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Cone Beam Computed Tomography (CBCT) Aid in the Management of Apical Root Resorption of Impacted Maxillary Canines and Physiologically Erupted Maxillary Canines after Orthodontic Treatment

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Abstract: The aim of this study is to evaluate the effects of orthodontic traction, by means of light and controlled forces, on root length in impacted maxillary canines and physiologically erupted maxillary canines. Disinclusion of impacted maxillary canines is a frequent procedure in orthodontics due to their higher incidence of impaction. The effects of orthodontic traction, by means of light and controlled forces, can lead to a resorption of the root length in impacted and physiologically erupted teeth. Therefore, apical root resorption is a common phenomenon that must be taken into consideration. Apical root resorption measurements were taken using pre-treatment CBCTs and pre-treatment and post-treatment digital panoramic radiographs of 52 patients who underwent fixed-appliance treatment by using light and controlled orthodontic forces. The experimental group consisted of 26 patients with one impacted maxillary canine. The control group consisted of 26 patients without any impaction. Apical root resorption was calculated from root lengths before and after orthodontic treatment. In the experimental group, impacted canines with incomplete apical formation underwent root elongation, while impacted canines with completed root formation went through apical root resorption. The latter showed a slightly greater apical root resorption (0.2 mm) compared to the control group (95% confidence interval; $p = 0.04$). The extent of root resorption of impacted canines was significantly higher than that of physiologically erupted ones. However, this differential resorption did not compromise the structural and functional integrity of the involved teeth. The orthodontic treatment performed with light and controlled forces is, therefore, a procedure to be considered acceptable and safe.

Keywords: orthodontics; root resorption; bone remodeling; impacted teeth; CBCT

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1. Background

Each tooth demonstrates a specific timing of eruption in the oral cavity. A tooth is defined as impacted when its root develops beyond three-quarters of its final root length and the spontaneous eruption has not occurred in a reasonable time [1].

Diagnosis is made by radiographs showing the presence of a non-erupted tooth with a root greater than three-quarters of its final root length. In most cases, following the extraction of the deciduous tooth, the corresponding permanent tooth is expected to erupt normally [1–3].

Permanent impaction typically involves maxillary teeth, which represent 79.1%, while mandibular teeth comprise the remaining 20.9% [4]. The maxillary and mandibular third molars are the most commonly impacted teeth. The frequency of tooth impaction is mandibular and maxillary third molars, maxillary canines (50.4%), maxillary second premolars (18.2%), and the mandibular second premolars (12.2%), with less frequent observation of the mandibular canines, maxillary central incisors, maxillary lateral incisors, and mandibular second molars [4,5]. Mandibular and maxillary first molars and mandibular second molars are rarely affected [6]. There is a difference in the distribution of impacted teeth in males and females [4]. Permanent maxillary canine eruption disorders arise because these elements have the longest period of development within the jaw and the longest eruption path than any other tooth to emerge into the oral cavity [6].

Permanent impaction of teeth can lead to different complications, such as ecchymosis of the soft tissues, infection, paresthesia and damage to adjacent structures, adjacent tooth root resorption, and the development of cystic-like lesions [5,7,8]. The surgical-orthodontic approach may represent a viable solution in most cases of canine impaction [3,6].

Several studies have demonstrated that orthodontic treatment with uncontrolled forces cause an increase in the incidence and severity of root resorption, and that heavy forces can be particularly harmful. To prevent this, it is essential to apply light orthodontic forces in order to reduce the formation of hyalinization areas that favor the reabsorption of the radicular cement. Since the impacted tooth is located in a position that makes it more difficult to position the bracket in the correct location of the crown, the mechanical forces that are applied on the tooth result less controlled. Slightly heavier orthodontic movements are usually needed for bringing the impacted tooth back into the correct position. Moreover, impacted teeth must travel a much longer distance to reach their final location. During this period, the impacted teeth are subject to different types of mechanics and forces with different directions [1,2,6].

The orthodontic treatment to disinclude a tooth in bone inclusion is on average longer than an orthodontic treatment performed to correct a simple dental alignment problem, with the presence of all the elements already erupted [9–11]. During orthodontic treatment, apical root resorption must be taken into consideration. External apical root resorption is a phenomenon consequent to orthodontic therapy, characterized by loss of dentine and cement, which leads to root shortening due to the activity of clastic cells [9]. In most cases, root resorption is clinically insignificant and not visible on X-rays. When it is significant, it can be noticed as a reduction in the radiographic lengths of the maxillary and mandibular teeth from the tip of the incisal edge or the tip of the most prominent cuspid to the root apex. This can be evaluated with several techniques, such as orthopanoramics, intraoral radiographies, or computed tomography (CBCTs) [12].

Only rarely will the tooth resorption be enough to impede the prognosis of tooth mobility or loss, but when it happens, it can cause tooth mobility or its loss [11,12]. A significant shortening of the root length brings to an unfavorable crown–root ratio. When this shortening is greater than 3 mm, it equates to 1 mm bone loss, which may accelerate the periodontal disease process [11,12].

The teeth that are most susceptible to root resorption due to orthodontic treatment are the upper and lower incisors [11]. The extent of external root resorption is influenced by various factors, which are divided into internal and external. Internal factors include genetics, age at the start of the treatment, diet, root shape, gender, alveolar bone density and impacted teeth [13–15]. External factors are mainly related to orthodontic treatment, such as the type of oral appliance, treatment technique, direction and intensity of orthodontic forces and duration of the therapy [16,17]. External factors are the most important ones which an orthodontist has to deal with when it comes to the forced disinclusion of impacted teeth because of the significant tooth movement, the important torque required, and the longer time needed.

The aim of this study was to evaluate the effects of orthodontic traction, by means of light and controlled forces, on the root length of impacted maxillary canines and physiologically erupted maxillary canines. The first part of this study aims to define the extent of the apical root resorption of the impacted teeth that have been subjected to orthodontic disinclusion, evaluating their root length at the first orthodontic treatment (T0) and at the end of orthodontic therapy (T1).

The second part of this study aims to determine the extent of the apical root resorption of the teeth physiologically erupted in the arch when they undergo orthodontic therapy. The extent of reabsorption root length is evaluated by measuring the root length of the element taken into consideration before orthodontic therapy (T0) and at the end of orthodontic treatment (T1).

In the third part of the study, the comparison of the treatment effects on the root length between teeth in bone inclusion and physiologically erupted teeth was carried out. The present study was conducted based on CBCTs taken in T0 and T1.

2. Methods

All of the patients were treated at the Dental Clinic of Fondazione IRCCS San Gerardo dei Tintori Hospital in Monza between September 2021 and July 2023. All patients suitable for the study were attributed to the control or experimental group and were treated by the same orthodontist. The study was approved by the Internal Ethical Committee and received clearance as a non-interventional study.

The impaction group (experimental group) consisted of 26 patients (15 females and 11 males) with a mean age of 12.9 $\pm$ 1.2 years (SD) at the start of fixed orthodontic treatment. Each of these patients had 1 impacted maxillary canine. The subjects were selected using the following inclusion criteria: (1) the presence of an impacted maxillary canine; (2) and the need for surgical exposure of the impacted tooth to carry out the disinclusion of the impacted tooth, by means of fixed orthodontic treatment and light forces. The exclusion criteria included: (1) craniofacial syndromes or malformations; (2) intake of medicines that can interfere with orthodontic movements; (3) apex visibly open on radiographs at the beginning of orthodontic treatment; (4) presence of root resorption secondary to trauma or pulp pathologies; (5) presence of cysts or apical lesions associated with the impacted tooth; (6) systemic disorders affecting orthodontic movements and the root resorption process; (7) and juvenile periodontitis. All patients of the impaction group underwent a surgical exposure of the impacted tooth in the most conservative way possible, by limiting the exposure to the crown area to minimize the deleterious effects on the periodontium, before applying orthodontic traction.

The non-impaction (control) group comprised 26 patients (12 females and 14 males). From each subject, 1 canine was randomly chosen to determine its apical root resorption. The mean age of these patients was 13.9 $\pm$ 1.2 years (SD) at the beginning of treatment. The inclusion criteria for the control group were: (1) fixed orthodontic treatment carried out with light and controlled forces; (2) and all teeth physiologically erupted. The exclusion criteria included: (1) craniofacial syndromes or malformations; (2) intake of medicines that can interfere with orthodontic movements; (3) apex visibly open on radiographs at the start of orthodontic treatment; (4) presence of root resorption secondary to trauma or pulp pathologies; (5) presence of cysts or apical lesions associated with the impacted tooth; (6) systemic disorders affecting orthodontic movements and the root resorption process; (7) and juvenile periodontitis.

Orthodontic force used during the treatment was considered light (25 g) in accordance with the current literature [13].

All 52 patients presented complete orthodontic records, including pre-treatment and post-treatment digital panoramic radiographs and pre-treatment CBCTs.

The study was approved by the Internal Ethical Committee and received clearance as a non-interventional study.

2.1. Data Analysis

Measurements on CBCTs were taken by the same examiner, assessed in millimeters, and rounded up to the nearest 0.01 mm. Before proceeding with the measurements, the examiner detected the long axis of the tooth on the radiographs before (T0) and after treatment (T1). On CBCTs, three points were individualized on the long axis of the tooth: (1) apex; (2) cement-enamel junction; (3) occlusal plane. In this way, the root length (the distance between the apex and the cement–enamel junction) and the crown length (the distance between the cement–enamel junction and the occlusal plane) were obtained (Figure 1).

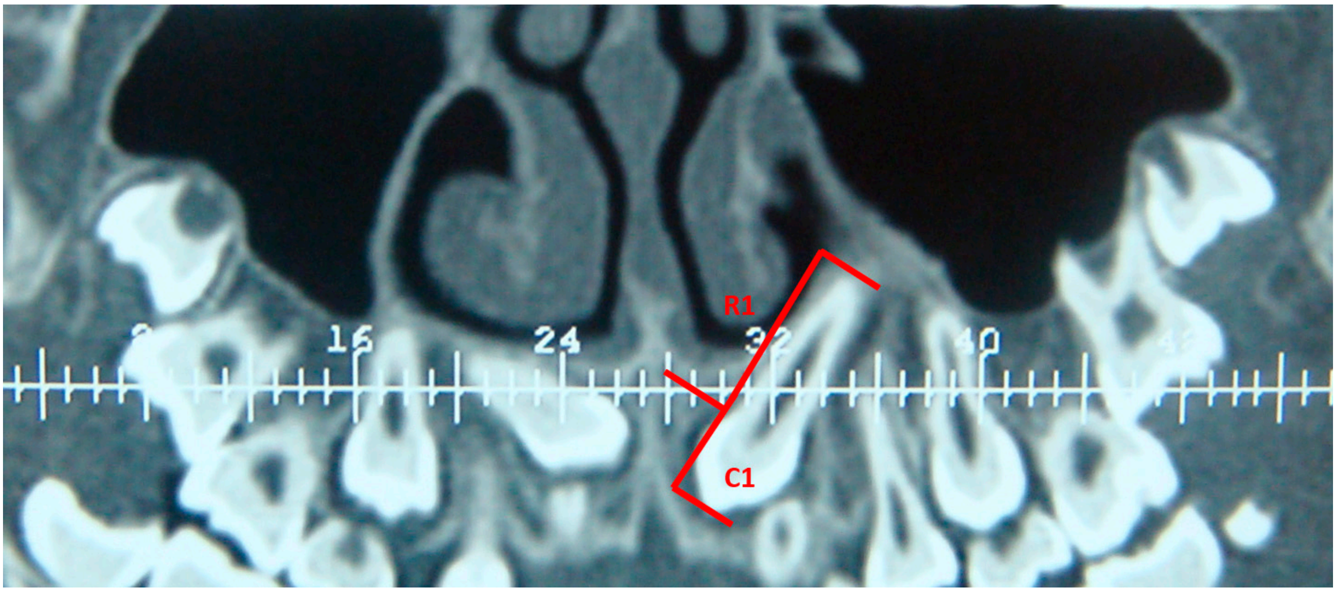

Figure 1. Cropped CBCT of the impacted upper left canine pre-treatment. C1, crown length before treatment; R1, root length before treatment.

This study was judged to have a moderate risk of bias, since the researchers were not blinded to treatment groups.

2.2. Statistical Analysis

Descriptive statistical analysis for quantitative and qualitative variables was performed. For statistical elaboration, a Social Science Statistics website was used. The data distribution was determined by the Kolmogorov–Smirnov Test. The independent sample *t*-test was utilized to compare the extent of apical root resorption between the impaction group and the non-impaction group. The level of significance was set at $p < 0.05$. Data were then collected and organized in a table (Excel, Microsoft Office 365, Microsoft, Redmond, WA, USA) and analyzed with R 4.3 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

In the impaction group, 10 maxillary canines (38.46%) underwent apical root resorption, while 16 maxillary canines (61.54%) went through root elongation. Root elongation is due to the completion of root development of these teeth. The extent of root resorption and root elongation were evaluated based on gender, root shape, and duration of the orthodontic treatment (Tables 1 and 2).

Table 1. Mean apical root resorption of the impaction group according to gender, root shape, and orthodontic treatment duration.

		Mean ARR	SD
		(mm)	
Gender	Female (N = 6; 60%)	0.95	0.35
	Male (N = 4; 40%)	1.09	0.31
Root shape	Normal (N = 3; 30%)	0.85	0.44
	Blunt (N = 1; 10%)	0.75	
	Apically bent (N = 4; 40%)	1.07	0.29
	Pipette-shaped root (N = 2; 20%)	1.27	0.12
Orthodontic treatment duration	<24 months (N = 4; 40%)	0.92	0.32
	>24 months (N = 6; 60%)	1.07	0.35

Table 2. Mean root elongation of the impaction group according to gender, root shape, and orthodontic treatment duration. NS = not significant.

		Mean RE	SD	
		(mm)		
Gender	Female (N = 9; 56.25%)	0.51	0.21	
	Male (N = 7; 43.75%)	0.50	0.16	
	p	0.45		NS
Root shape	Normal (N = 7; 43.75%)	0.61	0.20	
	Blunt (N = 4; 25%)	0.45	0.15	
	Apically bent (N = 3; 18.75%)	0.39	0.12	
	Pipette-shaped root (N = 2; 12.5%)	0.43	0.09	
Orthodontic treatment duration	<24 months (N = 10; 62,5%) 0.48	0.16		
	>24 months (N = 6; 37.5%)	0.55	0.21	
	p	0.27		NS

Among these ten impacted teeth that had apical root resorption, six teeth belonged to female patients (60%) and four teeth to males (40%). In female patients, the mean apical root resorption found was 0.95 $\pm$ 0.35 mm (SD) while in male patients it was 1.09 $\pm$ 0.31 mm (SD). According to the root shape, the mean apical root resorption was 0.85 $\pm$ 0.44 mm (SD) for teeth with normal root (three elements, 30%); 0.75 mm for the tooth with blunt root (one element, 10%); 1.07 $\pm$ 0.29 mm (SD) for teeth apically bent (four elements, 40%); 1.27 $\pm$ 0.12 mm (SD) for teeth with a pipette-shaped root (two elements, 20%). In subjects who underwent an orthodontic treatment duration for less than 24 months (4 patients, 40%), a mean apical root resorption of 0.92 $\pm$ 0.32 mm (SD) was found. On the other hand, subjects who had orthodontic therapy lasting 24 months or more (six patients, 60%) went through a greater mean apical root resorption, equal to 1.07 $\pm$ 0.35 mm (SD).

The mean root elongation was 0.51 $\pm$ 0.21 mm (SD) in females (nine patients; 56.25%) and 0.50 $\pm$ 0.16 mm (SD) in males (seven patients; 43.75%). This difference between female and male subjects was not statistically significant (95% confidence interval; p = 0.45). The mean root elongation calculated according to root shape were: 0.61 $\pm$ 0.20 mm (SD) for teeth with normal root (seven elements; 43.75%); 0.45 $\pm$ 0.15 mm (SD) for teeth with blunt root (four elements; 25%); 0.39 $\pm$ 0.12 mm (SD) for teeth apically bent (three elements; 18.75%); and 0.43 $\pm$ 0.09 mm (SD) for teeth with a pipette-shaped root (two elements; 12.5%). The difference of mean root elongation between patients who underwent an orthodontic treatment duration for less than 24 months (ten subjects; 62.5%; mean RE = 0.48 ± 0.16 mm (SD)) and patients who had an orthodontic treatment lasting 24 months or more (six subjects; 37.5%; mean RE = 0.55 ± 0.21 mm (SD)) was not statistically significant (95% confidence interval; $p = 0.27$).

In the non-impaction group, all 26 teeth went through apical root resorption (Table 3).

Table 3. Mean apical root resorption of non-impaction group according to gender, root shape, and orthodontic treatment duration. NS = not significant.

		Mean ARR	**SD**	
		(mm)		
Gender	Female (N = 12; 46.15%)	0.87	0.24	
	Male (N = 14; 53.85%)	0.76	0.34	
	p	0.18		NS
Root shape	Normal (N = 12; 46.15%)	0.80	0.24	
	Blunt (N = 6; 23.08%)	0.68	0.29	
	Apically bent (N = 5; 19.23%)	0.84	0.43	
	Pipette-shaped root (N = 3; 11.54%)	1.04	0.15	
Orthodontic treatment duration	<24 months (N = 19; 73.08%)	0.72	0.26	
	>24 months (N = 7; 26.92%)	1.04	0.24	
	p	0.10		NS

In female patients (twelve subjects; 46.15%), the mean apical root resorption was 0.87 ± 0.24 mm (SD) while in male patients (fourteen subjects; 53.85%) it was 0.76 ± 0.34 mm (SD) but the difference between the two genders was not statistically significant (95% confidence interval; $p = 0.18$). With regard to root shape, the mean apical root resorption was 0.80 ± 0.24 mm (SD) for canines with a normal root (twelve teeth; 46.15%); 0.68 ± 0.29 mm (SD) for canines with a blunt root (six teeth; 23.08%); 0.84 ± 0.43 mm (SD) for canines apically bent (five teeth; 19.23%); and 1.04 ± 0.15 mm (SD) for canines with a pipette-shaped root (three teeth; 11.54%). In subjects who underwent an orthodontic treatment that lasted less than 24 months (nineteen patients; 73.08%), a mean apical root resorption of 0.72 ± 0.26 mm (SD) was found, while subjects who had an orthodontic therapy that lasted 24 months or more (seven patients; 26.92%) went through a mean apical root resorption of 1.04 ± 0.24 mm (SD). These values were not significantly different from each other (95% confidence interval; $p = 0.10$).

The mean apical root resorption was 1.01 ± 0.33 mm (SD) for the impaction group and 0.81 ± 0.29 mm (SD) for the non-impaction group. It was slightly greater in the impaction group, with a significant difference of 0.2 mm (95% confidence interval; $p = 0.04$).

The difference of mean apical root resorption in impacted teeth and physiologically erupted teeth in relation to their root shape was not statistically significant (95% confidence interval; $p = 0.07$) (Table 4).

Table 4. Mean apical root resorption of impacted teeth and physiologically erupted teeth according to root shape. NS = not significant.

		Mean ARR	SD	
		(mm)		
Root shape	Normal (N = 15)	0.81	0.27	
	Blunt (N = 7)	0.69	0.27	
	Apically bent (N = 9)	0.94	0.37	
	Pipette-shaped root (N = 5)	1.13	0.17	
	p	0.07		NS

4. Discussion

Different studies evaluated the effects of orthodontic treatment on root length based on radiographs [18–21]. In previous studies that compared orthopanoramic radiographs with CBCTs, root resorption was underestimated in panoramic radiographs, while CBCTs exhibited higher sensitivity and specificity [20,22,23]. Extraoral radiographs might be less accurate than other imaging procedures, such as periapical radiographs or 3D images on CT scans to evaluate root resorption [24]. CBCT provides high image quality and allows the operator to precisely measure root and crown length. CBCTs performed before treatment were used to evaluate whether the measurements detected on pre-treatment digital panoramic radiographs were precise. Most patients did not have post-treatment CBCT, because it was not required, in order to avoid further radiation exposure. The decision aimed to prioritize patient safety while acknowledging that CBCT was not a mandatory component of their treatment follow-up protocol. Patients who presented CBCT conducted before the treatment were selected for this study. The calculation method used in this study to quantify the apical root resorption was applied by various authors [21–23].

External apical root resorption is a complex phenomenon encountered during orthodontic treatment and is marked by an inflammatory cascade that culminates in ischemic necrosis localized within the periodontal ligament, upon the application of orthodontic force. This process involves the gradual loss of root structure, a concern that has been extensively explored in the literature. Surprisingly, severe root resorption during orthodontics is reported to be relatively uncommon, affecting only 1–5% of patients, according to existing studies. A study conducted by DeShields in 1969 reported an exceptionally high incidence of root resorption, affecting 99.08% of the patients examined [25]. Such wide-ranging disparities in radiographical findings prompt a closer examination of the variables and assessment methods employed across different studies. The divergent outcomes may be attributed to variations in research protocols, patient populations, and diagnostic techniques utilized for evaluating root resorption. Understanding the mechanisms and predisposing factors associated with external apical root resorption is crucial for orthodontic practitioners. As research continues to refine our comprehension of this phenomenon, clinicians must navigate the delicate balance between achieving optimal tooth movement and minimizing the risk of severe root resorption in orthodontic patients.

Orthodontic tooth movement is accomplished by the simultaneous activation of bone resorption by osteoclasts and bone formation by osteoblasts. When orthodontic forces are applied, bone resorption obtained through the activation of osteoclasts occurs in the alveolar bone on the compression side, thus creating space for tooth displacement. Therefore, controlling the activity of the osteoclast is a key concept in orthodontic treatment; heavy forces do not allow this kind of control. On the tension side where the periodontal ligament is stretched, the work of the osteoblasts is enhanced, which results in osteoid deposition, subsequent mineralization, and eventually, new bone formation.

Prolonged orthodontic treatment necessary for the disinclusion of impacted teeth could be due to the longer distance to reach the occlusion. The duration of orthodontic treatment in the literature has been suggested to contribute significantly to apical root resorption [13].

Teeth with incomplete root formation have a higher resistance to root resorption than those with the root completely developed [26]. In the present study, teeth with roots that were almost at the end of formation and with their apexes not visibly open on radiographs, underwent a mean residual root elongation of about 0.5 mm. This means that the use of light orthodontic forces does not stop root development and allows teeth to reach their final length.

All the patients in the non-impaction group underwent apical root resorption because the mean age was higher than that in the impaction group, so presumably their teeth completed root formation.

The extent of apical root resorption was very limited in both impaction and non-impaction groups, thanks to the application of light and controlled orthodontic forces, and the young age of patients may have contributed to the result. There are conflicting opinions on the correlation between age and root resorption. It was found that in younger patients, the anatomical environment was more favorable because the presence of cementoid and predentine localized on the tooth apex constituted a protective factor [27–32].

Impacted maxillary canines may undergo a slightly higher root resorption (0.2 mm) than physiologically erupted ones, but the extent of resorption never caused serious damage to the root and compromised the prognosis of the tooth. The greater root resorption of impacted teeth is due to the longer distance to reach full occlusion, the prolonged orthodontic treatment, and the higher orthodontic forces. It is not yet possible to know the patient's genetic profile to identify which subjects are more vulnerable to root resorption. Root resorption on teeth adjacent to the impaction site was not evaluated.

There is not enough scientific evidence on the correlation between pain and unwanted tissue damage in response to orthodontic treatment movement. The only evidence available in the literature that clearly investigated this relationship, indicated that there is no correlation between age, sex, volume of the root resorption, and pain analyzed with the visual analog scale during the first seven days of the experimental period, but must be considered with caution, since it is supported by only one study [33]. Other studies presented results suggesting there is a correlation between pain and external apex root resorption, in response to orthodontic treatment movement [34–38]. The only review on the topic by Cuoghi et al., stated that pain and unintended root damage during orthodontic treatment was associated with mechanical stimuli and similar biological events, and that the correlations between these variables are not yet fully understood [39]. However, pain was not evaluated in the present study. Future studies should go deeper in this topic. The study may have some limitations: the measurements were performed by a single researcher. Some teeth may have not fully completed the root formation, even if the apex appeared closed in the CBCTs. In future studies the sample size could be increased, to obtain results that could be more statistically significant.

5. Conclusions

(1) Light orthodontic forces seem to allow teeth with incomplete root formation to reach their final length. In the present study the mean residual root elongation was limited to 0.5 mm; thus, confirming that the examined teeth were almost at the end of their root development.

(2) Gender and orthodontic treatment duration do not seem to have influenced root elongation.

(3) Gender, root shape, and orthodontic treatment duration do not significantly influence the extent of apical root resorption of maxillary canines.

(4) Impacted teeth which underwent surgical exposure and orthodontic traction had a similar level of root resorption to physiologically erupted teeth, with a difference of 0.2 mm. The extent of root resorption of impacted teeth was significantly higher than that of physiologically erupted teeth. However, this differential resorption has never been, such as to compromise the structural and functional integrity of the involved tooth (root shortening corresponded approximately to 4.5% of the total length of impacted teeth).

(5) External apical root resorption is a multifactorial phenomenon; therefore, radiographic control should be carried out routinely, especially in patients with orthodontic treatment exceeding six months. Panoramic radiographs can be used to evaluate it [24].
(6) Patients reporting pain during orthodontic treatment has never been investigated clearly to occur as a consequence of external apical root resorption, because of the lack of well-structured studies. During clinical practice, the orthodontist does not have clinical parameters that allow evaluating the intensity of force applied to different areas of the periodontal ligament. This means that analyzing the external apical root resorption during treatment and not after treatment is clearly difficult. Thus, pain during orthodontic treatment can be used as a clinical parameter for the use of biologically correct mechanical forces, minimizing the occurrence of tissue damage during therapy.

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