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ORIGINAL RESEARCH

Clinical efficacy of early intervention timing for inversely impacted maxillary central incisors

Kaige Liu[1,2], Ronghua Jiang[3], Chengmei Zhang[4], Hui Han[1,*], Linqin Shao[3,*]

[1]Jinan Stomatological Hospital, 250001 Jinan, Shandong, China
[2]Qilu Hospital of Shandong University, 250012 Jinan, Shandong, China
[3]Shandong University Stomatological Hospital, 250001 Jinan, Shandong, China
[4]Binzhou Medical University, 264003 Yantai, Shandong, China

***Correspondence**
hanhui20140520@bzmc.edu.cn
(Hui Han);
202299000046@sdu.edu.cn
(Linqin Shao)

Abstract

Background: Maxillary Impacted Central Incisors are a common oral issue among children with mixed dentition. This study evaluates the effectiveness of early traction treatment, which is vital for clinical treatment and management. **Methods**: This study included 59 patients with maxillary impacted central incisors, who were divided into three groups based on Nolla's method: the early group (Nolla 6–7), middle group (Nolla 8), and late group (Nolla 9–10). Mimics software was used to create 3 Dimensions (3D) reconstructions of postoperative Cone-beam computed tomography (CBCT) scans, which were used to compare the tooth volume and surface area between the impacted and contralateral teeth, as well as sagittal measurements of root length and loss of height on the labial-palatal aspects of the alveolar bone. Doppler laser flowmetry was used to assess pulpal blood flow in impacted and contralateral teeth three months after surgery. **Results**: Significant differences in root length, tooth volume, and surface area were observed between impacted and contralateral teeth in the middle and late groups ($p < 0.05$). The early group, however, showed significant differences in the labial-palatal height differential of the alveolar bone between the impacted teeth and their contralateral counterparts compared to the middle and late groups ($p < 0.05$). The study found no significant differences in pulpal vitality among the three groups ($p > 0.05$). **Conclusions**: The study's results indicate that orthodontic treatment during Nolla stages 6–7 is more beneficial in the development of impacted teeth in patients. This study supports the early orthodontic treatment approach in clinical practice.

Keywords

Impacted tooth; Early intervention; Three-dimensional reconstruction; Pulp blood flow volume

1. Introduction

During the Mixed Dentition Stage in children, maxillary impacted central incisors refer to upper central incisors that exceed the normal eruption age without emerging, or teeth on the opposite side that have already erupted for more than six months while the affected side remains unerupted [1]. Maxillary central incisors are the most commonly impacted, accounting for 71% of all impacted maxillary incisors, with an incidence rate of 0.2% among permanent dentition [2]. The etiology can be divided into two major categories: local factors, such as supernumerary teeth, odontogenic tumors, trauma to deciduous teeth, dental follicular cysts, ectopic permanent tooth buds, localized gingival hyperplasia and loss of eruption space; and systemic factors, such as genetic disorders, endocrine abnormalities, cleft lip and palate and craniofacial developmental abnormalities [2, 3]. Maxillary inversely impacted central incisors are mainly located on the labial side [4], and are more prone to root curvature and inverted impaction [5]. The development and application of imaging techniques have greatly facilitated early diagnosis, treatment planning, and treatment outcome assessment in the treatment of maxillary impacted central incisors.

Cone beam computed tomography (CBCT) is a technique that has significant advantages in detecting impacted teeth [6]. CBCT allows clinicians to create three-dimensional images with precision, which enables an accurate assessment of the position of the impacted tooth within the maxillary bone, tooth morphology, degree of crown-root curvature, its relationship with adjacent teeth, and crucial anatomical structures. Laser Doppler blood flow meters provide a highly reliable method for assessing pulp vitality, which surpasses traditional pulp diagnostic methods. This is especially useful for evaluating pulp vitality objectively, non-invasively, and reliably in juvenile patients with incomplete root development [7].

Currently, there need to be more comprehensive studies that specifically focus on the clinical outcomes of maxillary inverted impacted central incisors after orthodontic traction. Previous studies on the consequences of impacted teeth have generally divided them into two groups: early treatment (Nolla $\leq$8) and late treatment (Nolla >8) [8, 9]. However, maxillary inverted impacted central incisors are prone to root curvature, which increases as root development progresses [10]. As a result, simple grouping studies may not accurately represent the developmental status of impacted teeth at various stages. In this study, we have we further subdivided impacted teeth located within 2/3 of root formation into two groups, namely Nolla 6–7 and Nolla 8 periods, based on the Nolla dental age classification. We studied and compared the root length, tooth volume, tooth surface area, alveolar bone development, and pulp viability of impacted teeth to their homonymous counterparts after orthodontic treatment at various developmental stages. This research aims to look into the clinical effectiveness of early orthodontic traction scheduling for maxillary inverted, impacted central incisors.

2. Materials and methods

2.1 Patient population

This study is a retrospective observational study that involved a total of 59 pediatric patients, 27 males and 32 females aged 5 to 11 years, who underwent closed traction treatment for impacted maxillary central incisors at Jinan Stomatological Hospital between 2019 and 2022.

The inclusion criteria were as follows: (1) Unilateral impacted permanent maxillary central incisor completely bony impacted in the labial side of the maxilla. (2) Regular follow-up evaluations every 4 weeks. (3) Clear and complete CBCT images before and after treatment. (4) Strong willingness for treatment from the child and their legal guardian, with informed consent signed by the legal guardian. (5) No history of orthodontic treatment, no severe oral and maxillofacial diseases, and no systemic diseases in the child.

The exclusion criteria were as follows: (1) Multiple impacted teeth in the oral cavity. (2) Inability to follow up regularly. (3) Lack of CBCT images before and after treatment. (4) History of orthodontic treatment, severe oral and maxillofacial diseases, or systemic diseases in the child.

2.2 Patient stratification

The patients were classified into different groups based on the developmental stage of their impacted maxillary central incisor and its normally erupted homologous tooth. A skilled dental professional categorized the impacted teeth using the Nolla dental age analysis method. The categorization was based on the degree of calcification of the impacted central incisor on pre-treatment CBCT sagittal images. The patients were grouped into early-treatment groups, mid-treatment groups, and late-treatment groups. The early treatment group included patients with Nolla stage 6–7, the mid-treatment group included those with Nolla stage 8, and the late treatment group comprised patients with Nolla stage 9–10, as depicted in Fig. 1.

2.3 Treatment plan

All patients underwent a surgical procedure that involved exposing the impacted teeth using a guided eruption method [8]. The surgical approach was planned with the help of preoperative CBCT to determine the position of the teeth within the maxillary bone. Local anesthesia was administered, and the palatal aspect of the impacted tooth was exposed for bonding traction hooks. An orthodontic appliance was used to gently pull the impacted tooth into position. Approximately 60 g of force [11] was applied throughout the traction process. The traction was stopped once the tooth had erupted 1/2 to 2/3 of the way, and brackets were attached. The 2×4 fixed orthodontic technique was used to align the anterior teeth. Post-treatment, CBCT was performed, and patients were monitored during the retention phase. All CBCT scans were obtained using the NewTom CBCT scanner (5G version FP, Verona, Italy). Typical imaging parameters were as follows: 110 KVp, 1–20 mA pulse mode, 26 second scan time, 0.25 mm axial thickness, 15×15 cm field of view, and $0.30 \times 0.25 \times 0.25$ mm voxel size. The data was exported from the NewTom (NNT) workstation software (5G version FP, Verona, Italy) in Digital Imaging and Communications in Medicine (DICOM) format and imported into Materialise Interactive Medical Image Control System (Mimics 21.0 software, Materialise, Belgium). Follow-up appointments were scheduled 3 months after surgery, and pulpal vitality was assessed using Laser Doppler Flowmetry (LDF).

2.4 Measurement parameters

2.4.1 Measurement of postoperative tooth volume and surface area

The three-dimensional modeling of the oral and maxillofacial region was performed using Mimics 21.0 software (Materialise, Belgium) after importing the CBCT data of the pediatric patients. The impacted teeth were separated from their respective contralateral counterparts for separate measurements of their tooth volumes and surface areas. You can refer to Fig. 2 for a clear illustration.

2.4.2 Measurement of root length, labial-palatal alveolar height, and labial-palatal thickness in the apical region

In this study, we used the measurement methods described by Kim *et al*. [12] and Ma *et al.* [13]. We identified the widest part of the impacted tooth and its contralateral counterpart using images in the sagittal plane. We took measurements for root length, labial-palatal alveolar height and labial-palatal thickness in the apical region. Root length was determined by measuring the distance of line a-8 or a-b-8. The distance of line 2–4 was used to measure the labial height of the alveolar bone, and the distance of line 3–5 was used to measure the palatal height of the alveolar bone. The distances of lines 6–8 and 7–8 were used to measure the labial and palatal thickness of the alveolar bone in the apical region, respectively. We determined the curvature of the crown and root using the method described by Wang *et al*. [14]. This was done by checking whether the line connecting the midpoint of the incisal end and the apical point passes through the midpoint of the labio-palatal enamel-dentin junction, as depicted in Fig. 3.

2.4.3 Measurement of pulpal blood flow

During the 3-month follow-up appointment after treatment completion, the pulpal blood flow (PBF) [15] in the impacted

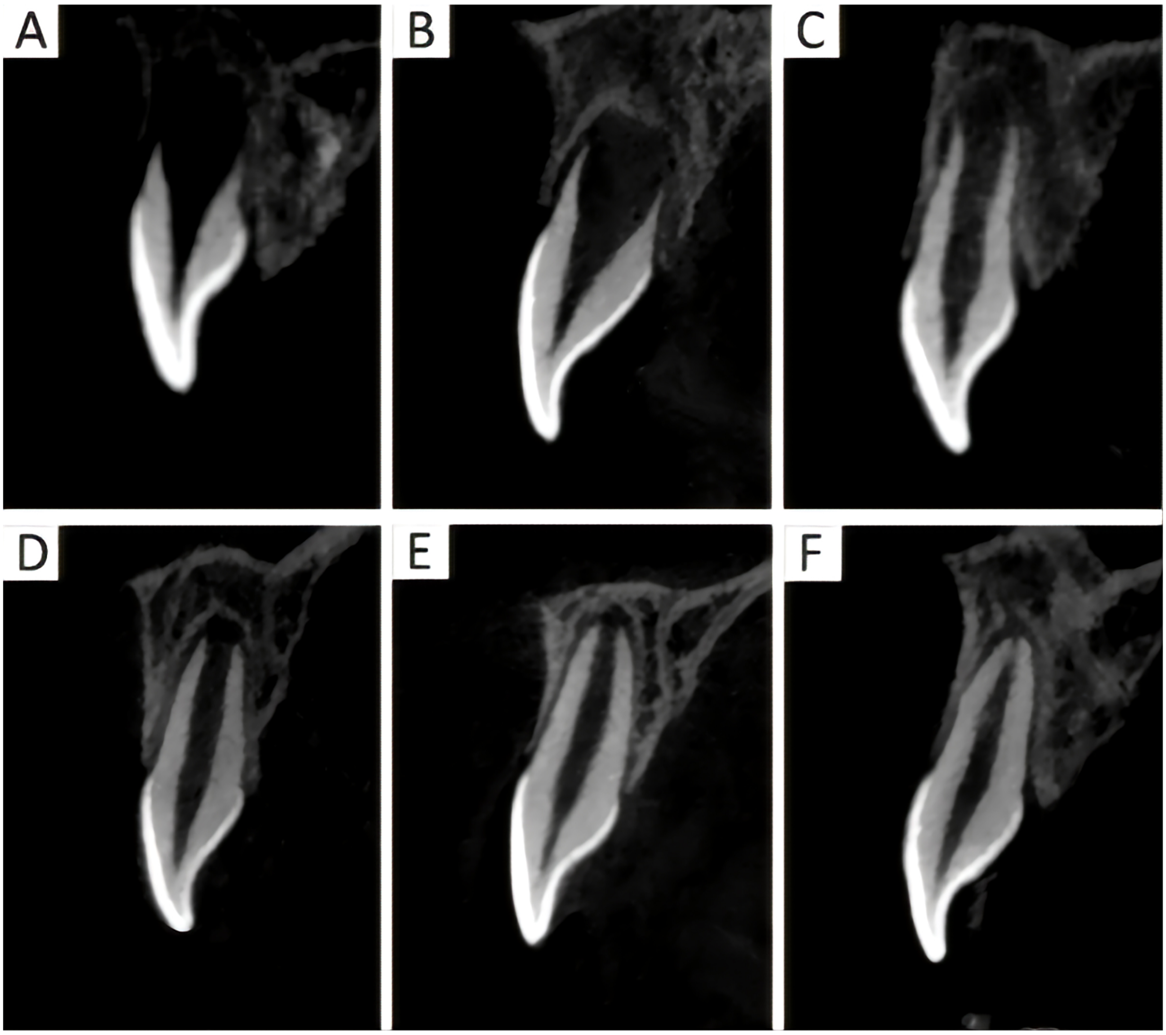

FIGURE 1. Stages of tooth root development. (A) Tooth development at Nolla 6, with complete crown development and the beginning of root development. (B) Tooth development at Nolla 7, with the root length developed to 1/3. (C,D) Tooth development at Nolla 8, with the root length developed to 2/3. (E) Tooth development at Nolla 9, with the root length nearing completion, and a larger apical foramen. (F) Tooth development at Nolla 10, with the root length essentially complete, and a reduced apical foramen.

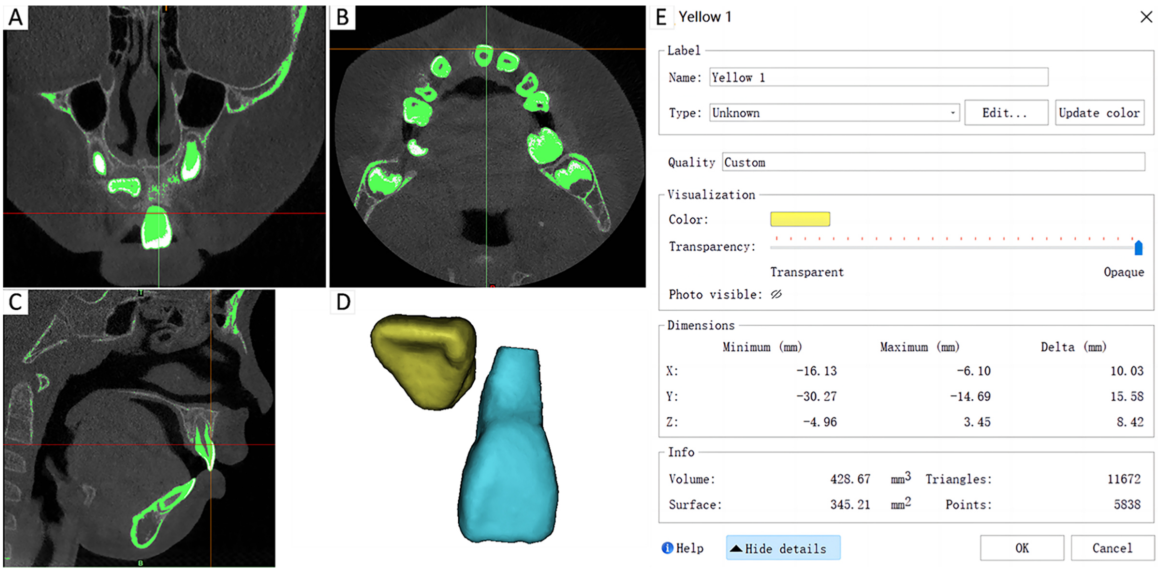

FIGURE 2. Mimics calculates tooth volume and surface area. (A–C) Establishment of the Initial Mask. (D) Separation of Impacted and Control Teeth, Filling of Cavities to Generate a New Mask. (E) Acquisition of Volume and Surface Area of the Impacted Teeth.

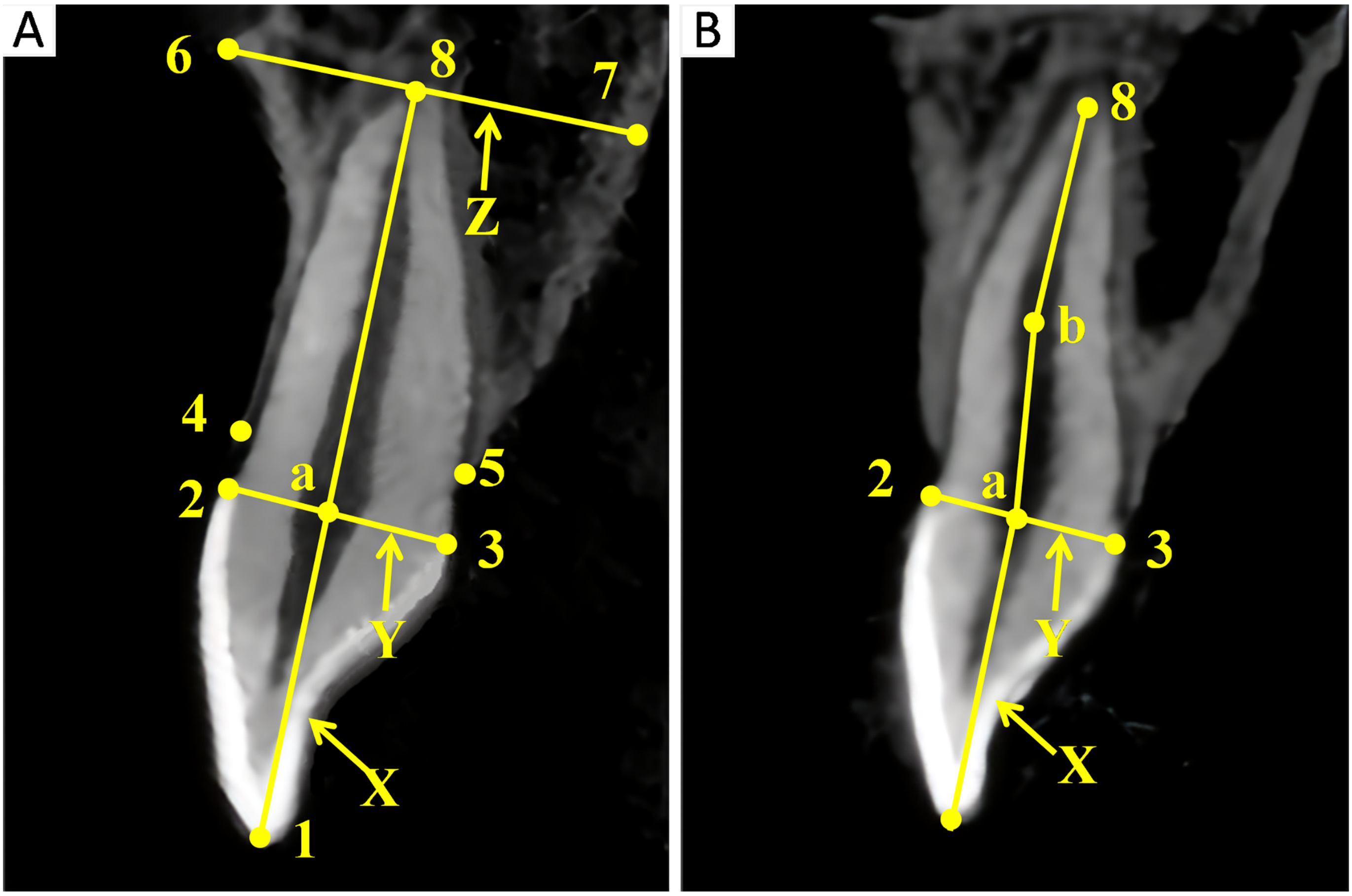

FIGURE 3. Description of relevant points and lines. (A) Measurement of the Mid-Sagittal View of the Tooth. (B) Measurement of the Root Length of a Curved Root Tooth Requires Rotation of the Image, Measuring Along the a-b-8 Line. (1) Midpoint of the Incisal Edge; (2) Labial Enamel-Cement Junction Point; (3) Palatal Enamel-Cement Junction Point; (4) Labial Alveolar Crest Point; (5) Palatal Alveolar Crest Point; (6) Intersection Point of Labial Alveolar Bone Cortex and Perpendicular to the Long Axis of the Tooth; (7) Intersection Point of Palatal Alveolar Bone Cortex and Perpendicular to the Long Axis of the Tooth; (8) Apex Point; X: Long Axis of the Incisor Tooth Body; Y: Line Connecting Points 2 and 3; (Z) Line Connecting Points 6 and 7; (a) Intersection Point of Line X and Line Y; (b) Midpoint of the Root Bending Point.

teeth and their corresponding teeth on the opposite side were examined using Laser Doppler Flowmetry (LDF). This was done to determine their pulpal vitality status, as shown in Fig. 4.

2.5 Data analysis

The same trained physician performed the aforementioned procedures, and the data was measured three times and then averaged.

SPSS 26.0 statistical software (IBM, Armonk, NY, USA) was used for data analysis. Before conducting the analysis, the normality of the data was checked using the Kolmogorov-Smirnov test. Descriptive statistics were presented as mean ± standard deviation ($\bar{x} \pm s$) for normally distributed data. Independent sample t-tests were used for comparisons between two independent groups, and one-way Analysis of Variance (ANOVA) was used for comparisons among multiple independent groups for normally distributed data. For data that did not follow a normal distribution, non-parametric independent sample Mann-Whitney U tests were used for comparisons between two groups, and non-parametric Kruskal-Wallis tests were utilized for comparisons among multiple groups. Chi-square tests were used for comparisons involving multiple rates or multiple proportions.

3. Results

3.1 Demographic information

This research study involved 59 cases in total. The early treatment group consisted of 10 males and 7 females, with an average age of 6.8 years and a typical duration of closed eruption guidance treatment of 5.3 months. The middle treatment group comprised 7 males and 12 females, with an average age of 7.8 years and a usual duration of closed eruption guidance treatment of 5.9 months. The late treatment group included 10 males and 13 females, with an average age of 9.0 years and a typical duration of closed eruption guidance treatment of 8.2 months. It is important to note that the developmental stage of tooth roots is positively associated with age, thus there is a significant difference in age distribution among the groups. However, there were no statistically significant differences in measured values between genders and impacted tooth positions ($p > 0.05$) for all cases, as confirmed by chi-square

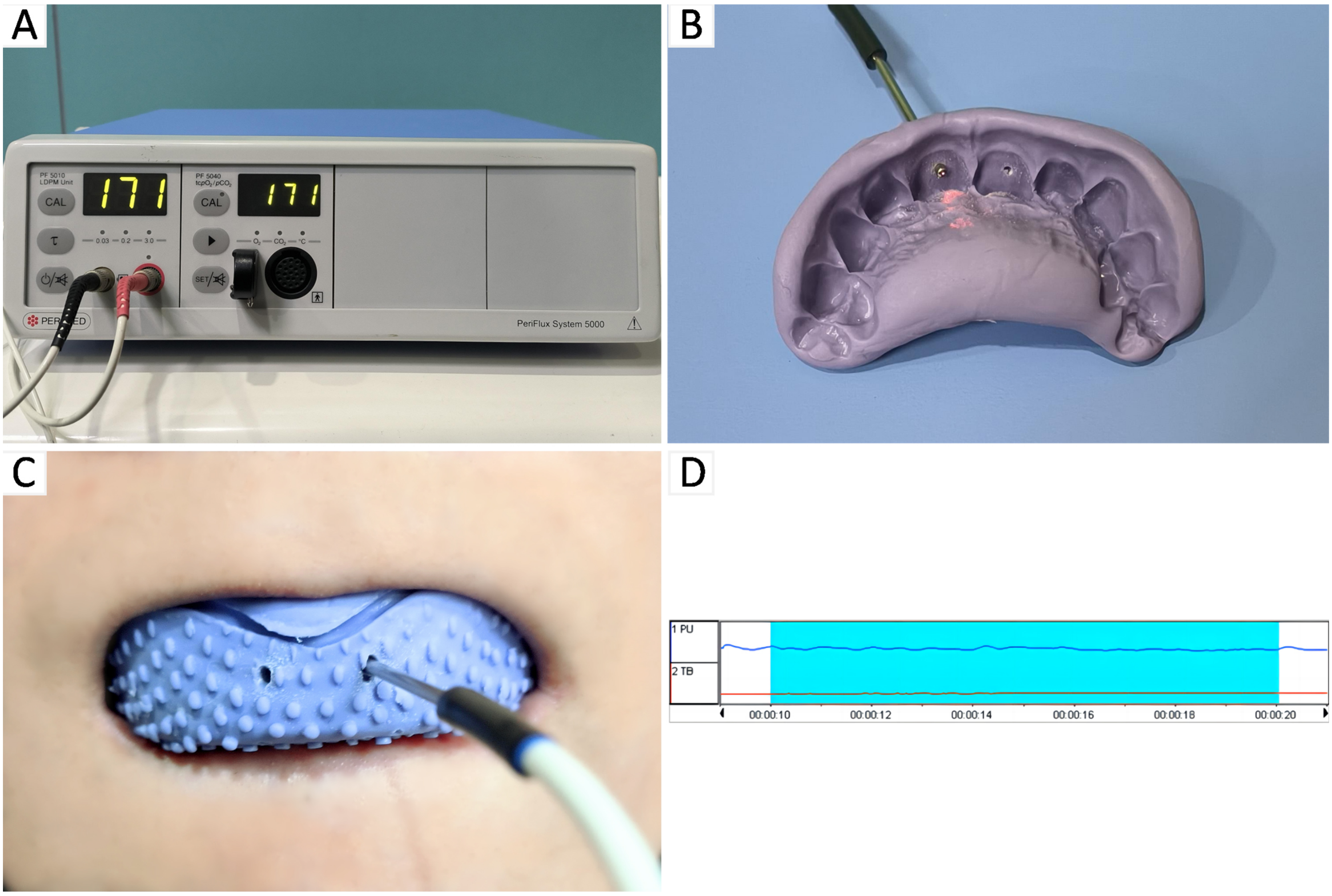

FIGURE 4. Dental pulp blood flow data collection process. (A) Laser doppler flowmetry device. (B) Fabrication of a silicone rubber guide. (C) The testing process. (D) Results of dental pulp blood flow. PU, Perfusion Unit; TB, Total light Back.

tests Additionally, none of the 59 cases reported significant discomfort due to closed traction treatment. The judgment criteria for this assessment include no discomfort after three months of treatment, the absence of redness or bleeding in the gingiva around the impacted tooth, no symptoms of pulpitis, no bone fenestration detected in the alveolar bone, and no shadow observed at the apex of the impacted tooth during radiographic examination. For more details, please refer to Table 1.

3.2 Crown-root curvature

Out of the total 17 cases in the early treatment group, 4 cases (23.53%) had impacted teeth with crown-root curvature. The middle treatment group had 19 cases, out of which 12 (63.16%) had the same issue. Whereas, in the late treatment group, out of 23 cases, 21 (91.30%) had impacted teeth with crown-root curvature. Chi-square tests confirmed that there was a significant difference in the percentage of crown-root curvature among the early, middle, and late treatment groups ($p < 0.05$). Refer to Table 1 for details.

3.3 Tooth development

During the middle and late stages of treatment, the impacted teeth had significantly shorter roots, smaller tooth volume, and reduced surface area compared to their contralateral teeth ($p < 0.05$). However, in the early treatment group, there were no significant differences in root length, tooth volume, and surface area between the impacted teeth and their contralateral teeth ($p > 0.05$). This observation indicates that the development of impacted teeth in the early treatment group becomes more similar to their contralateral teeth after orthodontic traction treatment. Please refer to Tables 2,3,4 for more details.

3.4 Alveolar bone development

The height of the alveolar bone on both the labial and palatal sides of impacted teeth was significantly lower in the early, middle, and late treatment groups compared to their respective contralateral teeth ($p < 0.05$). In the late treatment group, the thickness of the alveolar bone on the labial side in the apical region of impacted teeth was significantly smaller than that of their contralateral teeth ($p < 0.05$), and the alveolar bone height on both the labial and palatal sides was significantly lower than that of their contralateral teeth ($p < 0.05$). Moreover, the apical region of the alveolar bone on the palatal side was significantly thicker in the early treatment group compared to their contralateral teeth ($p < 0.05$). Significant differences were also observed between the early, middle, and late treatment groups concerning the differential values (impacted tooth–contralateral teeth) of the alveolar bone height on both the labial and palatal sides and in the thickness of the alveolar bone in the apical region on the labial and palatal sides ($p < 0.05$), with smaller differential values in the early treatment group. This suggests that the alveolar bone development in the early

TABLE 1. Patient information.

Item	Early group	Middle group	Late group	*p*-value
Age (yr)	6.8 ± 0.6	7.8 ± 0.8	9.0 ± 0.8	<0.001[a]
Gender (n)				
Male	10	7	10	0.401[b]
Female	7	12	13	
Crown-root curvature (n)	4	12	21	<0.001[b]
Tooth position (n)				
11	7	7	12	0.585[b]
21	10	12	11	
Traction duration (mon)	5.3 ± 1.2	5.9 ± 1.8	8.2 ± 2.7	<0.001[a]

[a], Kruskal-Wallis tests; [b], Chi-square test.
Note: The developmental stage of tooth roots is positively correlated with age, thus a significant difference exists in age distribution among groups.

TABLE 2. Intra-group comparison of dental and alveolar bone in the early group.

Item (Mean ± SD)	Impacted teeth (n = 17)	Contralateral teeth (n = 17)	*p*-value
TV (mm^3)	610.30 ± 70.43	633.50 ± 73.48	0.354[a]
TSA (mm^2)	447.33 ± 38.55	464.38 ± 41.41	0.223[a]
RL (mm)	10.90 ± 1.21	11.39 ± 1.28	0.266[a]
LABH (mm)	2.10 ± 0.54	1.82 ± 0.43	0.013[b]
PABH (mm)	2.13 ± 0.38	1.74 ± 0.49	0.014[a]
LABT (mm)	3.79 ± 0.61	4.11 ± 0.49	0.109[a]
PABT (mm)	7.34 ± 0.53	7.14 ± 0.48	0.269[a]

TV, Tooth Volume; TSA, Tooth Surface Area; RL, Root Length; LABH, Labial Alveolar Bone Height; PABH, Palatal Alveolar Bone Height; LABT, Labial Alveolar Bone Thickness; PABT, Palatal Alveolar Bone Thickness; [a], Independent Sample t-test; [b], Mann-Whitney U tests. SD, standard deviation.

TABLE 3. Intra-group comparison of dental and alveolar bone in the middle group.

Item (Mean ± SD)	Impacted teeth (n = 19)	Contralateral teeth (n = 19)	*p*-value
TV (mm^3)	583.44 ± 55.66	642.85 ± 55.94	0.002[a]
TSA (mm^2)	437.41 ± 36.45	489.50 ± 54.63	0.001[a]
RL (mm)	10.21 ± 0.97	11.58 ± 0.64	<0.001[a]
LABH (mm)	2.61 ± 0.60	1.82 ± 0.31	<0.001[a]
PABH (mm)	2.98 ± 0.76	1.58 ± 0.27	<0.001[a]
LABT (mm)	3.73 ± 0.58	3.99 ± 0.70	0.105[b]
PABT (mm)	7.46 ± 0.52	7.23 ± 0.97	0.372[a]

TV, Tooth Volume; TSA, Tooth Surface Area; RL, Root Length; LABH, Labial Alveolar Bone Height; PABH, Palatal Alveolar Bone Height; LABT, Labial Alveolar Bone Thickness; PABT, Palatal Alveolar Bone Thickness; [a], Independent Sample t-test; [b], Mann-Whitney U tests. SD, standard deviation.

treatment group is more similar to their contralateral teeth. For further details, please refer to Tables 2,3,4,5.

3.5 Pulp vitality

According to the results, there were no significant differences in pulp vitality between impacted teeth and their contralateral teeth in the early, middle and late treatment groups ($p > 0.05$). This means that the pulp vitality of the maxillary impacted central incisors is similar to that of their contralateral teeth after orthodontic traction treatment, regardless of the developmental stage. Please refer to Table 6 for more details.

TABLE 4. Intra-group comparison of dental and alveolar bone in the late group.

Item (Mean ± SD)	Impacted teeth (n = 23)	Contralateral teeth (n = 23)	p value
TV (mm^3)	539.99 ± 84.73	632.00 ± 97.38	0.001^b
TSA (mm^2)	412.70 ± 47.00	472.20 ± 48.93	$<0.001^b$
RL (mm)	9.21 ± 1.39	11.47 ± 1.22	$<0.001^a$
LABH (mm)	3.15 ± 1.12	1.79 ± 0.49	$<0.001^b$
PABH (mm)	2.92 ± 1.12	1.71 ± 0.33	$<0.001^b$
LABT (mm)	2.67 ± 0.98	4.14 ± 0.62	$<0.001^b$
PABT (mm)	7.83 ± 0.63	6.90 ± 0.96	$<0.001^a$

TV, Tooth Volume; TSA, Tooth Surface Area; RL, Root Length; LABH, Labial Alveolar Bone Height; PABH, Palatal Alveolar Bone Height; LABT, Labial Alveolar Bone Thickness; PABT, Palatal Alveolar Bone Thickness; ^{a}*, Independent Sample t-test;* ^{b}*, Mann-Whitney U tests. SD, standard deviation.*

TABLE 5. Inter-group comparison of alveolar bone differences in the 3 groups.

Item (Mean ± SD)	Early group (n = 17)	Middle group (n = 19)	Late group (n = 23)	p value
LHD (mm)	−0.23 ± 0.26	−0.80 ± 0.72	−1.35 ± 1.29	0.002^a
PHD (mm)	−0.39 ± 0.57	−1.40 ± 0.76	−1.21 ± 1.05	$<0.001^b$
LTD (mm)	0.31 ± 0.33	0.34 ± 0.50	1.47 ± 1.20	$<0.001^b$
PTD (mm)	−0.19 ± 0.20	−0.32 ± 0.97	−0.93 ± 1.08	0.021^a

LHD, Labial Height Difference; PHD, Palatal Height Difference; LTD, Labial Thickness Difference; PTD, Palatal Thickness Difference; ^{a}*, ANOVA test;* ^{b}*, Kruskal-Wallis tests. SD, standard deviation.*

TABLE 6. Intra-group comparison of pulp vitality in the 3 groups.

Item (Mean ± SD)	Early group (n = 17)	Middle group (n = 19)	Late group (n = 23)
Impacted teeth	15.37 ± 1.57	15.30 ± 1.33	15.38 ± 2.64
Contralateral teeth	15.74 ± 1.63	15.11 ± 1.48	15.09 ± 1.62
p-value	0.512^a	0.674^a	0.655^a

^{a}*, Independent Sample t-test. SD, standard deviation.*

4. Discussion

The long-term stability of upper impacted front teeth after orthodontic treatment depends on various factors including the integrity of the roots, their shape, and the surrounding bone structure [16]. In this study, we used advanced technology such as CBCT, 3D reconstruction models, and laser Doppler blood flowmetry to assess the development of teeth, bone and pulp vitality after orthodontic treatment of impacted front teeth at different stages of development. The findings of this study can provide valuable information for evaluating the effectiveness of early treatment of upper impacted front teeth. This will help in predicting the outcome of treating impacted teeth in patients during their transitional dentition period.

Through the eruption process, all impacted central incisors are gradually repositioned within the dental arch. However, the root development of the impacted central incisors in the early, middle and late treatment groups progressed differently. After treatment, there was no significant difference in root length between the early treatment group and their contralateral incisors ($p > 0.05$). On the other hand, there was a significant difference in root length between the middle and late treatment groups and their contralateral incisors ($p < 0.05$). The dental development status of the impacted central incisors in the early treatment group was similar to that of their contralateral incisors compared to the middle and late treatment groups. This can be explained by the fact that during the early developmental stages of maxillary central incisors, their permanent tooth buds are located above the apices of the primary maxillary central incisors. They progressively reroute their growth in the labial direction, bringing their crowns closer to the primary teeth's resorbed roots as they grow. At this point, the pressure from trauma or persistent apical periodontitis in the primary maxillary central incisors may force the growing permanent tooth buds to shift positions. The maxillary bone, when viewed in the sagittal plane, has a trapezoidal cross-section. If the permanent tooth bud's position shifts, its root development may face resistance from the palatal, labial or nasal cortical bone of the maxilla. This can cause the impacted tooth roots to develop slowly, leading to delayed development [17]. During development, temporary shock may occur due to stimuli from chronic apical periodontitis in the primary maxillary central incisors. As a result, the normal differentiation of dental pulp epithelial sheaths into odontoblasts and root-forming cells may be disrupted, leading to delayed root development [18, 19]. But as the child gets older, the impacted teeth's roots keep growing–albeit more slowly–until apical closure happens. Dentists reduce pressure on impacted teeth's root development when they treat impacted teeth with closed eruption. Impacted teeth can erupt similarly to their contralateral teeth, and dentists can guide them into their proper locations by making use of the impacted tooth roots' development potential. This facilitates their growth and development, bringing them closer to the root development of their contralateral teeth. Therefore, the root development of impacted teeth in the early treatment group is similar to that of their contralateral teeth [20, 21].

In the early treatment group, there was no significant difference in tooth volume or surface area between impacted and contralateral teeth ($p > 0.05$). In the middle and late treatment groups, there were significant variations in tooth volume and surface area between impacted and contralateral teeth ($p < 0.05$). The early treatment group was closer to their contralateral teeth, whereas the middle treatment group was closer to their contralateral teeth compared to the late treatment group. This discrepancy can be explained as follows: before treatment, the dental crowns of the teeth were fully matured and would not change much. As a result, root length and tooth shape were the most important factors influencing tooth volume and surface area expansion. Crown-root curvature is a type of dental deformity defined by non-axial deviation in both growing tissues and fully formed sections [14]. All the impacted teeth were maxillary inverted central incisors, which are prone to crown-root curvature due to the limited space within the maxillary bone as root development progresses [10]. Curved root-impacted teeth made up 63.16% of the total (12/19) in the middle treatment group, and 91.30% (21/23) in the late treatment group. It was observed that in the early treatment group, only 23.53% of the total impacted teeth had curved roots, whereas the majority of impacted teeth in the middle treatment group had already developed crown-root curvature, which affected the morphology of their roots. Also, the root apices had a conical shape, and as root length increased in the later stages, it did not lead to significant growth in tooth volume and surface area [22]. On the other hand, in the early treatment group, most of the impacted teeth were in the early stages of root development, and they exhibited minimal morphological variation. With traction treatment, the roots developed normally and compensated for the differences in tooth volume and surface area when compared to their contralateral teeth. In the late treatment group, the impacted teeth were mostly confined by the maxillary bone throughout their maturation stages, resulting in root morphological differences. Despite receiving traction treatment, the root development had stopped, and they could not adjust for the discrepancies in tooth volume and surface area between their contralateral teeth.

Studies have shown that teeth that are impacted and have a curved root require more complex traction forces and face greater resistance [23]. To prevent root resorption and use lighter forces, treatment duration for impacted teeth with severe root curvature is longer, and their development is inhibited for a more extended period. Therefore, starting traction treatment at the early stages of impacted tooth development can make the treatment process more manageable and less time-consuming by helping the tooth to resist eruption.

The distance between the enamel-cementum junction and the alveolar crest is an important measure used to assess the stability of teeth following orthodontic traction treatment. This distance is typically considered normal if it is less than or equal to 2 mm, but if it exceeds 2 mm, it indicates alveolar bone loss and absorption [24]. A study conducted by Becker *et al.* [25] found that some damage to the periodontal tissues is inevitable during orthodontic traction of impacted maxillary teeth, leading to some degree of attachment loss (AL) and a reduction in attached gingival width. The researchers compared the differences in alveolar bone height on the labial and palatal sides between impacted teeth and their counterparts in each group after treatment and found significant differences between the early, middle and late treatment groups ($p < 0.05$). The alveolar bone height of impacted teeth in the early treatment group was closer to the normal criterion of 2 mm compared to the middle and late treatment groups. This suggests that periodontal recovery of impacted teeth is more optimal in the early treatment group, possibly because the children in this group had a younger average age at the time of treatment, which led to greater potential for alveolar bone development. Additionally, the degree of root curvature in impacted teeth was lower in the early treatment group, making traction easier and leading to a relatively shorter traction time, which had a more optimal impact on postoperative recovery and periodontal health, thereby leading to enhanced treatment outcomes [26].

In previous studies, the assessment of pulp vitality in impacted teeth after orthodontic traction was often conducted using a combination of pulp vitality testers and clinical examinations. However, these results often needed more objectivity. Laser Doppler blood flowmetry has emerged as a reliable method for assessing pulp vitality, providing a more objective, non-invasive, and accurate assessment, particularly for children patients whose root development is incomplete [7]. Foreign scholars have demonstrated the potential of utilizing Laser Doppler Flowmetry (LDF) in evaluating pulp vitality in cases of dentin hypersensitivity, maxillofacial surgery, and dental trauma [27–29]. After retaining traction treatment for three months, the pulp vitality of impacted teeth and their counterparts were evaluated a Laser Doppler blood flowmeter. The results showed that there was no significant difference in pulp blood flow between impacted teeth and their counterparts. Orthodontic forces primarily affect the blood vessels at the root apex, stimulating the differentiation of odontoblasts and osteoblasts, possibly leading to pulp calcification [30]. Thus, a larger pulp chamber in young permanent teeth can facilitate faster recovery from injury, indicating that earlier timing of traction can help avoid pulp damage.

This study was limited due to the low incidence of maxillary impacted central incisors and the lengthy orthodontic treatment required. Further research with more data and statistical analysis can generate more accurate assessments of clinical outcomes. It's important to note that the measurements only represent the status of teeth, alveolar bone, and pulp blood flow at the end of treatment. Over time, further changes may occur, and the ultimate results will require long-term follow-up.

5. Conclusions

Timing is crucial when it comes to orthodontic traction for impacted maxillary central incisors. It's best to start the treatment when the root is in its early development stage and hasn't yet reached two-thirds of its length. By doing so, the post-treatment measurements of root length, tooth volume, surface area, and alveolar bone height will be closer to those of the normal incisors on the other side. Depending on the developmental stage of the treatment, orthodontic traction can result in similar pulp vitality levels to those of normal incisors.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

LQS and HH—designed the research study. KGL—performed research work; analyzed the data. RHJ and CMZ—provided help and advice on treatment design. KGL and HH—wrote the manuscript. All authors contributed to the editorial changes in manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All procedures performed in this study were in accordance with the Declaration of Helsinki (1964) and it was obtained approval from the Ethics Committee of Jinan Stomatological Hospital (JNSKQYY-2021-025). Informed consent was obtained from a parent or guardian; assent was obtained from the minor. Patients could withdraw from the study whenever they wanted without compromising the agreed treatment.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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