ORIGINAL RESEARCH

Adjustable Removable Traction Appliance With Surgically Assisted Eruption for Impacted Maxillary Central Incisors

Wei Chen, MM; Yiguo Li, MM; Ke Wang, MM; Sibo Xu, MM; Hailiang Feng, MM; Wei Zhang, MM

ABSTRACT

Context • Impacted maxillary central incisors (MCIs) can seriously affect children's appearance, verbal abilities, and maxillofacial development. Clinically, a combination of surgically assisted eruption and orthodontic traction is the treatment modality most acceptable to dentists and children's families. However, previously used traction methods have been complex and required a long treatment time.

Objective • The study intended to evaluate the clinical effects of the use of the research team's adjustable removable traction appliance combined with a surgically assisted eruption of impacted MCIs.

Design • The research team performed a controlled prospective study.

Setting • The study took place at Department of Orthodontics, Hefei Stomatological, Hospital.

Participants • 10 patients with impacted MCIs, aged 7-10 years, who had visited the hospital between September 2017 and December 2018.

Intervention • The research team assigned the impacted MCIs to the intervent ion group and contral ateral normal MCIs to the control group. For the intervention group, the research team performed a surgical eruption and inserted the adjustable removable traction appliance. The control group received no treatments.

Outcome Measures • Postintervention, the research team determined the mobility of both groups' teeth. At baseline and immediately postintervention for both groups, the team performed cone-beam computed tomography (CBCT) and measured root length, apical-foramen width, volume, surface area, and root-canal wall thickness for the labial and palatal sides. For both groups, after the intervention group's treatments, the team: (1) performed electric pulp testing and periodontal probing on the participants' teeth; (2) measured and documented pulp vitality, gingival index, periodontal probing depth, and gingival height (GH)for the labial and palatal sides; and (3) measured labial-and-palatal, alveolar bone level and alveolar bone thickness.

Results • At baseline, the intervention group showed delayed root development, and that group's root length was significantly shorter ($P < .05$) and apical-foramen width ($P < .05$) was significantly greater than those of the control group. The intervention group's treatment success rate was 100%. And the intervention group did not have any adverse reactions, such as tooth loosening, gingival redness and swelling, or bleeding. Postintervention, the intervention group's labial GH was significantly higher than that of the control group, at 10.58 ± 0.45 mm and 9.47 ± 0.31 mm, respectively ($P = .000$). The increase in the intervention group's root length postintervention was significantly greater than that of the control group, at 2.80 ± 1.09 mm and 1.84 ± 0.97 mm, respectively ($P < .05$). The intervention group also had significantly greater decrease in the apical-foramen width than the control group did, at 1.79 ± 0.59 mm and 0.96 ± 0.40 mm, respectively ($P < .05$). At the end of traction, the intervention group had significantly higher labial-and-palatal alveolar-bone levels, at 1.77 ± 0.37 mm and 1.23 ± 0.21 mm, respectively, than the control group did, at 1.25 ± 0.26 mm ($P = .002$) and 1.05 ± 0.15 mm ($P = .036$), respectively. The labial alveolar-bone thickness in the intervention group was thinner than that of the control group, at 1.49 ± 0.31 mm and 1.80 ± 0.11 mm, respectively ($P = .008$). The volume and surface area ($P < .01$) of the intervention group's impacted teeth had increased significantly postintervention (both $P < .01$), but both were significantly smaller than those of the control group, both at baseline and postintervention.

Conclusions • An adjustable removable traction appliance combined with a surgically assisted eruption can be a reliable treatment for impacted MCIs and can provide root development and a good periodontal-pulp condition postintervention. (*Altern Ther Health Med.* 2023;29(6):134-142).

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An impacted tooth is a common developmental anomaly in clinical practice that can have a great impact on the functioning of the human system and can create aesthetics issues. Some studies have shown that the incidence of impacted maxillary central incisors (MCIs) is as high as 1.5% to 4.22%, and MCIs can seriously affect children's appearance, verbal abilities, and maxillofacial development.[1-3] Impacted MCIs that aren't treated in a timely manner can lead to adjacent root resorption[4] and the formation of contiguous cysts,[5] causing serious physical and psychological harm to patients.

Tan et al found that the three main etiologies of impaction of MCIs include curved roots (27.5%), multiple teeth (19.1%), and abnormal tooth germ position (16.5%), with the last one being the major contributor.[2] Those researchers also found that abnormal tooth germ position was significantly correlated with trauma to deciduous teeth.

Treatment of impacted MCIs is difficult due to deep impaction; commonly recommended methods include surgical extraction, tooth autotransplantation, and surgically assisted eruption combined with orthodontic traction.[6-8]

Treatments

Clinically, a combination of surgically assisted eruption and orthodontic traction is the treatment modality most acceptable to dentists and children's families. This modality can treat impacted central incisors early so that they assume the correct eruption position, thus achieving protection of dental pulp vitality, maximum preservation of maxillary basal bones, and early restoration of facial aesthetics and pronunciation function.[9,10] Sun et al showed that immediate mild traction can relieve partial resistance and unleash the root's growth potential, which can result in satisfactory therapeutic results for impacted MCIs.[11]

However, previously used traction methods have been complex and required a long treatment time. Worse, the direction and size of the traction force were difficult to control, leading to orthodontic, anchorage-associated periodontium damage and even root resorption or traction failure in severe cases, with consequent removal of the affected tooth.

Traction Methods

The methods for traction of impacted MCIs include fixed traction and removable traction, which use different traction tools. Fixed traction includes: (1) main arch-wire traction, (2) auxiliary-arch traction, (3) micro-implant-assisted traction, and (4) modified Nance[12] arch traction. Removable appliances fall into two types: (1) a protraction appliance and (2) appliances made with baseplates.

Researchers have different views on the timing of traction for impacted central incisors. Some believe that traction can damage the epithelial root sheath and thus affect root development when the root isn't yet mature,[13] while others have found that early traction of impacted central incisors can be beneficial in preserving the labial bone plate and reduce root resorption.[13-15] The latter have demonstrated that early traction is associated with stronger remodeling ability for the alveolar bone, can relieve some resistance and release the growth potential of the root by pulling the developing root from the cortical bone to the cancellous bone.

Cheng et al found that the roots of impacted tooth receiving early traction could advance growth, and the growth rate wasn't covered.[16] Sun et al and Lygidakis et al found that: (1) late treatment showed a higher incidence of curved roots in the impacted MCIs than early treatment; (2) late treatment increased the risk of root resorption and labial-bone opening; (3) early treatment facilitated traction to help advance root growth and development; and (4) late treatment of an impacted MCI had no chance of improving the root shape.[11,17,18]

Kuvvetli also reported an ideal long-term postoperative effect for traction therapy for impacted MCIs with curved roots.[19] The reason may lie in a good physical inlay state between curved roots and the alveolar bone, allowing the crowns to bear normal occlusive force.

Adjustable Removable Traction Appliance

Considering the characteristics of the currently available traction tools, the research team designed an adjustable removable appliance that expands the tooth gaps and creates traction of the MCIs at the same time.

The current research team's appliance has some advantages. First, the traction and expanding of tooth gaps using springs can occur at the same time, reducing treatment time. Other treatment methods require 3-6 months to attain gap expansion before traction can occur. The shortened time is not only conducive to the premature separation of the root from the cortical bone but also favors the root's development. Additionally, the early recovery of missing anterior teeth can provide positive effects on the physical and mental health of children, which is a unique feature of the current team's treatment.

Second, the removal and wearing of the appliance is easy for children, who can clean it with the help of parents. Therefore, patients can avoid the oral-hygiene problems that are common with the use of fixed appliances and that can affect periodontal health. Also, the appliance can prevent food-debris retention and the resulting palatal gingival redness and swelling that can cause failure in the return of the affected teeth to the correct position.

Third, the appliance provides appropriate traction force. The traction hook on the appliance can adjust the traction force as far as possible, to be vertical to the long axis of the tooth. This reduces periodontal stress and obtains a faster tooth-movement speed, with the lightest traction force, and protection of root development.

Fourth, dental personnel can perform the adjustment of the traction-force size and direction after the appliance's removal from the patient's mouth. This chair-side operation can avoid the adverse effects of intraoral force on the adjacent teeth and periodontium.

Current Study

The current study intended to evaluate the clinical effects of the use of the research team's adjustable removable traction appliance combined with a surgically assisted eruption of impacted MCIs.

METHODS

Participants

The research team performed a controlled prospective study, which took place on Department of Orthodontics, Hefei Stomatological, Hospital, Hefei, China. Potential participants were patients with impacted MCIs and contral ateral normal MCIs,, who had visited Hefei Stomatological Hospital between September 2017 and December 2018. We found the participants through a combination of recruitment strategies, including advertising on social media, distributing flyers, and contacting local clinics and hospitals. We used a screening process to select participants who met our study criteria, and we ensured that both the intervention group and the control group were recruited in the same way. In terms of contacting participants, we initially reached out to them through email or phone to provide information about the study and assess their eligibility. If they met our criteria and were interested in participating, we scheduled an initial meeting to obtain informed consent and conduct baseline assessments. To clarify, we were not the participants' doctors, and we did not provide any medical treatment or advice. Our study focused on evaluating the effectiveness of a specific intervention, and we collaborated with healthcare providers to ensure that participants received appropriate medical care throughout the study.

The study included potential participants with impacted MCIs if: (1) they were 6-12 years old age at the time of the visit to the hospital; (2) they had had a contralateral MCI eruption for more than 6 months, a lower-incisor eruption for more than one year, or a lateral-incisor eruption; (3) they had a labial-inverted impacted MCI, (3) they had only one impacted central incisor in the maxilla, with a contralateral MCI that had erupted normally. Such patients are hard to treat and have a higher failure rate in cases of traction of impacted central incisors.

The study included potential participants with contralateral normal MCIs if: (1) absence of any neurological or psychiatric conditions that could affect cognitive function, (2) no history of significant head injury or substance abuse, (3) no current use of medications that affect cognitive function, and (4) absence of significant visual or hearing impairment.

The study excluded potential participants with impacted MCIs if: (1) both sides of the mouth had MCIs that presented with no normal eruption; (2) patients and their families rejected traction therapy or were poorly compliant; (3) systemic diseases had cause the impaction of the MCIs; (4) the affected teeth weren't suitable for traction treatment, such as impacted teeth occurring near the nasal floor; or (5) traction therapy would have easily led to adjacent root resorption because of the close relationship between the impacted tooth and the adjacent root in the position.

We initially screened 50 individuals, but we excluded some of them based on specific inclusion and exclusion criteria that we established for the study. The criteria included factors such as age, gender, medical history, and medication use, among others. We selected the final 10 participants based on their ability to meet these criteria and their willingness to participate in the study. We believe that this group was representative of the target population and allowed us to obtain meaningful results.

The patients and their families signed informed consent forms at baseline to show that they fully understood the treatment risks and significance. The Medical Ethics Committee of Hefei Stomatological Hospital (20190102) discussed and approved the study's protocols.

Procedures

Data collection. At baseline, the research team performed a clinical examination of participants and data collection, recording the participants' ages, genders, tooth positions, treatment times, and crown angles. We recorded treatment times during the intervention as a process measure to assess fidelity of implementation. It was not an outcome measure per se, but rather a means of monitoring the intervention delivery. We used a standardized protocol to ensure consistent and accurate recording of treatment times.

Groups. The research team assigned the impacted MCIs to the intervention group and contralateral normal MCIs to the control group.

Cone beam computed tomography (CBCT). One senior radiologist at Hefei Stomatological Hospital West obtained CBCT images of all participants under the same conditions and using the same radiological equipment (Meyer CBCT, Hefei, China). The radiologist positioned participants in a sitting position to maintain the mandibular posture position.

Additionally, the Frankfort horizontal plane was parallel to the ground, while the facial midline was perpendicular to the ground. The scanning range of the CBCT examination was from the nasion to the lower edge of the third cervical vertebra, and the scanning conditions were: (1) a scanning resolution of 0.25 mm, (2) a scanning time of 14 seconds, (3) a tube voltage of 84 kV, and (4) current at 5-7 mA.

Positioning of impacted tooth. For the intervention group, the research team used periapical radiographs or panoramic radiographs to rule out a congenital absence and then used the CBCT to determine the impaction of the MCI, including the impaction type, depth, and positional relationship with adjacent teeth. The CBCT images determined the location of the incision for the surgical eruption, the extent of exposure, and the choice of attachments, to ensure that adjacent teeth didn't block the eruption route and that the linear distance was the shortest possible.

In the CBCT sagittal view (Figure 1), the anterior nasal spine (ANS) point and posterior nasal spine point (PNS) shows the hard palate plane (PP). The research team: (1) created a line, VP, that was perpendicular to the PP; (2) connected the A1 point, the palatal cementoenamel junction (CEJ) to the A2 point, the labial CEJ, (3) marked an A point that was the midpoint of the A1-A2 line; (4) created a line, MP, that was perpendicular to the A1-A2 line; and (5) created the B1 point, the labial apical foramen, and connected it to the B2 point, the palatal apical foramen, placing a B point as the midpoint of B1-B2 line.

Figure 1. CBCT Sagittal View of the Labially Inverted, Maxillary Central Incisor for the Participant in the Intervention Group. The research team: (1) created a line, VP, that was perpendicular to the hard palate plane; (2) connected the A1 point, the palatal cementoenamel junction (CEJ) to the A2 point, the labial CEJ, and (3) marked an A point that was the midpoint of the A1-A2 line; (4) created a line, MP, that was perpendicular to the A1-A2 line, and (5) created the B1 point, the labial apical foramen, and connected it to the B2 point, the palatal apical foramen, placing a B point as the midpoint of B1-B2 line.

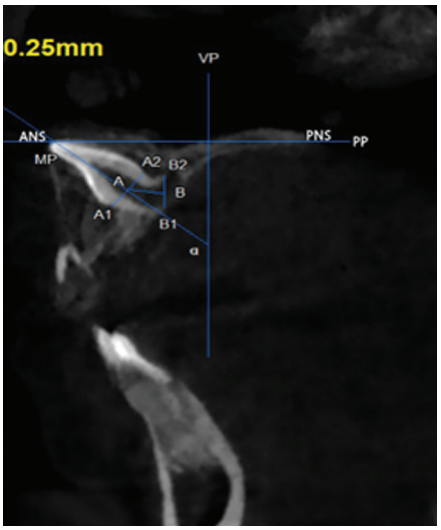


Figure 2. Drawing and Actual Photograph of Adjustable Removable Traction Appliance. Figure 2A shows a drawing of the appliance with its components, including the base plate (1), labial arch (2), spring (3), traction hook (4), interproximal hook (5), Adam's clasp (6), and W curve on labial arch (7). Figure 2B shows a front view of the appliance, and Figure 2C shows a side view of the appliance.

Based on information in Wang et al's study, the MP suggested the direction the crown's long axis, and the angle alpha (α) between the MP and VP was the crown's angle.[20] The research team diagnosed participants with an incisor edge below the tooth's neck as labially inverted impactions.

Intervention. For the intervention group, the research team performed a surgical eruption and inserted the adjustable removable traction appliance. The control group received no treatments.

Outcome measures. Postintervention, the research team determined the mobility of both groups' teeth. At baseline and immediately postintervention for both groups, the team performed cone-beam computed tomography (CBCT) and measured root length, apical foramen width, volume, surface area, and root-canal wall thickness for the labial and palatal sides.

For both groups, after the intervention group's treatments, the team: (1) performed electric pulp testing and periodontal probing on the participants' teeth; (2) measured and documented pulp vitality, gingival index, periodontal probing depth, and gingival height (GH) for the labial and palatal sides; and (3) measured labial-and-palatal, alveolar-bone level and alveolar-bone thickness.

Interventions

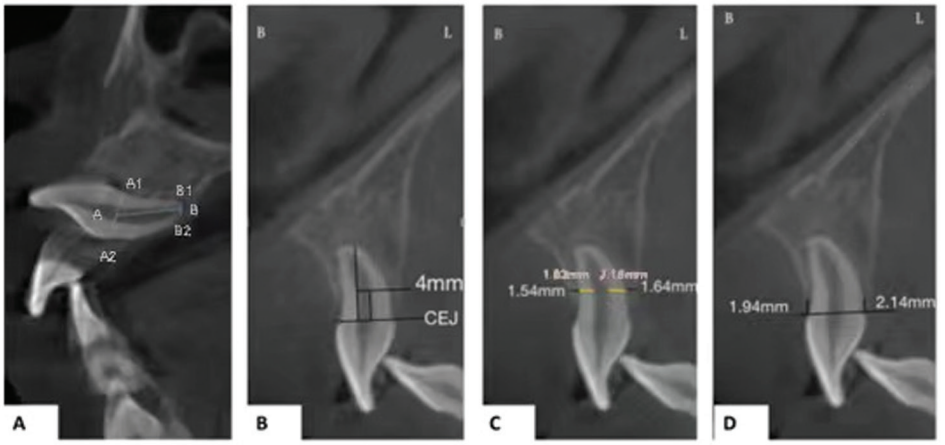
Surgical eruptions. The research team used the closed-eruption technique. The team routinely disinfected the maxillofacial region using iodine and isolated the surgical area using sterile drapes. During the procedure, the team achieved adequate hemostasis with a dental cotton roll soaked in epinephrine and avoided exposure of the CEJ.

To perform the eruption, the team: (1) gave the participants an epinephrine injection and then after determination of the position of the crown using CBCT, made a surgical incision on the labial side under local infiltration anesthesia with Primacaine Adrenaline 1/100 000 (Produits Dentaires Pierre Rolland, MERIGNAC, France); (2) turned over the mucoperiosteum and removed only the bone around the impacted tooth's incisive edge; (3) opened part of the dental sac's wall to allow the bonding of brackets; (4) carried out etching of the tooth's surface after obtaining adequate hemostasis, using brackets or lingual buttons (Shinye Orthodontic Products, Hangzhou, China) with hooks made of bended 0.25 mm ligatures; (5) classified the wound and exposed the hooks; (6) performed postoperative anti-infection procedures for 3 to 5 days; (7) postoperatively for one week after surgery had participants use 0.12% -0.2% chlorhexidine gluconate, an oral rinse; and (9) removed the stitches at 7 to 10 days after surgery.

Traction treatments. The research team: (1) connected the traction hook coming out of the mucoperiosteum with the hook attached to the adjustable removable traction appliance, using a rubber band (Figures 2A, 2B, and 2C); (2) instructed the participant or his or her family to change the rubber band every day, an easy process that expanded the tooth gaps and traction of the MCIs; (3) revisited participants every 3-4 weeks to examine the traction of the affected teeth and adjust the direction and size of the traction force by adjusting the hooks on the appliance, to ensure that the traction force continued to be acceptable to the participant; (4) when one-half of the impacted MCI's crown returned to the dentition, used a 2 × 4 fixed orthodontic appliance to align the dentition.

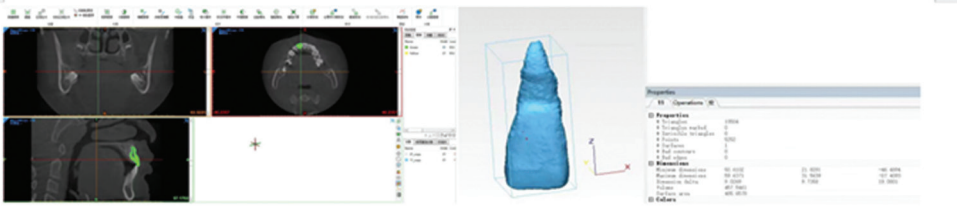
The first aligning used a 0.12-mm, nickel-titanium arch wire, and at the visits every 3-4 weeks, the research team gradually changed the arch wire into a thicker one until final alignment of the dentition occurred. After that point, participants wore a fixed orthodontic appliance with the final arch wire for one month continuously. After the removal of the fixed appliance, the research team bonded the lingual retainer to the lingual side of the affected tooth and the contralateral tooth.

Figure 3. CBCT Images Showing Detection and Calculation of the Clinical Characteristics of an MCI for a Participant in the Intervention Group. Figure 3A shows the root length and apical-foramen width; Figure 3B shows the root-canal wall thickness; Figure 3 C shows the alveolar-bone thickness; and Figure 3D shows the alveolar-bone level.



Abbreviations: CBCT, cone-beam computed tomography; CEJ, cementoenamel junction

Figure 4. Three-dimensional (3D) Reconstruction Using Mimics 21.0 Software



Outcome Measures

Loosening inspection, determination of tooth mobility. For both groups, the research team clamped the affected tooth's incisive edge with a forceps to wiggle the tooth labiolingually, mesiodistally, and vertically. Based on the observation, the team indicated the degree of the tooth's looseness as being grade 1—labiolingual mobility, grade 2—labiolingual and mesiodistal mobility, or grade 3—labiolingual, mesiodistal, and vertical mobility.

Electric pulp testing. The research team subjected both groups' pulp vitality to a pulp tester by covering the probe with a conductive agent, toothpaste, and placing it on the labial surface of middle third of the tooth, after isolating it from the adjacent teeth. The team tested the control group's teeth first, followed by intervention group's affected teeth that had been processed with traction.

The electrical current was zero at the beginning of the test, and the team slowly increased the current. When patients felt any sensation, the team removed the tester and recorded the current's value.

Measurements of gingival index, periodontal probing depth, and gingival height. The research team measured: (1) the gingival index using the mean value from measurement of three sites on the labial surface—mesial, central, distal—and one site on the palatal surface—central; (2) the probing depth using the mean value of six sites, three on the labial surface—mesial, central, and distal—and three on the palatal surface—mesial, central, and distal; and (3) the GH using the distance from the highest point of the gingival margin on the labial and palatal sides to the incisive edge.

Detection of root status and periodontal status. The research team: used the points and lines previously drawn on the previously mentioned CBCT sagittal view to determine: (1) the root length—the straight-line distance from point A to point B, and (2)the width of the apical foramen—the distance from B1 to B2 was the (Figure 3A).

Additionally, the team: (1) at 4 mm below the CEJ on the labial (Figure 3B) and palatal (Figure 3C) sides, measured and recorded the root-canal wall thickness and alveolar-bone thickness, and (2) recorded the distance from the labial and palatal alveolar crest to the CEJ as the labial and palatal alveolar bone level (Figure 3D).

Measurement of volume and surface area. The research team imported the CBCT data into Mimics 21.0 software (Materialise , Shanghai, China) in DICOM format for separation and three-dimensional (3D) reconstruction of the target teeth, with a segmentation threshold of 620-3517 (Figure 4). The team calculated both groups' tooth volume and surface area at baseline and postintervention as well as the difference between the time points.

Statistical Analysis

The same investigator repeated all measurements at two-week intervals and determined the intra-examiner error using the interclass correction coefficient, based on a two-way mixed analysis of variance (ANOVA). The investigator used the average of the two measurements as the final result.

The research team performed the data analysis using SPSS 26.0 software (IBM, Armonk, NY, USA). The team: (1) expressed measurement data as means ± standard deviations (SDs), (2) performed homogeneity tests, (3) used the independent sample *t* test for comparisons between groups for measurement data that conformed to a normal distribution, (4) used the nonparametric rank sum test for comparisons between groups for data not conforming to a normal distribution, (5) expressed counting data as numbers (N) and percentages (%) and compared the groups using the chi-square test (χ^2). $P < .05$ indicated a statistically significant result.

Table 1. Participants' Demographic and Clinical Characteristics (n = 10)

Groups	n (%)	Gender		Tooth Position		Age, y Mean ± SD	Treatment Time, m Mean ± SD	Crown Angle, degree Mean ± SD
		Male n (%)	Female n (%)	Left n (%)	Right n (%)			
Intervention	10 (50.00)	4 (40.00	6 (60.00)	4 (40.00)	6 (60.00	8.20 ± 0.92	8.60 ± 1.26	119.98 ± 14.15

Table 2. Comparison of the Clinical Outcome Measures Between the Intervention and Control Groups Postintervention (N = 20)

Groups	n (%)	Pulp Vitality Mean ± SD	Probing Depth, mm Mean ± SD	Labial Gingival Height, mm Mean ± SD	Palatal Gingival Height, mm Mean ± SD
Intervention	10 (50.00)	28.30 ± 3.62	1.30 ± 0.22	10.58 ± 0.45	8.21 ± 0.46
Control	10 (50.00)	26.50 ± 3.00	1.17 ± 0.14	9.47 ± 0.31	8.15 ± 0.28
t value		1.212	-	6.412	0.355
P value		.241	.218	.000[a]	.727

[a]$P < .05$, indicating that the intervention group's labial gingival height was significantly higher than that of the control group

Table 3. Comparison of Changes Between Baseline and Postintervention in Root Status for the Intervention and Control Groups (N = 20)

	Intervention Group, n = 10			Control Group, n=10			Difference at Baseline		Difference Postintervention	
	Baseline Mean ± SD	Postintervention Mean ± SD	Change	Baseline Mean ± SD	Postintervention Mean ± SD	Change	*t* value	*P* value	*t* value	*P* value
Root length	7.28 ± 1.03	10.08 ± 0.63	2.80 ± 1.09	9.80 ± 1.46	11.75 ± 0.90	1.84 ± 0.97	4.460	<.01[a]	4.807	<.01[b]
Apical-foramen width	2.18 ± 0.63	0.39 ± 0.12	1.79 ± 0.59	1.26 ± 0.40	0.29 ± 0.10	0.96 ± 0.40	3.389	<.01[a]	2.024	.058
Labial root-canal wall thickness	1.55 ± 0.12	1.70 ± 0.12	0.15 ± 0.07	1.56 ± 0.12	1.69 ± 0.12	0.12 ± 0.05	0.186	.854	0.186	.854
Palatal root-canal wall thickness	1.57 ± 0.14	1.72 ± 0.19	0.16 ± 0.12	1.59 ± 0.15	1.74 ± 0.14	0.15 ± 0.07	2.715	.014	0.268	.791

[a]$P < .01$, indicating that the intervention group's root length was significantly shorter and apical-foramen width was significantly longer than those of the control group at baseline

[b]$P < .01$, indicating that the intervention group's increase in root length and decrease in apical-foramen width between baseline and postintervention were significantly greater than those of the control group

RESULTS

Participants

The study included and analyzed the data of 10 participants (Table 1), included four males (40.00%) and six females (60.00%), and the tooth position was left for four participants (40.00%) and right for six participants (60.00%). That group's mean age was 8.20 ± 0.92 years, mean treatment time was 8.60 ± 1.26 months, and mean crown angle was 119.98 ± 14.15 degrees.

Clinical Outcomes

Postintervention, the incisive edge of the intervention group's affected MCIs were in the same horizontal line as those of the control group selected MCIs. Additionally, the intervention group's affected MCIs showed no abnormal crown color or shape and no adhesion; the treatment success rate reached 100%. Neither group had adverse reactions such as tooth loosening, gingival redness and swelling, or bleeding.

Table 2 shows that the intervention group's labial GH, at 10.58 ± 0.45 mm, was significantly higher than that of the control group, at 9.47 ± 0.31 mm ($P = .000$). No significant differences existed in pulp vitality, probing depth, or palatal GH between the groups ($P > .05$).

Root Status

At baseline, the intervention group's root length was 7.28 ± 1.03 mm and apical-foramen width was 2.18 ± 0.63 mm, which were significantly shorter and greater, respectively, than those of the control group, at 9.80 ± 1.46 ($P < .01$) and 1.26 ± 0.40 ($P < .01$), respectively, indicating a growth and development delay for the intervention group's inverted impacted MCIs (Table 3).

Between baseline and postintervention, the intervention group's root length increased from 7.28 ± 1.03 mm to 10.08 ± 0.63 mm, a change of 2.80 ± 1.09, and the increase was significantly greater than that of the control group, at 1.84 ± 0.97 mm ($P < .05$), from 9.80 ± 1.46 mm to 11.75 ± 0.90 mm.

Between baseline and postintervention, the intervention group's apical-foramen width decreased from 2.18 ± 0.63 to 0.39 ± 0.12, a change of 1.79 ± 0.59, and the decrease was significantly greater than that of the control group, at 0.96 ± 0.40 ($P < .05$), from 1.26 ± 0.40 to 0.29 ± 0.10.

Table 4. Comparison of Periodontal Development Between the Intervention and Control Groups Postintervention (N = 20)

Groups	n (%)	Labial Alveolar-bone Level Mean ± SD	Palatal Alveolar-bone Level Mean ± SD	Labial Alveolar-bone Thickness Mean ± SD	Palatal Alveolar-bone Thickness Mean ± SD
Intervention	10 (50.00)	1.77 ± 0.37	1.23 ± 0.21	1.49 ± 0.31	1.71 ± 0.33
Control	10 (50.00)	1.25 ± 0.26	1.05 ± 0.15	1.80 ± 0.11	1.89 ± 0.26
t value		3.667	2.264	-3.002	-1.361
P value		.002[a]	.036[a]	.008[a]	.190

[a]$P < .05$, indicating that the intervention group's labial and palatal alveolar-bone levels were significantly higher and labial alveolar-bone thickness was significantly lower than those of the control group postintervention

Table 5. Comparison of the Changes in the Tooth Volume and Surface Area Between Baseline and Postintervention for the Intervention and Control Groups and Comparison Between the Groups (N = 20)

		Tooth Volume			Difference Between Time Periods	
Group	n (%)	Baseline Mean ± SD	Postintervention Mean ± SD	Change	*t* value	*P* value
Intervention	10 (50.00)	405.68 ± 61.10	430.80 ± 57.61	25.12 ± 8.40	5.478	<.01[b]
Control	10 (50.00)	440.77 ± 62.87	466.75 ± 64.90	25.99 ± 6.80	0.909	.375
t value		4.587	5.694			
P value		<.01[a]	<.01[a]			
		Surface Area			Difference Between Time Periods	
Group	n (%)	Baseline Mean ± SD	Postintervention Mean ± SD	Change	*t* value	*P* value
Intervention	10 (50.00)	386.16 ± 51.01	413.65 ± 49.09	27.50 ± 8.98	4.454	<.01[b]
Control	10 (50.00)	418.96 ± 41.63	444.43 ± 40.65	25.47 ± 8.54	1.384	.183
t value		3.746	4.678			
P value		<.01[a]	<.01[a]			

[a]$P < .01$, indicating that the intervention group's tooth volume and surface area were significantly smaller than those of the control group both at baseline and postintervention
[b]$P < .01$, indicating that the intervention group's tooth volume and surface area significantly increased between baseline and postintervention

No significant differences existed between the groups in the changes between baseline and postintervention in the labial or palatal root-canal wall thicknesses.

Periodontal Status

Table 4 shows that postintervention the intervention group's labial alveolar-bone level was 1.77 ± 0.37 mm and palatal alveolar-bone level was 1.23 ± 0.21 mm, and the levels were significantly higher than those of the control group, at 1.25 ± 0.26 mm ($P = .002$) and 1.05 ± 0.15 mm ($P = .036$), respectively.

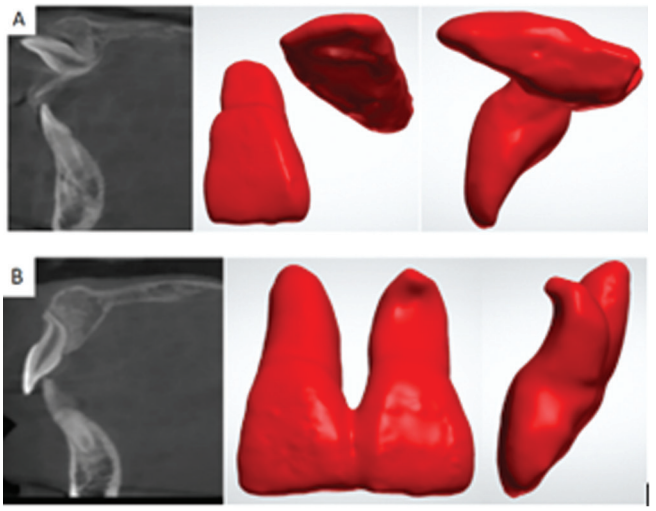
Postintervention, the intervention group's labial alveolar-bone thickness was 1.49 ± 0.31 mm, which was significantly lower than that of the control group, at 1.80 ± 0.11 mm ($P = .008$).

No significant difference existed in the groups' palatal alveolar-bone thickness postintervention ($P > .05$).

Tooth Volume and Surface Status

Table 5 shows that between baseline and postintervention, the intervention group's tooth volume increased significantly, from 405.68 ± 61.10 to 430.80 ± 57.61 for a change of 25.12 ± 8.40 ($P < .01$), and the group's surface area also increased

Figure 5. CBCT Images of the Front and Side Views of Participant's Teeth at Baseline and Postintervention. Figure 5A shows the teeth at baseline, and Figure 5B shows the teeth postintervention.



Abbreviations: CBCT, cone-beam computed tomography

Figure 6. Views of Participant's Teeth Throughout the Intervention

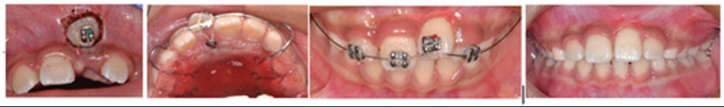
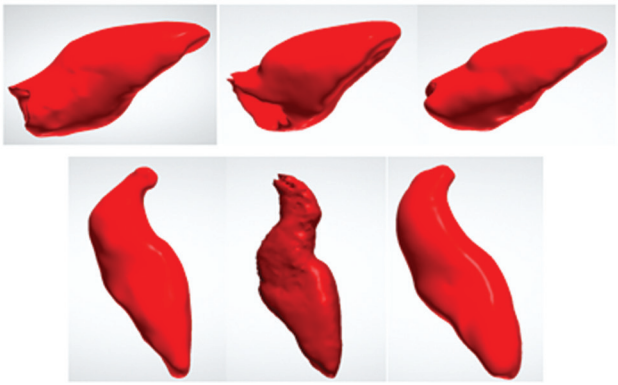


Figure 7. Three-dimensional (3D) Reconstruction of Participant's Teeth Between Baseline and Postintervention



significantly, from 386.16 ± 51.01 to 413.65 ± 49.09 for a change of 27.50 ± 8.98 ($P < .01$).

The intervention group's volume and surface area were significantly smaller than those of the control group, both at baseline ($P < .01$) and postintervention ($P < .01$).

The increase in the volume and surface area of the impacted MCIs was 25.12 ± 8.40 and 27.50 ± 8.98, respectively, after traction. The 3D reconstruction of the traction for one participant's tooth found a significant secondary-bending phenomenon (Figure 7).

This bending indicates that even though the root development of impacted MCIs was obstructed by the inverted block, the Hertwig's epithelial root sheath could still produce new dentin and allow the roots to develop ideally as long as a suitable traction force was applied to give the roots room to develop before the apical foramen closed.

Case Study

A nine-year-old boy visited the hospital because his left permanent MCI had failed to erupt, although his exact primary MCIs had detached two years prior to the visit. At the same time, the boy had had normal growth of the right permanent MCIs for two years.

The relevant examinations occurred. The CBCT showed an inverted impaction of the low site (Figure 5A). Collectively, the test results suggested a clinical diagnosis of inverted labial impaction. The research team used the closed-eruption technique and provided the adjustable removable traction appliance until one-half of the crown had returned to the dentition.

The child returned to the hospital 10 days after the operation, after wearing the removable appliance, and thereafter returned once a month. With the tooth eruption, the team appropriately adjusted the length and position of the traction hook on the adjustable removable appliance to ensure an effective traction force and traction direction. After a treatment period of 13 months, the boy had achieved a good therapeutic effect in terms of tooth, connective tissue, and dental pulp (Figure 5B).

Subsequently, the team used a 2 × 4 fixed orthodontic appliance to reach final aligning of the dentition. The operation went smoothly (Figure 6).

DISCUSSION

After treatment, the intervention group's teeth showed no significant differences from the control group's normal contralateral MCIs in terms of the tooth or periodontal or pulp status.

The intervention group's treatment time in the current study was 8.60 ± 1.26 months. In contrast, the modified Nance arch appliance for labial inverted impacted MCIs requires an average treatment time of 18.10 ± 6.23 months.[12] A shortening in treatment time is not only conducive to the premature separation of the root from the cortical bone but also favors the development of the root.

Additionally, the early recovery of missing anterior teeth can bring positive effects to the physical and mental health of children, which is a unique feature of the team's treatment. The shorter treatment time, generally, is the greatest advantage of the adjustable removable traction appliance.

The change in the intervention group's the root length and apical-foramen width indicates that the early use of an adjustable traction appliance had a promoting effect on the root's development. In terms of the root length, the intervention group had a shorter length than the control group at baseline and postintervention, which was similar to the findings of Cheng et al, Sun et al, and Wang et al.[16,21,22]

The current research team conjectures that although the traction intervention makes the root free from the palatal cortical bone and restores the growth potential of the root, the thickness of the palatal cortical bone at baseline affects the growth of epithelial root sheaths. The epithelial root sheaths shrink prematurely form the epithelial diaphragm, thus affecting root length.

Although the root length of the treated teeth was different from that of the control teeth, the crown-to-root ratios were both above 1:1. Although 80% of the central incisors after traction were curved roots, no significant differences existed in mobility between the two groups. These results suggest that the central incisors after traction could function normally.

The two groups had significantly different labial bone-plate thickness and alveolar-crest height, but no significant difference on the palatal side. The research team suspects that the labial alveolar-bone defects often occur in labial inverted impaction and result in movement of teeth from the palatal side to the labial side.

The traction movement path affected the labial alveolar bone while the palatal side didn't show significant abnormalities after traction treatment because the alveolar bone was thick at baseline. Therefore, the former is associated with low bone remodeling and unsatisfactory results for the

labial alveolar-bone height and thickness and even gingival recession can occur. However, Cheng et al found that the labial alveolar bone was markedly improved one year postintervention compared with that immediately postintervention.[16] This confirms the current research team's conjecture on painful bone remodeling.

The current study had some limitations. Postoperative follow-up was absent, and more follow-up records of numerous examinations of patients' teeth, especially for patients with insufficient gingival height could further improve the trial. If gingival height still fails to reach satisfactory levels until adulthood, dentists could perform mucogingival surgery to restore gingival height.

The current research team's adjustable removable traction appliance is a reliable and effective treatment for early traction of impacted MCIs, and it greatly shortens the traction time and provides appropriate traction with an adjustable angle and a light and continuous force.

CONCLUSIONS

An adjustable removable traction appliance combined with a surgically assisted eruption can be a reliable treatment for impacted MCIs and can provide root development and a good periodontal-pulp condition postintervention.

AUTHORS' DISCLOSURE STATEMENT

The authors declare that they have no conflicts of interest related to the study.

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