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ORIGINAL ARTICLE

Pre-treatment radiographic features predict root resorption of treated impacted maxillary central incisors

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Structured Abstract
Objectives – To determine independent predictors of root resorption for surgical-orthodontic treatment of impacted maxillary central incisors.
Setting and Sample Population – The Department of Dentistry at Show Chwan Hospital, Changhua, Taiwan. Eighty patients with unilateral osseous–impacted maxillary central incisors receiving a surgical-orthodontic treatment.
Material and Methods – This is a retrospective observational study. Root resorption and its predictors were abstracted from patients' charts, pre-treatment cephalometric radiographs, and post-treatment periapical radiographs. Predictors included demographics, treatment duration, crown angle, crown height, crown depth, and root dilacerations.
Results – The patients' mean age was 9.2 ± 2.3 years (6.4–20.6 years), and 60% were females. Impacted maxillary central incisors had greater root resorption than naturally erupted contralateral incisors ($\Delta = -2.8$ mm, $p < 0.001$). Independent predictors of root resorption for impacted maxillary central incisors were shown by linear regression analysis to be crown height ($\beta = -0.2$, $p < 0.01$), crown depth ($\beta = -0.3$, $p = 0.001$), treatment duration ($\beta = 0.2$, $p < 0.01$), and root dilacerations ($\beta = 3.1$, $p = 0.001$).
Conclusions – Impacted maxillary central incisors had greater root resorption during surgical-orthodontic treatment than their naturally erupted contralateral incisors. Predictors of a greater root resorption were highly and deeply impacted incisors, longer treatment, and root dilacerations. These predictors may help to inform patient and family counseling before treatment.

Key words: cephalometry; impacted incisors; orthodontic traction; predictors; root dilaceration; root resorption; surgical exposure; surgical-orthodontic treatment

Introduction

In the anterior maxillary region, the most frequently impacted tooth is the maxillary canine, with an incidence of 1–3% (1). The second most common maxillary impaction is the central incisor.

Canines are most often impacted palatally, but this is not the case for central incisors.

The presence of maxillary central incisors is an issue for patients and their family because of esthetics and related emotional concerns (2, 3). An alternative approach to extraction has been to surgically expose impacted incisors and orthodontically extrude the incisors to their final position in the dental arch. Aligning an impacted incisor from a difficult radiographic position is now possible with current fixed orthodontic techniques (4–9).

A common outcome of orthodontic treatment is root resorption. For example, some level of root resorption has been found in most patients (10–13). Most resorption is clinically insignificant, but if severe, it may threaten the longevity of the teeth (14, 15). The reported extent of root resorption varies widely, with mean values ranging from 0.5 to 3 mm during treatment (16–18). Similarly, the frequency of severe apical root resorption has varied from 5 to 18% (17–21). Most studies (11, 22–24) on root resorption and its relationship with orthodontic treatment have found root resorption to be associated with multiple factors, including age, gender, nutrition, genetics, type of appliance, amount of force used during treatment, duration of treatment, and the distance the teeth are moved. Generally, the causes and mechanism of resorption are still unclear.

Little is known about root resorption during surgical-orthodontic treatment of impacted teeth. Some level of root resorption was found in 22 impacted canines (25), and nearly a millimetre more root resorption was reported for 30 impacted central incisors than for naturally erupted contralateral incisors (26). However, both studies were conducted on small samples. Root resorption studies are needed on larger samples to learn as much as possible about the causes, effects, and prevention of this phenomenon. The aims of this study were therefore to 1) evaluate the root resorption of unilateral osseous–impacted maxillary central incisors treated by a combined surgical-orthodontic treatment in comparison with naturally erupted contralateral incisors and to 2) identify predictors of root resorption.

Material and methods

Design and patients

In this retrospective study, we analyzed patient records over 20 years from the Department of Dentistry, Show Chwan Hospital, Changhua, Taiwan. The hospital's ethical committee approved the study protocol. Patients were included if they met these criteria: 1) unilateral osseous–impacted maxillary central incisor treated by a surgical-orthodontic approach (impaction was diagnosed as the absence of one permanent incisor when its contralateral incisor had been erupted for at least 6 months and confirmed by radiographs); 2) complete diagnostic and treatment notes; 3) pre-treatment and post-treatment panoramic, cephalometric and periapical radiographs, photographs, and dental casts; and 4) no mechanical obstacle to eruption, such as supernumerary teeth, tumors, odontoma, or cysts.

The study population consisted of 80 patients, 32 males and 48 females, ranging in age from 6.4 to 20.6 years. None had suffered a traumatic injury to the anterior region of the oral cavity. Five had supernumerary teeth and two had odontomas removal at least 6 months before surgical-orthodontic treatment. The clinical characteristics are described in Table 1.

Impacted maxillary central incisors were always treated with a standardized combined surgical-orthodontic approach by the same orthodontist (KHH) and two periodontists. All patients received standard orthodontic edgewise appliances with a 0.018-inch slot. The incisors were exposed by a flap, and a closed- or open-eruption technique was used for deeply impacted incisors and for labially and not far apically impacted incisors, respectively. A bonded attachment device was applied during surgery, and orthodontic traction force was applied 1–2 weeks after surgery (sutures were removed on the seventh postoperative day) to guide the impacted central incisor toward the center of the alveolar ridge. The traction force measured with a tension gauge was approximately 100 g.

Patients were recalled every 4 weeks to adjust their appliance and monitor their oral hygiene. A 0.017×0.022 inch Elgiloy wire with 2 L loops is

Table 1. **Patients' characteristics (N = 80)**

Characteristic	n (%)	Mean (SD)	Range
Gender			
Male	32 (40)		
Female	48 (60)		
Age, years		9.2 (2.3)	6.4–20.6
Location of impaction			
Right	35 (44)		
Left	45 (56)		
Root dilaceration			
Yes	16 (20)		
No	64 (80)		
Surgical exposure technique			
Open eruption	51 (64)		
Closed eruption	29 (36)		
Mean orthodontic traction time, months		8.0 (4.5)	2.0–24.1
Mean follow-up time, months		21.8 (28.6)	6.0–146.1

sometimes necessary to tip and torque the root of the incisor to attain proper root and crown angulation. For dilacerated incisors, special care was taken not to expose the root despite an insufficient torque. When the erupting incisor was properly aligned within the dental arch, the patients were discharged with Hawley's retainers. During the follow-up period, the patients were recalled every 3–6 months for professional hygiene and orthodontic control.

Treatment history

Patients' charts were reviewed for the following information: age, gender, banding/bonding date, surgical exposure date, surgical exposure technique, debanding/debonding date of the upper arch or full-mouth fixed appliances, and pulp vitality.

Cephalometric evaluation

All pre-treatment cephalometric radiographs were traced by an experienced orthodontist on acetate tracing paper with a 0.3-mm diameter pencil. The tracing papers were then scanned and digitized and the following variables were measured:

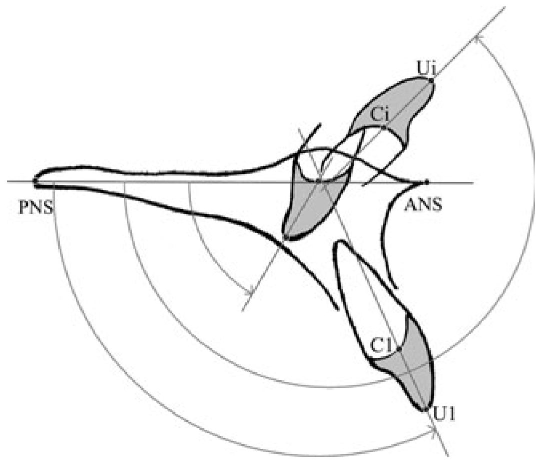

Fig. 1. Cephalometric radiograph showing the measured crown angle. Crown angle: angle between the crown axis of the maxillary central incisor and the palatal plane (from the ANS to the PNS). Ui-Ci and U1-C1, crown axes of the impacted and erupted maxillary central incisors, respectively; Ui and U1, incisal tips of the impacted and erupted maxillary central incisors, respectively; Ci and C1, centers of crown cervices of the impacted and erupted maxillary central incisors, respectively; ANS, anterior nasal spine; PNS, posterior nasal spine.

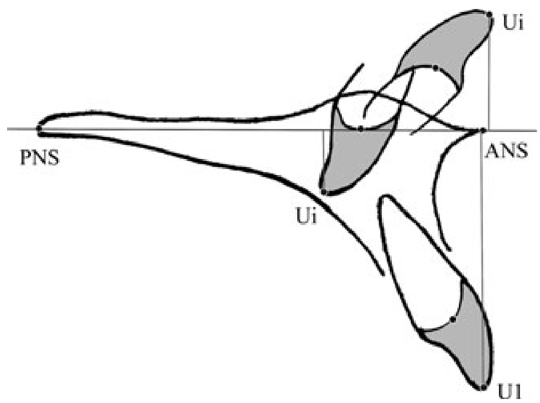

Fig. 2. Cephalometric radiograph showing the measured crown height. Crown height: distance between the incisal tip of the maxillary central incisor and the palatal plane (from the ANS to the PNS). Ui and U1: incisal tips of the impacted and erupted maxillary central incisors, respectively. Positive and negative signs indicate Ui or U1 located below and above the palatal plane, respectively.

1. crown angle: angle between the crown axis of the maxillary central incisor and the palatal plane (from the ANS to the PNS), to determine the inclination of the maxillary central incisor (Fig. 1),
2. crown height: distance between the incisal tip of the maxillary central incisor and the palatal plane (Fig. 2),
3. crown depth: distance between the incisal tip of the maxillary central incisor and the facial plane (from point N to the Pog) (Fig. 3).

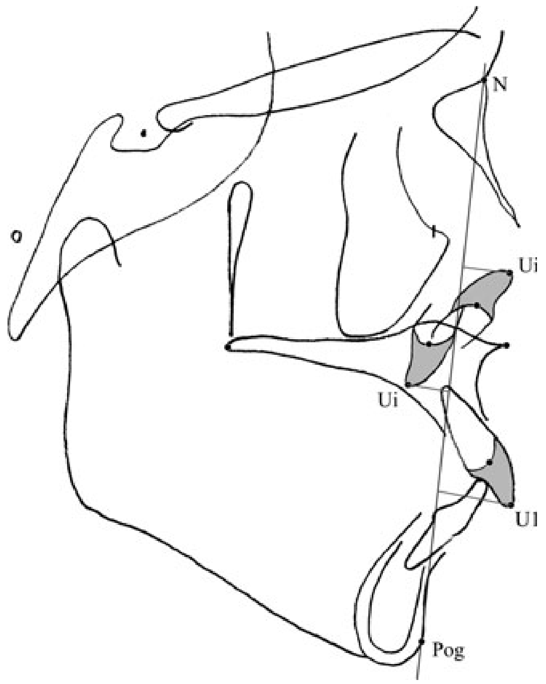

Fig. 3. Cephalometric radiograph showing the measured crown depth. Crown depth: distance between the incisal tip of the maxillary central incisor and the facial plane (from point N to the Pog). Ui and U1: incisal tips of the impacted and erupted maxillary central incisors, respectively. N: nasion. Pog: pogonion. Positive and negative signs indicate Ui or U1 located in front of and behind the facial plane, respectively.

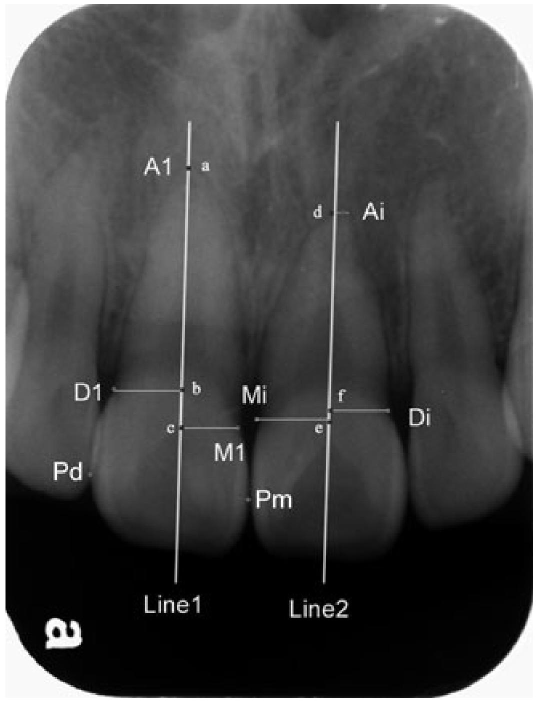

Fig. 4. Periapical radiograph showing measured root length and crown width. Root length of erupted maxillary central incisor = [(distance between a and b) + (distance between a and c)]/2. Root length of extruded maxillary central incisor = [(distance between d and e) + (distance between d and f)]/2. Crown width of the erupted maxillary central incisor: distance between Pd and Pm. Line 1 and Line 2: long axes of the erupted and extruded maxillary central incisors, respectively. a: intersection of A1 with Line 1. b: intersection of D1 with Line 1. c: intersection of M1 with Line 1. d: intersection of Ai with Line 2. e: intersection of Mi with Line 2. f: intersection of Di with Line 2. A1 and Ai: tooth apices of the erupted and extruded maxillary central incisors, respectively. M1 and Mi: mesial cement–enamel junctions of the erupted and extruded maxillary central incisors, respectively. D1 and Di: distal cement–enamel junctions of the erupted and extruded maxillary central incisors, respectively. Pd and Pm: distal and mesial contours, respectively, of the erupted maxillary central incisor.

Radiographic evaluation

Post-treatment periapical radiographs were scanned and viewed at double magnification on a large color monitor with 0.25-dot pitch fineness. We considered the following radiographic variables: 1) root length (Fig. 4), 2) crown width (Fig. 4), and 3) presence of periapical radiolucency.

Dental cast evaluation

Post-treatment dental casts were used to measure the crown widths of erupted maxillary central incisors. Crown width (Fig. 5) was used as a normalization factor to account for different angulation and magnification between periapical radiographs when calculating root lengths in the extruded and erupted incisors (Fig. 6). Thus, root resorption was calculated as root length in the erupted incisor minus root length in the extruded incisor.

To reduce method error, all measurements were repeated by the same investigator (KHH) on three

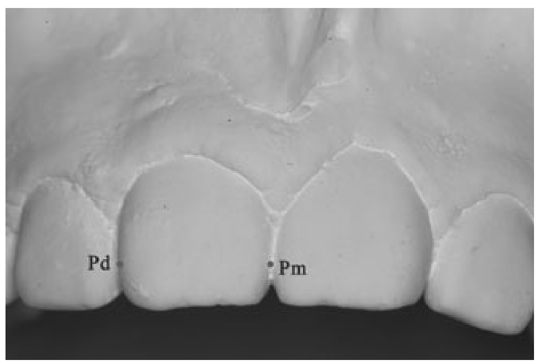

Fig. 5. Dental cast showing the measured crown width of the erupted maxillary central incisor. Crown width: distance between Pd and Pm. Pd and Pm: distal and mesial contours, respectively, of the erupted maxillary central incisor.

$$RL = RL_r \times \frac{CW_d}{CW_r}$$

Fig. 6. Calculation of root lengths in the extruded and erupted incisors. RL: root length. RL_r: root length in the periapical radiograph. CW_d: crown width in the dental cast. CW_r: crown width in the periapical radiograph.

separate occasions at 1-week intervals, and the nearest two values were averaged.

Statistical analysis

Descriptive statistics are expressed as means ± SD for metric variables and as frequency and percentage for nominal variables. Groups were compared using paired t-test, Mann–Whitney U, chi-square, or Fisher's exact test when indicated. Multiple linear regression analysis was used to evaluate the role of demographics, treatment duration, and pre-treatment radiographic factors in root resorption. Statistical analyses were carried out using SPSS v 17.0 (Chicago, IL, USA). All p-values reported are two-tailed, with statistical significance set at 0.05.

Results

General

The study sample consisted of 80 patients, 32 males and 48 females, with a mean age of 9.2 ± 2.3 years (range 6.4–20.6). Their clinical characteristics are described in Table 1. None of the patients complained of significant discomfort. All 80 impacted central incisors were successfully moved and aligned in the dental arch with no loss of pulp vitality. The mean duration of orthodontic traction (time between applying the traction device and good alignment of the impacted incisor in the dental arch) was 8.0 ± 4.5 months.

Root resorption

The extruded central incisors had greater root resorption than the naturally erupted incisors ($\Delta = -2.8$ mm, $p < 0.001$) (Table 2). The majority of extruded central incisors with no root dilaceration had <3 mm of root resorption (Table 3).

Table 2. **Comparison of root lengths between extruded and erupted maxillary central incisors**

		Extruded		Erupted		
		Root length, mm				
	n	Mean	SD	Mean	SD	p
All	80	10.9	3.5	13.7	2.9	<0.001*
No dilaceration	64	12.2	3.0	14.0	2.9	<0.001*
Dilaceration	16	7.5	2.5	12.8	2.9	0.001†

*Paired t-test.
†Mann–Whitney U-test.

Table 3. **Distribution of root resorption for extruded maxillary central incisors by severity (from <3 to >5 mm)**

	Root resorption, n (%)			
	<3 mm	3–5 mm	>5 mm	p
All	46 (58)	21 (26)	13 (16)	<0.001*
No dilaceration	44 (69)	16 (25)	4 (6)	<0.001*
Dilaceration	2 (13)	5 (31)	9 (56)	0.1†

*Chi-square test.
† Fisher's exact test.

Linear regression revealed that root resorption was related to crown height ($\beta = -0.2$, $p < 0.01$), crown depth ($\beta = -0.3$, $p = 0.001$), treatment duration ($\beta = 0.2$, $p < 0.01$), and root dilaceration ($\beta = 3.1$, $p = 0.001$) (Table 4).

Discussion

Our study revealed some interesting findings on the relationship between crown height and crown depth of extruded maxillary incisors. In other words, the greater the distance (vertical and horizontal) that the teeth were moved, the greater their root resorption. This finding is consistent with a previous finding that root resorption was associated with distance the teeth are moved (22). Our data also showed that treatment duration significantly influenced resorption after treatment. Hence, a patient undergoing a long orthodontic treatment may well be susceptible to root resorption, as previously reported (22, 23, 27). In fact, one study of 31 variables found that treatment

Table 4. **Linear regression model for the root resorption of 80 treated patients**

	Root resorption, mm			
Independent variable	Regression coefficient*	Standard error	95% Confidence limit	p
Intercept	0.7	2.1	(−3.5, 4.9)	0.7
Δ Crown angle, †degrees	0.01	0.01	(−0.01, 0.03)	0.5
Δ Crown height, †mm	−0.2	0.1	(−0.3, −0.1)	0.002
Δ Crown depth, †mm	−0.3	0.1	(−0.4, −0.1)	0.001
Age, years	0.1	0.2	(−0.4, 0.5)	0.7
Gender	0.1	0.6	(−1.0, 1.3)	0.8
Root dilaceration	3.1	0.9	(1.3, 4.9)	0.001
Exposure technique	0.4	0.6	(−0.7, 1.6)	0.5
Orthodontic traction, months	0.2	0.1	(0.1, 0.4)	0.003

Crown angle: angle between the incisor's crown axis and the palatal plane. Crown height: distance between the incisor's incisal edge and the palatal plane. Crown depth: distance between the incisor's incisal edge and the facial plane. Age: age at start of traction of the impacted tooth. Gender: 1, male; 0, female. Root dilaceration: 1, dilacerations; 0, no dilaceration. Exposure technique: 1, closed eruption; 0, open eruption.

*Mean difference of root resorption (mm) with one more unit in the explanatory variable than another.

†Extruded minus erupted.

duration was the factor most highly correlated with root resorption in maxillary incisors (27).

This study found no significant difference in root resorption between male and female patients, in contrast to some reports (28, 29) that females have more resorption than males, but in agreement with most other research (23, 30–34).

Age is believed to be an important factor related to root resorption because older patients have reduced ability to repair root resorption. However, our study found no difference in age for root resorption of maxillary central incisors, in agreement with recent large-scale studies (32, 34). In contrast, among 719 orthodontic patients, those starting treatment after 11 years of age were found to experience significantly greater root resorption than those starting earlier (35).

In our study, cases involving root dilacerations tended to have greater root resorption (Δ = 3.1 mm, Table 4) even with the same treatment duration which is in agreement with previous studies (32, 34–36). A high incidence of dysmorphic roots was also found in patients with severe root resorption (29). No evidence is available to understand why a dilacerated root would resorb more easily, but a strong possibility is the anatomical structure of dilacerated incisors and anterior maxilla. That is, when dilacerated incisors are extruded, the root apices tend to contact the cortex, and this root–cortex contact was found to be an important factor in root resorption after orthodontic treatment (37). Another possibility is that the deviant process that caused the short root would lead to root resorption. In other words, the dilacerated incisors lack the root length of normally erupting incisors, and this difference results from developmental differences rather than resorptive differences.

These predictors of a greater root resorption assessed at the pre-treatment radiographic features may help to inform patient and family counseling before treatment. Further research might analyze improvement of diagnostic radiologic approaches to impacted maxillary central incisors by using recently developed technology such as cone-beam computed tomography. Such techniques could help in visualizing aspects related to impacted central incisors (three-dimensional location, root dilaceration, root resorption, ankylosis) that may assist in treatment planning.

Conclusions

Impacted maxillary central incisors have greater root resorption during surgical-orthodontic treatment than their naturally erupted contralateral incisors. Highly and deeply impacted incisors, longer treatment, and root dilacerations were predictors for greater root resorption.

Clinical relevance

Evaluation of root resorption of impacted maxillary central incisors following surgical-orthodontic treatment would be helpful to find predictors that could be assessed at the pre-treatment radiographic features. This study showed that predictors for root resorption were highly and deeply impacted incisors, longer treatment, and root dilacerations.

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