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ORIGINAL RESEARCH

Alveolar bone retention following treatment of dilacerated labial inversely impacted maxillary central incisors—a retrospective study

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Abstract

The root of late-dental-age labial inversely impacted maxillary central incisors (LIIMCIs) typically develops to severe dilacerated morphology. Therefore, reliable posttreatment periodontal estimates of orthodontic treatment prognosis would be critical to the treatment value of impacted incisors. This study aims to analyze further changes in dimensions of the alveolar bone following the closed-eruption treatment of late-dental-age dilacerated LIIMCIs. Cone beam computed tomography (CBCT) scanning data of 16 patients with unilateral dilacerated late-dental-age LIIMCIs were collected, including the pretreatment (T1) and at the 2.23 ± 0.78 years follow-up stage (T2) respectively. Patients underwent closed-eruption treatments to bring the impacted incisor into the dental arch. Dolphin imaging software was used to measure alveolar bone height labially, palatally, and proximally to the site at T1 and T2, as well as alveolar bone thicknesses at 0, 2, 4, 6 and 8 mm below the initial measurement plane (IMP). The alveolar bone heights on the impacted and contralateral sides increased from T1 to T2 ($p < 0.05$). Alveolar bone growth on both sides had no significant difference. In T2, the mean values of labial and distal alveolar heights on the contralateral sides were greater than on the impacted sides ($p < 0.05$). The mean values of total alveolar bone thicknesses on the impacted sides in T1 were significantly smaller than those on the contralateral sides in IMP-0, 2, 4, 6, 8 ($p < 0.05$). The total thicknesses on the impacted sides in T2 increased and were significantly greater than on the contralateral sides ($p < 0.05$), except for the thickness in IMP-0. The closed-eruption treatment of dilacerated late-dental-age LIIMCIs results in no significant changes to alveolar bone height, except on the labial and distal sides, with increased alveolar bone thickness, suggesting that this approach may be viable first choice therapy for non-extraction orthodontic cases.

Keywords

Impacted tooth; Dilaceration; Incisors; Alveolar bone; Prognostic value; Cone beam computed tomography

1. Introduction

Dilaceration is a deviation or bend in the linear relationship between the tooth crown and root, the angle of dilaceration being equal to or greater than 90° in the root or crown of a developed tooth. It is widely accepted to be caused by trauma in the deciduous dentition, or other factors, such as idiopathic developmental disturbances, presence of cysts, supernumerary teeth, odontoma and *et al.* [1, 2]. The labial inversely impacted maxillary central incisor (LIIMCI), with its crown directing upwards and its palatal aspect facing the labial, has a low incidence of occurrence (0.06% to 0.20%) [3]; and is often accompanied by a dilacerated root [4].

Dilaceration is also a key factor in the long treatment duration and treatment failure of impacted incisors. Summarizing data from studies, impacted central incisor root dilaceration was significantly associated with root resorption [5], ankylosis, loss of attachment and/or root exposure following orthodontic traction [1], and had a longer eruption time in comparison to those without root dilacerations [5–7]. Therefore, some dentists may choose alternative treatment methods, such as surgical repositioning [8], crown rotation surgery [9], extraction and prosthetic replacement [10]. The main practical problem confronting clinicians is whether the treatment of dilacerated LIIMCIs is warranted.

Alveolar bone morphology is closely related to aesthetics and tooth stability. Several researchers have investigated changes in alveolar bone after treatment of impacted incisors, with varying results between studies. Calil and Shi [11, 12] reported labial bone resorption after treatment; however, Hu [13] reported that labial bone loss at impacted incisors did not differ from that of contralateral incisors during the follow-up period. There are some biases in these studies: subjects of all dental ages and with impacted incisors in all positions were included, potentially ignoring the high probability of dilacerated roots penetrating the labial cortical plate in LIIMCIs. Also, pre-treatment alveolar bone dimensions were not measured; therefore, the effect of treatment on the alveolar bone cannot be determined. We therefore hypothesize that alveolar bone dimensions in the impacted incisor zone would increase following closed-eruption treatment. The aim of this study was to analyze and compare alveolar bone dimensions of treated dilacerated LIIMCIs with the contralateral incisors, through long-term follow-up.

2. Materials and methods

2.1 Treatment procedure

This is a retrospective study. A total of 16 patients were diagnosed with LIIMCIs and treated by the same orthodontic specialist (R.H.) using the Guide rod appliance developed by Rongdang Hu [13] (Fig. 1). They received long-term follow-up for approximately 2 years at the Department of Orthodontics, School and Hospital of Stomatology, Wenzhou Medical University, from 2002 to 2020.

A bracket was bonded to the crown of the impacted incisor during surgery. This bracket was then tied to the Guide rod appliance using an orthodontic elastomeric chain (639-0002; Ormco, Orange, Calif), for orthodontic traction. The hook of the appliance was adjusted in three-dimensions, according to the movement of the impacted teeth, providing reasonable traction force on the impacted crown. As the crown erupted into the oral cavity, the button was rebonded on the labial surface of the incisor. At the same time, the space in the arch was opened, potentially shortening treatment duration. The closed-eruption treatment was considered complete, when the impacted incisor was well aligned with the adjacent teeth.

Pretreatment (T1) and two-year follow-up (T2) cone beam computed tomography (CBCT) scans were obtained for each patient. CBCT scans were obtained using a New-Tom machine (QRs.r.1., Verona, Italy). Typical imaging protocols were as follows: 110 KV, 1–20 mA (pulse mode), 26-second scanning time with an axial width of 0.25 mm; the field of view was 15 × 15 cm and the voxel size was 0.30 × 0.25 × 0.25 mm. The data generated from NNT Workstation software was imported into Dolphin Imaging 3D software version 11.8 (Patterson Supply, St Paul, Minn, USA) for 3D reconstruction.

2.2 Study sample

The protocol used in this study have not previously been reported in the literature. Sample size was estimated using G*Power (version 3.1.9, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) [14, 15]. Based on the primary outcome of the pilot analysis, 5 subjects were included in this study. The mean difference in labial alveolar bone height between the LIIMCIs and contralateral incisors was 2.56 ± 2.20 mm. Sample size calculation indicated that 12 subjects were necessary to achieve reliable results (95% power; 5% significance level; 2-tailed). Finally, 16 patients were included according to the following criteria, thus exceeding the required minimum sample size.

The inclusion criteria for the patients were: (1) had been diagnosed and successfully treated for unilateral LIIMCI; (2) received posttreatment follow-up for about 2 years; (3) the dental age of impacted incisors was at stage 8–10 before treatment (dental age was assessed according to the method of Nolla) [16]; (4) clear posttreatment and follow-up CBCT images; (5) the contralateral incisor erupted with normal root morphology; (6) completed informed consent form signed by the guardians of all children. The exclusion criteria were: (1) the presence of other oral and maxillofacial diseases; (2) the presence of any systemic disease.

2.3 Measurement method

CBCT scans of the maxillary lateral incisors on the impacted (IS) and contralateral (CS) sides were evaluated, including pretreatment (T1) and follow-up (T2) stages. Before measurement, we adjusted the three reference planes to make the head symmetrical, to eliminate measurement errors [17]. Our reference points, lines and measurement variables are described in Table 1.

The root morphology and position of the incisors before treatment were described as previously reported by Sun *et al.* [2], including root and crown length, dilaceration angle, inverse angle and dental age. The dilacerated root was divided into two parts: the direct part and the dilacerated part (Fig. 2). The presence of fenestration and the direction of the root apex were also assessed in the follow-up images.

In CBCT images, the incisor is inclined mesially or distally. The sagittal slice of the alveolar bone measurement is set parallel to the midsagittal plane and passes the maxillary central incisor where the incisor has a maximum labial-lingual width. To make the alveolar bone on the impacted side comparable before and after treatment, an initial measurement plane-IMP-was defined as follows: vertically to the midsagittal slice, the long axis of the contralateral incisor measurement, and passing through the anterior nasal spine (ANS). Because the palatal morphology is curved and the position of the central incisors is asymmetrical, the ANS point does not appear in the image when the sagittal slice passes the incisor (Fig. 3).

Alveolar bone morphology includes bone height around the maxillary central incisor and labial-palatal thickness. Alveolar heights were measured in the labial (LH), palatal (PH), distal (DH) and mesial (MH) aspects of the impacted and contralateral sides (Fig. 4). The D-values of T1 and T2 on each side were compared. Starting from the IMP, vertically to the sagittal slices, the labial (LBT) and palatal (PBT) alveolar bone thicknesses were measured in the axial slice every 2 mm (0, 2, 4, 6, 8 mm) downward, and the sum was recorded as the total alveolar bone thickness (Fig. 5).

All measurements were taken twice within 2 weeks by the same examiner.

2.4 Statistical analysis

Two examiners independently repeated all measurements at two-week intervals. Interclass corrections (ICCs) were used to determine intra-examiner errors. The mean of the 2 measurements was used as the final result, and the results are expressed

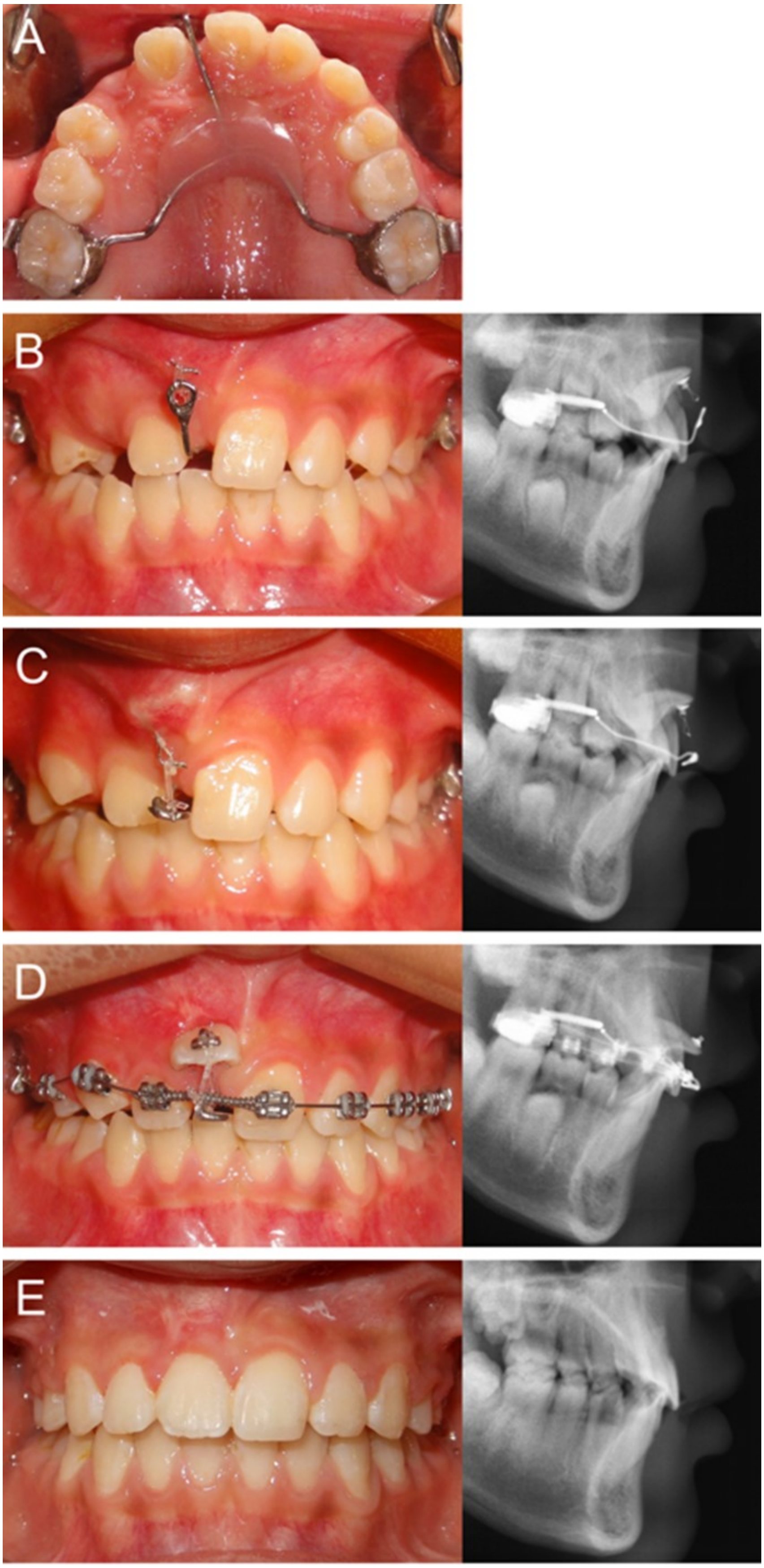

FIGURE 1. Guide rod appliance used in treating a LIIMCI. (A) Occlusal view of Guide rod appliance. (B) Postsurgical view after a button was bonded to the crown and tied to the Guide rod appliance with orthodontic elastomeric chain. (C) The hook adjusted according to the direction of the crown shown in the X-ray. (D) Crown exposure, and the button rebonded on the labial aspect, with simultaneous space opening. (E) The erupting incisor was properly aligned in the dental arch.

TABLE 1. Definitions of measurements and landmarks used in this study.

Measurement variable	Definition
a	Incisal edge of the maxillary central incisor (see Fig. 2)
b	Midpoint of the line where the root bends (see Fig. 2)
c	Midpoint of the line connecting the cementoenamel junction (CEJ) on the labial and palatal sides (see Fig. 2)
d	Root apex of the maxillary central incisor (see Fig. 2)
e	Root apex of contralateral incisor in sagittal slice (see Fig. 3)
f	Incisal edge of contralateral incisor in sagittal slice (see Fig. 3)
Direct root length	Root length before root direction change: distance from b to c
Dilacerated root length	Root length after root direction change: distance from c to d
Dilaceration angle	Angle between the 2 parts of the root: ∠bcd
Inverse angle	Anterior upper angle between the long the axis of the crown and palatal plane
IMP	Initial measurement plane: Vertically to the midsagittal slice and the contralateral incisor measurement long axis, and passing through the anterior nasal spine (ANS) point
LH	Labial alveolar bone height: the shortest distance from the labial alveolar bone crest to IMP
PH	Palatal alveolar bone height: the shortest distance from the palatal alveolar bone crest to IMP
MH	Mesial alveolar bone height: the shortest distance from the mesial alveolar bone crest to IMP
DH	Distal alveolar bone height: the shortest distance from the distal alveolar bone crest to IMP
IMP-0/2/4/6/8	Total thickness of the alveolar crest 0/2/4/6/8 mm under IMP
LBT-0/2/4/6/8	Labial bone thickness 0/2/4/6/8 mm under IMP
PBT-0/2/4/6/8	Palatal bone thickness 0/2/4/6/8 mm under IMP

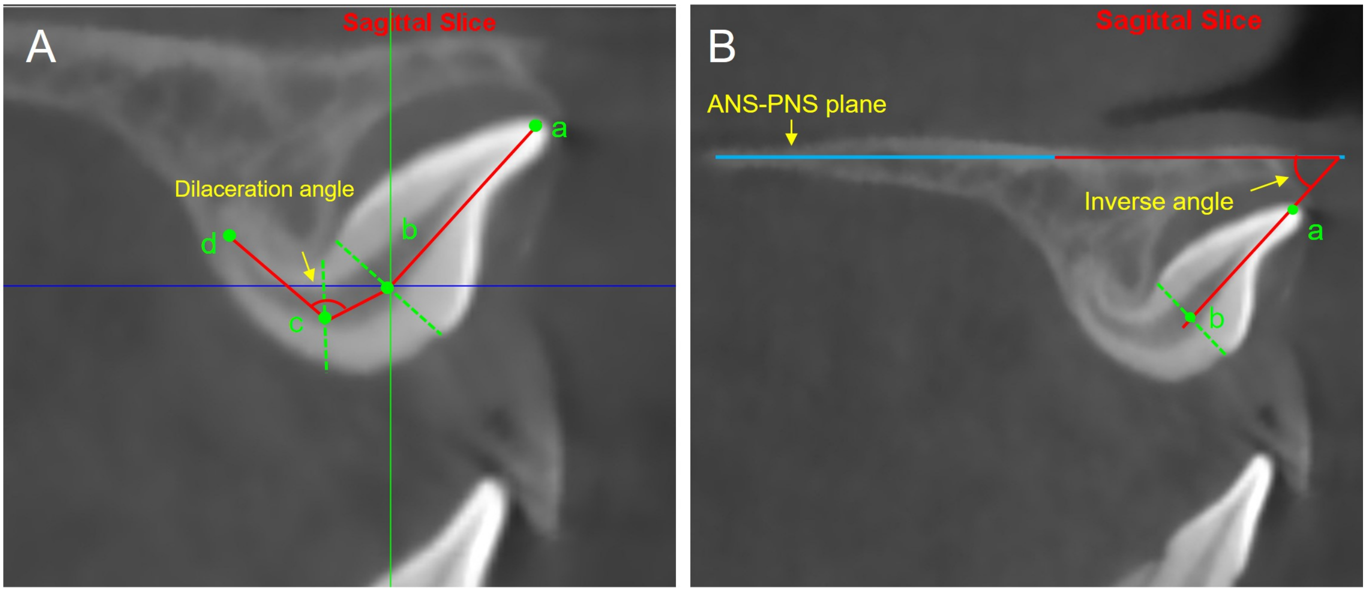

FIGURE 2. Illustration of measurements used for the morphological description of LIIMCIs at T1. (A) Sagittal slice passes through the long axis of the tooth. (B) Sagittal slice is parallel to the midsagittal plane. a, incisal edge of the maxillary central incisor; b, midpoint of line connecting the cementoenamel junction (CEJ) on the labial and palatal aspects; c, midpoint of line where the root bends; d, root apex of maxillary central incisor. ANS: anterior nasal spine; PNS: posterior nasal spine.

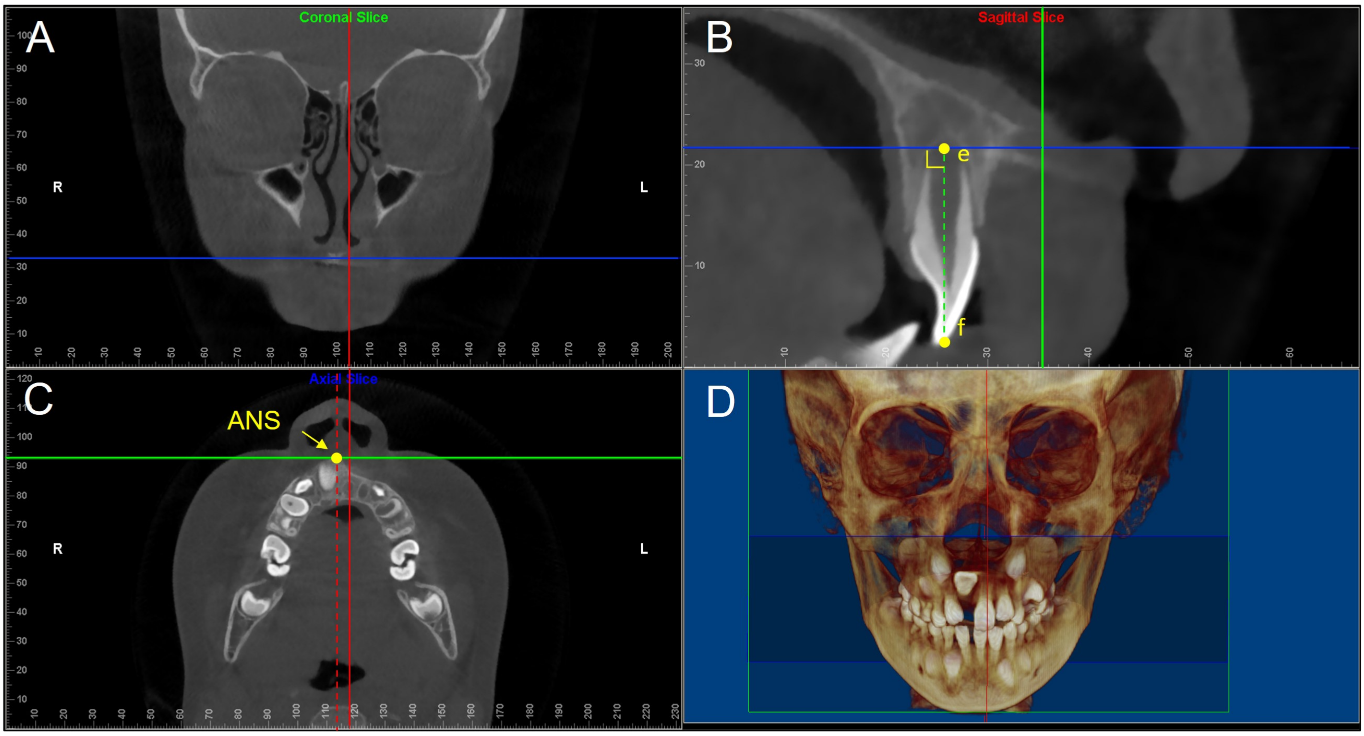

FIGURE 3. Illustration of the measurement reference planes of the alveolar bone. This figure was captured from a CBCT image of one patient at T1. (A) Coronal section slice. (B) Sagittal section slice is parallel to the midsagittal plane and passes the maxillary contralateral incisor, on which the incisor has a maximum labial-lingual width. e, root apex of contralateral incisor in sagittal slice; f, incisal edge of incisor in sagittal slice; ef, tooth measurement long axis, vertically to the initial measurement plane (IMP). (C) Axial section slice, corresponding to IMP, vertically to midsagittal plane (red dotted line) and ef, and passing through the anterior nasal spine (ANS) point. (D) 3D reconstruction of the maxillofacial region.

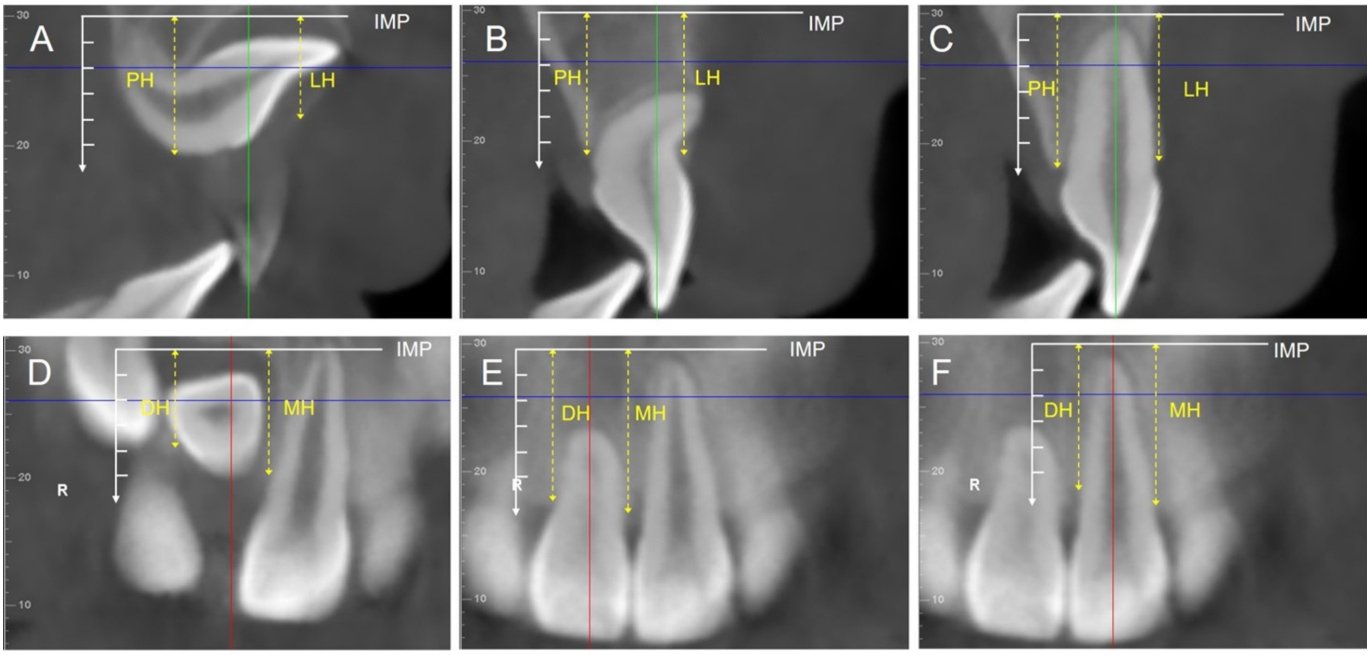

FIGURE 4. Illustration of alveolar bone height measurements. (A,D) Sagittal slice in impacted quadrant at T1. (B,E) Sagittal slice in impacted side at T2. (C,F) Sagittal slice in contralateral side at T2. (A–C) LH, vertical distance from labial alveolar bone crest to IMP represents labial alveolar bone height; PH, vertical distance from palatal alveolar bone crest to IMP represents palatal alveolar bone height. (D–F) MH, vertical distance from mesial alveolar bone crest to IMP represents mesial alveolar bone height; DH, vertical distance from distal alveolar bone crest to IMP represents distal alveolar bone height. IMP: initial measurement plane.

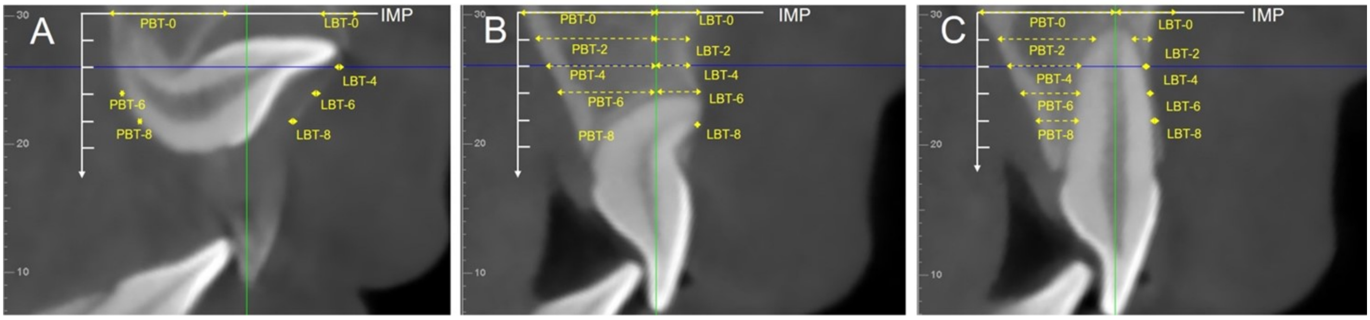

FIGURE 5. Illustration of alveolar bone thickness measurements used in this study. (A) Sagittal slice in impacted side at T1. (B) Sagittal slice in impacted side at T2. (C) Sagittal slice in contralateral side at T2. LBT-0/2/4/6/8 mm, labial alveolar bone thickness every 0/2/4/6/8 mm below the IMP; PBT-0/2/4/6/8 mm, palatal alveolar bone thickness every 0/2/4/6/8 mm below the IMP. IMP: initial measurement plane.

as means with standard deviations (SD). The Wilcoxon signed-rank test was used to compare the measurements. All statistical analyses were performed using Statistical Product and Service Solutions (SPSS) statistical software (version 18.0; SPSS, Chicago, IL, USA).

3. Results

3.1 Sample characteristics

This study finally included 16 patients, 9 males and 7 females, with a mean age of 8.71 ± 1.78 years at the beginning of treatment. After 1.57 ± 0.67 years of treatment, the impacted incisors successfully erupted to the correct position with the presence of periodontal membrane space, and the tooth pulp vitality can be detected. Patients were reassessed with a CBCT scan after 2.23 ± 0.78 years.

The interclass correction coefficient was 0.849, indicating good intra-examiner reliability.

All unliteral central incisors were impacted with a dilacerated root before treatment; the root morphology and the position of the incisors before and after treatment are described in Table 2. Based on the Nolla classification, 7 impacted incisors reached stage 8, 8 impacted incisors reached stage 9, and 1 impacted incisor reached stage 10. The presence of fenestration was found in 12 patients after treatment. The root apices of 8/16 impacted incisors were labially oriented and 8/16 root apices of impacted incisors were palatally oriented.

3.2 Alveolar bone height alterations

The results of the alveolar bone heights in the impacted and contralateral sides at T1 and T2 are presented in Table 3.

There was a significant increase in labial, palatal, mesial and distal alveolar bone heights in the impacted and contralateral sides after treatment ($p < 0.05$); the D-value of T2 and T1 shows that alveolar bone growth in the impacted side is significantly greater than that in the contralateral side.

At T1, the distal alveolar height in the impacted side is less than that in the contralateral side ($p = 0.004$). No significant difference was found on the labial, palatal and mesial aspects.

At T2, the labial and distal bone heights of the impacted incisors at T2 were less than the corresponding contralateral values (LH: $p = 0.001$; DH: $p = 0.006$).

3.3 Alveolar bone thickness alterations

Regarding the differences in the alveolar bone thickness values of T1 and T2 stages (D-value), as shown in Table 4.

There was a significant increase in D-values of total bone thickness in the impacted sides after treatment at different planes (IMP-0: 3.26 ± 4.33 mm; IMP-2: 4.51 ± 3.60 mm; IMP-4: 4.58 ± 3.18 mm; IMP-6: 4.17 ± 3.9 mm; IMP-8: 3.01 ± 3.56 mm) ($p < 0.05$). No significant difference was found in the contralateral sides, except for the thickness at IMP-0, 2 (IMP-0: −3.12 ± 2.95 mm; IMP-2: −1.46 ± 2.44 mm).

The D-values of labial bone thickness in the impacted sides at IMP-0, 2 (IMP-0: 2.27 ± 2.57 mm; IMP-2: 1.69 ± 2.86 mm) and the D-values of palatal bone thickness at IMP-2, 4, 6, 8 (IMP-2: 2.82 ± 2.88 mm; IMP-4: 3.48 ± 2.47 mm; IMP-6: 3.38 ± 3.19 mm; IMP-8: 2.56 ± 3.27 mm) showed a significant increase in thickness ($p < 0.05$). The increase in alveolar bone thicknesses was also greater in the impacted side than that in the contralateral side.

The total bone thicknesses at different planes at T1 in the impacted sides were all significantly thinner than those in the contralateral sides ($p < 0.05$). The labial bone thicknesses at IMP-0, 2, 4, 8 (IMP-0: 1.46 ± 1.54 mm, IMP-2: 1.14 ± 1.98 mm, IMP-4: 1.09 ± 1.53 mm, IMP-8: 0.40 ± 0.39 mm) and the palatal bone thicknesses in each plane were significantly thinner in the impacted, compared to the contralateral sides ($p < 0.05$).

The total bone thicknesses at T2 in the impacted sides at different planes were all thicker than those in the contralateral sides (IMP-2, 4, 6, 8: $p < 0.05$). The palatal bone thicknesses at IMP-2, 4, 6, 8 in the impacted sides were significantly thicker than those in the contralateral sides. No other values showed significant differences between the two sides.

4. Discussion

This study investigated the alterations in alveolar bone for 16 patients with dilacerated late-dental-age LIIMCIs, after closed-eruption treatment. After treatment, alveolar bone height increased significantly in the dilacerated late-dental-age LIIMCI sides. This is similar to results seen with natural growth of contralateral incisors. There was a significant increase in total alveolar bone thickness in all planes around the impacted in-

TABLE 2. Description of root morphology and position of the incisors pretreatment and posttreatment.

			Mean ± SD	n (%)
Impacted incisor				
Pretreatment				
Direct root length (mm)			2.68 ± 1.57	
Dilacerated root length (mm)			4.39 ± 1.82	
Dilaceration angle (°)			125.70 ± 26.25	
Inverse angle (°)			47.53 ± 11.18	
Dental age				
	Stage 8			7 (42.9%)
	Stage 9			8 (50.0%)
	Stage 10			1 (7.1%)
Posttreatment				
Position of the root apex	Labial	Mesial		0 (0.0%)
		Middle		5 (31.3%)
		Distal		3 (18.9%)
	Palatal	Mesial		0 (0.0%)
		Middle		5 (31.3%)
		Distal		3 (18.9%)
Presence of fenestration				12 (75.0%)
Contralateral incisor				
Pretreatment				
Root length (mm)			9.40 ± 1.05	
Dental age				
	Stage 8			4 (25.0%)
	Stage 9			4 (25.0%)
	Stage 10			6 (37.5%)

SD: standard deviations.

TABLE 3. Height of the alveolar bone before and after the treatment.

Alveolar height	Impacted sides	Contralateral sides	*p*
	Mean ± SD (Range) (mm)	Mean ± SD (Range) (mm)	
LH			
T1	8.88 ± 2.48 (5.4, 11.5)	10.08 ± 1.90 (6.7, 13.3)	NS
T2	10.50 ± 2.22 (6.4, 13.9)	11.74 ± 2.18 (7.5, 14.6)	0.001
D-value	1.63 ± 2.92 (−2.8, 9.6)*	1.66 ± 1.99 (−2.8, 5.8)**	NS
PH			
T1	10.87 ± 2.56 (6.9, 14.8)	10.36 ± 1.94 (6.0, 13.0)	NS
T2	11.75 ± 2.69 (7.4, 15.1)	11.85 ± 2.40 (7.3, 14.6)	NS
D-value	0.88 ± 2.34 (−4.6, 5.2)*	1.49 ± 1.65 (−2.0, 4.1)**	NS
MH			
T1	12.13 ± 1.99 (9.3, 14.4)	12.28 ± 1.78 (9.4, 15.6)	NS
T2	13.54 ± 2.32 (8.9, 16.1)	13.43 ± 2.28 (8.8, 16.1)	NS
D-value	1.41 ± 1.92 (−2.6, 4.5)*	1.15 ± 1.92 (−4.1, 3.7)**	NS
DH			
T1	10.38 ± 2.74 (6.5, 13.7)	12.04 ± 2.00 (7.6, 13.9)	0.004
T2	12.78 ± 2.34 (8.2, 15.7)	13.55 ± 2.38 (8.8, 16.9)	0.006
D-value	2.40 ± 2.69 (−4.7, 6.6)***	1.51 ± 1.87 (−3.5, 3.4)**	0.046

**, comparison between alveolar height of T1 and T2; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

p, comparison between alveolar height on impacted and contralateral sides in T1 or T2; NS: No statistical difference between variables.

LH: labial alveolar bone height; PH: palatal alveolar bone height; MH: mesial alveolar bone height; DH: distal alveolar bone height;

T1: pretreatment; T2: follow-up; D-value: T2 − T1.

TABLE 4. Buccal and palatal alveolar bone thickness before and after treatment.

Alveolar plane			Impacted side	Contralateral side	p
			Mean ± SD (Range) (mm)	Mean ± SD (Range) (mm)	
IMP-0	LBT	T1	1.46 ± 1.54 (0.0, 4.1)	5.33 ± 1.24 (3.5, 7.8)	<0.001
		T2	3.73 ± 1.41 (0.0, 5.4)	3.68 ± 1.36 (1.5, 6.2)	NS
		D-value	2.27 ± 2.57 (−3.0, 5.2)**	−1.65 ± 1.46 (−4.8, 1.8)***	0.001
	PBT	T1	5.77 ± 4.25 (0.1, 15.3)	7.59 ± 4.18 (2.8, 19.3)	0.021
		T2	6.76 ± 2.31 (3.5, 11.0)	6.13 ± 2.57 (3.3, 10.6)	NS
		D-value	0.99 ± 3.59 (−4.9, 7.2)	−1.47 ± 3.50 (−10.1, 2.3)	0.016
	Total	T1	7.23 ± 4.61 (0.1, 15.3)	12.93 ± 3.52 (8.9, 22.8)	<0.001
		T2	10.49 ± 2.08 (7.9, 13.8)	9.81 ± 2.98 (4.8, 13.5)	NS
		D-value	3.26 ± 4.33 (−2.3, 12.4)**	−3.12 ± 2.95 (−9.8, 1.0)***	<0.001
IMP-2	LBT	T1	1.14 ± 1.98 (0.0, 3.4)	3.68 ± 0.77 (2.7, 4.6)	0.001
		T2	2.83 ± 1.53 (0.0, 5.1)	2.92 ± 2.12 (0.8, 4.0)	NS
		D-value	1.69 ± 2.86 (−6.5, 5.1)**	−0.76 ± 1.66 (−3.4, 4.4)***	0.008
	PBT	T1	3.71 ± 3.35 (0.0, 10.3)	5.89 ± 3.52 (1.8, 14.9)	0.002
		T2	6.53 ± 2.16 (3.5, 10.5)	5.19 ± 2.48 (1.7, 10.3)	0.004
		D-value	2.82 ± 2.88 (−2.2, 7.9)**	−0.76 ± 2.69 (−7.0, 3.7)	0.001
	Total	T1	4.86 ± 4.32 (0.0, 12.7)	9.57 ± 3.53 (5.8, 18.3)	0.001
		T2	9.36 ± 2.01 (6.4, 12.6)	8.11 ± 3.08 (3.4, 12.8)	0.026
		D-value	4.51 ± 3.60 (−2.7, 8.8)***	−1.46 ± 2.44 (−7.2, 2.2)*	0.001
IMP-4	LBT	T1	1.09 ± 1.53 (0.0, 6.1)	2.33 ± 0.71 (1.6, 2.8)	0.010
		T2	2.19 ± 1.40 (0.0, 4.6)	2.11 ± 2.02 (0.7, 3.3)	NS
		D-value	1.10 ± 2.01 (−3.9, 4.1)	−0.22 ± 1.40 (−1.5, 4.6)*	0.038
	PBT	T1	2.21 ± 2.33 (0.0, 7.3)	4.61 ± 2.96 (1.1, 12.5)	0.002
		T2	5.69 ± 2.40 (2.2, 9.7)	3.85 ± 2.16 (1.4, 8.0)	0.001
		D-value	3.48 ± 2.47 (−0.2, 9.0)***	−0.78 ± 2.36 (−6.6, 2.4)	0.001
	Total	T1	3.31 ± 3.03 (0.2, 9.8)	6.94 ± 3.01 (2.7, 14.2)	0.003
		T2	7.89 ± 3.09 (3.1, 12.7)	5.96 ± 2.76 (2.3, 10.6)	0.001
		D-value	4.58 ± 3.18 (−1.5, 10.0)***	−0.98 ± 2.55 (−7.6, 4.4)	0.001
IMP-6	LBT	T1	1.50 ± 2.46 (0.0, 9.7)	1.43 ± 0.53 (0.0, 2.2)	NS
		T2	1.89 ± 1.61 (0.1, 5.5)	1.59 ± 1.97 (0.4, 1.9)	NS
		D-value	0.39 ± 2.86 (−6.5, 5.2)	0.17 ± 1.85 (−1.1, 6.9)	NS
	PBT	T1	1.38 ± 1.70 (0.1, 5.5)	3.63 ± 2.90 (0.0, 11.8)	0.007
		T2	5.16 ± 2.89 (0.5, 10.3)	2.85 ± 1.76 (0.6, 6.9)	0.003
		D-value	3.38 ± 3.19 (−2.6, 8.4)**	−0.78 ± 2.36 (−6.6, 2.4)	0.002
	Total	T1	2.88 ± 2.72 (0.1, 9.9)	5.05 ± 2.94 (0.0, 12.8)	0.030
		T2	7.05 ± 3.61 (0.6, 12.1)	4.44 ± 2.44 (1.1, 10.0)	0.002
		D-value	4.17 ± 3.99 (−2.1, 12.0)**	−0.61 ± 2.30 (−6.8, 3.0)	0.002
IMP-8	LBT	T1	0.40 ± 0.39 (0.0, 1.0)	1.06 ± 0.47 (0.0, 1.7)	0.001
		T2	0.84 ± 1.32 (0.0, 5.2)	1.24 ± 1.77 (0.0, 1.4)	NS
		D-value	0.44 ± 1.38 (−0.8, 5.0)	−0.18 ± 1.58 (−0.7, 6.0)*	NS
	PBT	T1	1.11 ± 1.20 (0.0, 3.1)	2.70 ± 2.52 (0.0, 10.3)	0.048
		T2	3.68 ± 2.93 (0.0, 9.8)	2.03 ± 1.64 (0.0, 6.3)	0.011
		D-value	2.56 ± 3.27 (−3.1, 9.6)*	−0.67 ± 1.79 (−5.5, 1.7)	0.005
	Total	T1	1.51 ± 1.23 (0.0, 3.6)	3.76 ± 2.57 (0.0, 11.0)	0.011
		T2	4.52 ± 3.38 (0.0, 10.0)	3.27 ± 2.40 (0.0, 8.7)	0.028
		D-value	3.01 ± 3.56 (−3.1, 9.4)**	−0.49 ± 2.20 (−5.9, 4.5)	0.004

**, comparison between alveolar thickness of T1 and T2; *p < 0.05, **p < 0.01, ***p < 0.001.*

p, comparison between alveolar thickness on impacted and contralateral sides in T1 or T2; NS: No statistical difference between variables.

LBT: labial alveolar bone thickness; PBT: palatal alveolar bone thickness; Total: the sum of LBT and PBT.

IMP-0/2/4/6/8, The total thickness at the alveolar crest 0/2/4/6/8 mm under the initial measurement plane.

T1: pretreatment; T2: follow-up; D-value: T2 − T1.

IMP: initial measurement plane.

cisors. These results demonstrated that there was a significant increase in the amount of alveolar bone around the impacted incisors.

To rule out age-related changes in alveolar bone, comparisons were made between the impacted and contralateral sides. After treatment, labial and distal alveolar bone heights in the impacted sides was determined to be significantly lower, which was consistent with observations from previous studies, in which labial alveolar bone resorption at impacted incisors had been reported [11, 13, 18]. The distal bone loss may be due to stress concentration in the periodontal tissues caused by the dilacerated root [19]; in this study, 6 out of 16 roots of impacted incisors were oriented distally, and none of the roots of the impacted incisors was oriented mesially. The observed direction of root curvature is consistent with the characteristic root direction of impacted incisors reported in the literature [20]—the roots of labial impacted incisors are more likely to be oriented labially and distally.

Before treatment, the total alveolar bone thickness in each plane was thinner in the impacted sides, compared to the contralateral sides, conceivably due to the labial-palatal run-through position of the impacted incisors and the presence of odontogenic cysts, as shown in Fig. 2. However, follow-up CBCT images showed no further thinning of the alveolar bone on the impacted sides, indicating that tissue regeneration had been achieved within the alveolar bone, induced by orthodontic traction on the periodontal ligament [21]; coupled with the presence of dental follicle cells, which have a strong ability to regenerate periodontal tissue [22].

After treatment, there was a significant increase in labial alveolar bone thickness in the impacted sides at IMP-0 and 2 (near the apical zone), as well as palatal alveolar bone thickness at IMP-2, 4, 6 and 8 (near the alveolar crest zone). In contrast, the labial alveolar bone thickness decreased in the contralateral sides. These findings suggest that the impacted incisors are labially inclined [13], and that the contralateral incisors moved labially after treatment. The tooth crown was stabilized in a labial inclination, to minimize dilacerated root penetration through the labial cortical bone. And we sacrifice some symmetry in the torque of the incisor crowns on both sides to avoid external root resorption, mucosal fenestrations and pulpal necrosis after treatment. Unlike previous studies which measured alveolar bone thickness based on root length, this study focused on the three-dimensional alveolar bone morphological changes before and after treatment. Alveolar bone thickness was measured by cutting down from the reference plane (IMP), which made it possible to compare alveolar bone thickness before and after treatment.

Fenestration is a defect or a window-like opening at the cortical plate of the alveolar bone, which can develop from physiological or pathological processes. Its presence does not necessitate treatment, unless associated with endodontic problems [23]. The late-dental-age LIIMCIs patients in this study, had a higher incidence of labially oriented root apices compared to other studies [13, 18, 24]. At follow-up, 12 of 16 impacted roots exceeded alveolar bone contour; however, periapical lesions and mucosal fenestrations were absent. If damage to the periodontium were detected, an interdisciplinary treatment approach would have been employed for optimizing periodontal outcomes, including, but not limited to: periodontally accelerated osteogenic orthodontics for decreasing the incidence of fenestration, apicoectomy for treating pulp necrosis and periodontal surgical strategies for the esthetic treatment of inverted dilacerated incisors [25–27].

If the dilacerated LIIMCI was extracted and the patient did not choose to close the space with orthodontic therapy, the teenage patient would have to wait almost 8–10 years for permanent implant placement, during which time removable dentures or fixed Maryland bridge would be used to replace the missing tooth and maintain anterior tooth space. The correction of midline deviation in the permanent dentition is more complicated than in the mixed dentition. Our research indicated that tractional forces during treatment for dilacerated impacted incisors has a significant effect on alveolar bone preservation and osteogenesis. There would be a dramatic loss in ideal alveolar bone morphology if impacted incisors were extracted [28–32].

There were limitations in this study. Because of the small sample size, it was not possible to adjust for confounders which may influence alveolar bone height and thickness, such as chronological age, dental age, gender and type of malocclusion [33]. Additionally, the measured alveolar bone width has a relatively large standard deviation; this may be due to the difference in bone height at the dilacerated portion of the impacted incisor. This peculiarity should be factored in future studies. Our group plans to continue studying bone alternations, gingival and general changes in the periodontium, with increased number of cases, and longer follow-up intervals.

5. Conclusions

1. Closed-eruption treatment of dilacerated late-dental-age LIIMCIs promotes alveolar bone reconstruction. The amount of alveolar bone height growth is no less than at the contralateral incisors. Alveolar bone height was unchanged, except on the labial and distal aspects, with increased labial-palatal alveolar bone thickness.

2. Closed-eruption treatment of dilacerated late-dental-age LIIMCIs could be the first choice in treating non-extraction orthodontic cases.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

LQZ—conceptualization, methodology, writing-original draft preparation. YW—data analysis, writing-review & editing. ZQH and TTC—investigation, data curation. RDH and GV—conceptualization, writing-review & editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This retrospective study was reviewed and approved by the Hospital of Stomatology of Wenzhou Medical University (Hospital of Stomatology, Wenzhou Medical University Clinical Ethical Registry: WYKQ2019018). Completed informed consent forms were signed by the guardians of all children.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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