors and in 78.2 % (*n*=409) of the lateral maxillary incisors. Contact between the crowns of the impacted canines with presence of root resorption was found in 1.8 %

Table 1 Root resorption of incisors associated with impacted maxillary canines

Incisor	Resorption	No resorption
Central (*n* (%))	11/557 (2)	546/557[a] (98)
Lateral (*n* (%))	43/557 (7.7)	514/557[a] (92.3)

[a]Including missing central and lateral incisors

Table 2 Severity of diagnosed root resorption of maxillary central and lateral incisors

Root resorption					
Incisor	No resorption	Slight resorption	Moderate resorption	Severe resorption	Total
Central (*n* (%))	538 (98)	5 (0.9)	2 (0.4)	4 (0.7)	549 (100)
Lateral (*n* (%))	480 (91.8)	16 (3.1)	7 (1.3)	20 (3.8)	523 (100)

(*n*=10) of the central maxillary incisors and in 8 % (*n*=42) of the lateral maxillary incisors. The presence of root resorption of central and lateral maxillary incisors was significantly correlated with an existing contact relationship of the impacted maxillary canines (Table 4).

Localisation of the impacted canine

The inclination of the maxillary impacted canine to the midline showed ectopically erupting canines in 90.5 % (*n*=504) and normally erupting canines in 9.5 % (*n*=53).

As regards the position of the 557 impacted canines within the dental arch, 67.5 % (*n*=376) were found to be palatally, 15.4 % (*n*=86) buccally and 17.1 % (*n*=95) centrally in line with the arch. Root resorption of the central maxillary incisors was caused in 54.5 % (*n*=6) by palatally located impacted maxillary canines, in 36.4 % (*n*=4) by buccally located ones and in 9.1 % (*n*=1) by centrally located impacted maxillary canines. An existing root resorption of the lateral maxillary incisors was caused by palatally located impacted maxillary canines in 62.8 % (*n*=27), by buccally located ones in 16.3 % (*n*=7) and by centrally located maxillary impacted canines in 20.9 % (*n*=9). No significant differences regarding the eruption pathway of the impacted maxillary canines were seen between root resorption of the central and the lateral incisors (Table 5).

Shape of the dental follicle of the canine

Five hundred forty-one existing dental follicles of impacted canines could be observed in the 3D radiographic assessment. Of the dental follicles, 85.2 % (*n*=461) had a symmetric extension with the crown of the impacted canines in the centre; an asymmetric extension of the dental follicle was seen in 14.8 % (*n*=80).

In total, 4.4 % (*n*=46) symmetric dental follicles and 0.7 % (*n*=7) asymmetric dental follicles were observed with resorption of central and lateral maxillary incisors (*n*=1,041); 85.2 % (*n*=445) symmetric and 14.8 % (*n*=77) asymmetric dental follicles were recorded with no resorption of maxillary central incisors; 90.9 % (*n*=10) symmetric and 9.1 % (*n*=1) asymmetric dental follicles were recorded with root resorption of maxillary central incisors; 85.4 % (*n*=398) symmetric and 14.6 % (*n*=68) asymmetric dental follicles were observed with no resorption of maxillary lateral incisors; 85.7 % (*n*=36) symmetric and 14.3 % (*n*=6) asymmetric dental follicles were recorded in combination with root resorption of maxillary lateral incisors. The incidence of root resorption of the central and lateral incisors regarding the shape of the dental follicle of the impacted maxillary canines showed no significant differences (Table 6).

Symmetric dental follicles of the impacted canines were assessed in younger patients ($p<0.0001$), gender distribution of symmetric and asymmetric dental follicles showed borderline significance ($p=0.056$), and no significant difference was observed concerning the shape of the dental follicles of the impacted canines and their localisation within the dental arch.

Width of the dental follicle of the canine

The width of each dental follicle of the impacted canines was measured in the transversal plane. The follicle size varied from 0.5 to 14 mm (SD=±1.37 mm; median=1.5 mm). No significant relationships were found between the occurrence of root resorption of the central and lateral

Table 3 Periodontal contours of the permanent maxillary incisors

Periodontal contours of maxillary incisors				
Incisor	Unbroken contours	Broken contours no root resorption	Broken contours with root resorption	Total
Central (*n* (%))	313 (57)	225 (41)	11 (2)	549 (100)
Lateral (*n* (%))	63 (12.1)	417 (79.7)	43 (8.2)	523 (100)

Table 4 Contact relationship between the maxillary impacted canines and the incisors

Contact relationship	No contact	Contact	Significance (p value)
Central incisor (n (%))			
No root resorption	390 (71)	148 (27)	<0.0001
Root resorption	1 (0.2)	10 (1.8)	
Lateral incisor (n (%))			
No root resorption	71 (13.6)	409 (78.2)	<0.023
Root resorption	1 (0.2)	42 (8)	

maxillary incisors and a widened dental follicle of the maxillary canines (Table 7).

The follicles of younger patients showed a significantly higher width compared with those of older subjects ($p<0.0001$). Female patients showed significantly smaller dental follicles of canines than male patients ($p<0.0001$). No significant difference was seen with respect to the width of the dental follicles of the impacted canines and their localisation within the dental arch. The presence of root resorption of the central and lateral incisors regarding the width and the shape of the dental follicle of the impacted maxillary canines showed no significant differences.

Stage of eruption

The determination of the eruption path with respect to the cortical lining of the alveolar bone showed a broken lining of compact bone with no root resorption in 64.5 % (n=347) of central maxillary incisors and in 65.2 % (n=313) of lateral maxillary incisors. Absence of dehiscence of the cortical bone plate in maxillary impacted canines with root resorption was observed in 36.4 % (n=4) of the central maxillary incisors and in 41.9 % (n=18) of the lateral maxillary incisors. Impacted maxillary canines with a breakthrough of the cortical bone plate of the alveolus with presence of root resorption was discovered in 63.6 % (n=7) of the central maxillary incisors and in 58.1 % (n=25) of the lateral maxillary incisors.

No significant differences were seen for the occurrence of root resorption of maxillary incisors and the impacted canine eruption path with respect to the cortical lining of the alveolar bone (Table 8).

Deciduous maxillary canines

A total of 300 persistent deciduous maxillary canines could be assigned in 3D radiographic assessment of 557 impacted maxillary canines; 91.3 % (n=274) deciduous maxillary canines occurred with ectopically positioned erupting maxillary canines and 8.7 % (n=26) occurred with normally positioned erupting maxillary canines; 58.3 % (n=175) of the persisting deciduous maxillary canines had no contact with the follicle of the permanent maxillary canines, 41.7 % (n=125) of the remaining deciduous canines were in contact with the follicle of the adjacent impacted canines. Root resorption of the deciduous maxillary canines was seen in 43.4 % of those canines with no contact with the follicle of the permanent maxillary canines. Root resorption was seen in 64.8 % (n=81) of the deciduous maxillary canines if contact with the follicle of the permanent maxillary canines was present (Table 9). The relationships between root resorption of the deciduous maxillary canines, width of the dental follicles and contact of the follicles of the maxillary canines were evaluated. A significant relationship was found between intact deciduous maxillary canines and enlarged dental follicles of impacted canines if contact of the follicle was present ($p<0.0174$). Enlarged dental follicles of impacted canines showed a significant relationship with root resorption of the deciduous maxillary canines if contact of the follicles was existing ($p<0.001$).

Table 5 Relationship between root resorption of the maxillary incisors and localisation of the impacted canines

Canine localisation	Palatal	Buccal	Central	Total	Significance
Central incisor (n (%))					
No root resorption	369 (68.6)	76 (14.1)	93 (17.3)	538 (100)	NS
Root resorption	6 (54.5)	4 (36.4)	1 (9.1)	11 (100) 549	
Lateral incisor (n (%))					
No root resorption	332 (69.2)	69 (14.4)	79 (16.4)	480 (100)	NS
Root resorption	27 (62.8)	7 (16.3)	9 (20.9)	43 (100) 523	

NS not significant

Table 6 Relationship between root resorption of the maxillary incisors and the shape of the dental follicles of the impacted canines

Shape of dental follicle of canine				
	Symmetric	Asymmetric	Total	Significance
Central incisor (*n* (%))				
No root resorption	445 (85.2)	77 (14.8)	522 (100)	NS
Root resorption	10 (90.9)	1 (9.1)	11 (100)	
			533[a]	
Lateral incisor (*n* (%))				
No root resorption	398 (85.4)	68 (14.6)	466 (100)	NS
Root resorption	36 (85.7)	6 (14.3)	42 (100)	
			508[a]	

NS not significant

[a]Excluding aplasia of incisors and inexistent dental follicles

Discussion

Maxillary canines are the last teeth to erupt prior to the third molars and they reach the occlusal plane at a time when growth of the jaw is nearly completed. Their normal development begins with the calcification of the crown towards the end of the first year of life with the crown located between the roots of the first deciduous molars. During eruption of the deciduous first molar, the canine is situated high in the maxilla with the crown directed mesially and palatally. As the maxillary canine migrates toward the occlusal plane, it becomes more upright until it reaches the distal aspect of the root of the lateral incisor and the mesial aspect of the root of the deciduous canine. Further eruption of the maxillary canine (average eruption age, 11–12 years) normally proceeds without resorption of any hard tissue of the root of the lateral incisor due to its guidance during eruption [29–31].

Apart from early clinical evaluation, radiographic investigation is recommended in patients with impacted maxillary canines older than 10 years to avoid serious complications of root resorption of maxillary incisors [20, 32]. Primary diagnostic 2D radiographs are common for evaluation and treatment planning; however, these radiographic imaging techniques are limited to the assessment of root resorption of maxillary incisors by impacted maxillary canines. 2D radiographs involve several potential misinterpretation factors, such as image enlargement, distortion projection errors, blurred images, overlapping structures and limited identifiable landmarks, that may adversely affect radiological image quality and consequently increase the risk of misinterpretation [4, 22]. 3D imaging techniques, such as dental CT, have proven to be superior to 2D radiographs with a 50 % higher detection rate of root resorption and are also a mandatory source of information in treatment planning for patients with impacted maxillary canines [1, 25, 27, 33, 34]. Recent investigations have also introduced CBCT for the diagnosis of root resorption of maxillary incisors and localisation of impacted canines [1, 8, 22, 35]. Although different CBCT devices vary in the field of volume, resolution and radiation dose levels, this imaging technique may contribute to improve radiographic imaging in the future. CT can still remain the technique of choice, especially when appropriate low-dose CT protocols can be used for radiographic evaluation [36, 37].

In the present investigation, subjects with diagnosed impacted maxillary canines were referred for further 3D radiographic assessment using a standard low-dose CT protocol in order to obtain detailed information required for treatment planning.

Four hundred forty consecutive patients with 557 impacted maxillary canines were examined regarding the location of impacted maxillary canines and the occurrence of root resorption of maxillary central and lateral incisors. The prevalence of root resorption was 2 % of central and 7.7 % of lateral maxillary incisors. In similar and comparable 3D investigations root resorption ranged between 9 and

Table 7 Relationship between root resorption of the maxillary incisors and the width of the dental follicles of the impacted canines

Width of dental follicle of canine (mm)							
	Max	Q3	Median	Q1	Min	Total	Significance
Central incisor							
No root resorption	10.5	2.5	1.5	1	0.5	522[a]	NS
Root resorption	14	2	1.5	1	1	11[a]	
Lateral incisor							
No root resorption	10.5	2.5	1.5	1	0.5	466[a]	NS
Root resorption	14	2	1.5	1	0.5	42[a]	

NS not significant

[a]Excluding aplasia of incisors and inexistent dental follicles

Table 8 Relationship between root resorption of the maxillary incisors and the stage of eruption of the impacted canines

Cortical lining of the alveolar bone				
	Unbroken	Broken	Total	Significance
Central incisor (*n* (%))				
No root resorption	191 (35.5)	347 (64.5)	538 (100)	NS
Root resorption	4 (36.4)	7 (63.6)	11 (100)	
Lateral incisor (*n* (%))				
No root resorption	167 (34.8)	313 (65.2)	480 (100)	NS
Root resorption	18 (41.9)	25 (58.1)	43 (100)	

NS not significant

23 % for central incisors and between 27 and 67 % for lateral incisors [8, 25, 35]. In the present investigation, a lower incidence of root resorption of maxillary incisors could be determined in a much larger patient population as compared with these 3D investigations.

The inclination of the impacted canines to the midline showed ectopically erupting canines in 90.5 % and normally erupting canines in 9.5 %. No correlation between the eruption path of the impacted canines and root resorption of maxillary central and lateral incisors could be observed. These results confirm that ectopically erupting and even normally erupting maxillary canines may induce root resorption of incisors and that these findings should be considered in treatment planning [1, 15]. As regards the position of the 557 impacted canines within the dental arch, these were found to be palatally in line with the arch in 67.5 %, buccally in 15.4 % and centrally in 17.1 % [1, 9, 10, 34, 38]. In this evaluation, the incidence of root resorption of the central and lateral incisors concerning the eruption path of the impacted maxillary canines and the cortical lining of the alveolar bone showed no significant differences [28].

The prevalence of maxillary canine impaction is frequently described as being more common in females than in males (ratio, 2:1) as coinciding with the results in our investigation (34.55 % male/65.45 % female) [4, 10, 11]. However, the frequency of root resorption of the central and lateral incisors regarding the relationship between gender and age showed no significant differences as reported in previous investigations [16, 25, 34].

Previous surveys have suggested that an enlarged or active dental follicle and the pressure caused by erupting maxillary canines may be responsible for the root resorption of maxillary incisors [1, 8, 15–18]. The present study showed no significant differences in the width and the shape of the dental follicle of the impacted maxillary canines and the presence of root resorption of the central and lateral incisors, which is also consistent with other reports [1, 9, 15, 16]. Similarly, it could be shown that the location of the impacted maxillary canine within the dental arch had no influence regarding the width of the dental follicle. However, this evaluation showed a correlation between the width and the shape of the dental follicle and the age and gender of the patients. Symmetric dental follicles of impacted canines were assessed in younger patients ($p<0.0001$) and younger patients showed a significantly higher width of the dental follicle compared with the width in older subjects ($p<0.0001$). Female patients showed significantly smaller widths of dental follicles than male patients ($p<0.0001$). Although shape and width of the dental follicle of erupting maxillary canines have been shown to vary between individuals, our study with a much larger patient population confirms the findings of previous examinations that the dental follicle of impacted maxillary canines does not cause resorption of adjacent maxillary incisors by itself [1, 9, 15, 16, 34]. Our findings are consistent with those of other reports showing that the dental follicle of the impacted canine may frequently expose the root of maxillary incisors as a result of its guidance during normal eruption by broken periodontal contours without resorbing hard tissue of the roots [1, 9, 15, 18].

Table 9 Numbers of deciduous maxillary canines and contact relationships between the deciduous and permanent maxillary canines

Deciduous maxillary canines				No contact with the follicle		Contact with the follicle	
Position of impacted canine	Total (*n* (%))	Missing (*n* (%))	Present (*n* (%))	Intact	Resorbed	Intact	Resorbed
Ectopic (*n* (%))	504 (90.5)	230 (89.5)	274 (91.3)	99	74	38	63
Normal (*n* (%))	53 (9.5)	27 (10.5)	26 (8.7)	0	2	6	18
Total (*n* (%))	557 (100)	257 (100)	300 (100)	99	76	44	81

In addition, our study also assessed the relationship between the deciduous maxillary canines and the contact of the dental follicle of the impacted maxillary canines. A significant relationship was found in the group of intact deciduous maxillary canines ($p<0.0174$) and also in the group of resorbed deciduous maxillary canines ($p<0.001$) concerning an enlarged dental follicle of impacted canines if contact of the follicle was present. Moreover, no significant differences could be shown between intact and resorbed deciduous maxillary canines concerning the width of the dental follicle, if no contact of the dental follicle was present. In obvious contrast to the roots of the permanent maxillary incisors, the roots of the deciduous maxillary canines were frequently resorbed with and without contact of the dental follicle. These findings are consistent with other reports and confirm the yet unclear phenomenon of root resorption of deciduous teeth [10, 15, 39, 40].

However, it had been suggested in previous investigations that the effect of contact with active pressure and cellular activities caused by erupting maxillary canines may be responsible for the root resorption of maxillary incisors [15, 25, 26, 35]. In our study, the presence of root resorption of central ($p<0.0001$) and lateral ($p<0.023$) maxillary incisors was significantly correlated with an existing contact relationship of the impacted maxillary canines. Our observations confirm the hypothesis of prior reports that active pressure and cellular activities, as effects of contact of the maxillary canine during eruption are the major factors generating maxillary incisor root resorption.

Conclusions

Our findings support the following conclusions:

- Ectopically erupting and even normally erupting maxillary canines may induce root resorption of maxillary incisors.
- The dental follicle of impacted maxillary canines does not cause resorption of adjacent maxillary incisors by itself.
- The width and the shape of the dental follicle of the impacted canines do not correlate with root resorption of maxillary incisors.
- The dental follicle of the impacted canines may expose the root of maxillary incisors due to their guidance during eruption without resorption.
- The roots of the deciduous maxillary canines may be resorbed with or without contact of the dental follicle.
- The presence of root resorption of maxillary incisors is correlated with its contact of the maxillary canines during eruption.
- An active pressure of the impacted maxillary canine to adjacent teeth could be prevented with precocious orthodontic therapy and surgical exposure techniques to avoid root resorptions of maxillary incisors.
- An early clinical and accurate radiological diagnosis is essential for treatment planning for patients with impacted maxillary canines.

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