https://doi.org/10.5933/JKAPD.2025.52.4.496
ISSN (print) 1226-8496 ISSN (online) 2288-3819

JOURNAL OF THE KOREAN ACADEMY OF PEDIATRIC DENTISTRY JKAPD

Original Article

Skeletal, Dentoalveolar, and Soft Tissue Changes Following Prefabricated Functional Appliance Treatment for Functional Anterior Crossbite in Mixed Dentition

Wonbin Seo[1], Eungyung Lee[1,2], Soyoung Park[1,2], Taesung Jeong[1,2], Jonghyun Shin[1,2]

[1]Department of Pediatric Dentistry, School of Dentistry, Dental and Life Science Institute, Pusan National University, Yangsan, Republic of Korea
[2]Department of Pediatric Dentistry, Dental Research Institute, Pusan National University Dental Hospital, Yangsan, Republic of Korea

Abstract

In this study, we aimed to evaluate the therapeutic effects of a prefabricated functional appliance (PFA) for managing functional anterior crossbite during the mixed dentition phase and to assess its potential applicability as an interceptive treatment modality. Thirty patients (15 males and 15 females) presenting with anterior crossbite were treated with Pre-Ortho® Type 3 exclusively. Participants were instructed to wear the appliance for 1 hour during the day and continuously while sleeping. Compliance was monitored according to the caregiver's instructions. Lateral cephalometric radiographs were obtained at pretreatment (T0) and posttreatment (T1) and analyzed using a total of 16 angular and linear variables, respectively, to assess for skeletal, dentoalveolar, and soft tissue changes. The cephalometric examination was conducted using V-Ceph™ 8.0 (Osstem, Seoul, South Korea) and ON3D software (3D ONS Inc., Seoul, Korea). Correction of the anterior crossbite was achieved in all patients after treatment. The statistically significant changes included an increased ANB angle and a decreased SNB angle. The dental changes involved maxillary incisor proclination and mandibular incisor retroclination. We observed forward displacement of the upper lip relative to the E-plane. These findings suggest that PFA could be an effective treatment for the initial correction of functional anterior crossbite, leading to favorable dentoalveolar, skeletal, and soft tissue changes. However, considering the short-term nature of this study, further longitudinal follow-up is necessary to evaluate the long-term stability of these therapeutic effects. [J Korean Acad Pediatr Dent 2025;52(4):496-508]

Keywords

Functional anterior crossbite, Prefabricated functional appliance, Mixed dentition, Orthodontics

ORCID
Wonbin Seo
https://orcid.org/0009-0003-1489-5941
Eungyung Lee
https://orcid.org/0000-0001-8313-8571
Soyoung Park
https://orcid.org/0000-0003-3264-4014
Taesung Jeong
https://orcid.org/0000-0002-0431-5574
Jonghyun Shin
https://orcid.org/0000-0002-9777-0196

Article history
Received July 14, 2025
Revised August 27, 2025
Accepted September 3, 2025

Corresponding author: Jonghyun Shin
Department of Pediatric Dentistry, School of Dentistry, Dental and Life Science Institute, Pusan National University, 49, Busandaehak-ro, Mulgeum-eup, Yangsan, 50612, Republic of Korea
Tel: +82-55- 360-5183 / Fax: +82-55-360-5174 / E-mail: jonghyuns@pusan.ac.kr

Funding information
This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number : RS-2025-02293109).

Introduction

Occlusion is established and maintained by the complex interplay of neuromuscular and dental forces within the oral environment. Disruption of this equilibrium could result in malocclusion, which could adversely affect function and facial esthetics[1,2].

Anterior crossbite is a commonly observed malocclusion during the primary and mixed dentition stages[3,4]. If timely orthodontic intervention is not implemented, particularly in the mixed dentition stage, it may progress to more severe skeletal discrepancies[3,4]. Anterior crossbite is characterized by one or more maxillary incisors positioned lingual to the mandibular incisors[3].

Generally, anterior crossbites combine skeletal, dental, and functional etiologies[5]. Functional Class III malocclusion (pseudo-class III) is characterized by functional forward displacement of the mandible and may be amenable to correction through early interceptive treatment[4].

The prevalence of anterior crossbite in pediatric populations has been reported to range from 2.2% to 11.9%, depending on the previous study and diagnostic criteria, and is notably higher among individuals with skeletal Class III malocclusion[3,6].

Anterior crossbite is usually established during the mixed dentition period[3], but could often be corrected with relatively simple interventions if detected at an early stage. Interceptive treatment during growth may not only improve occlusal relationships and skeletal development, but also increase the maxillary arch perimeter, thereby facilitating the proper eruption of canines and premolars. Such early intervention could reduce the need for more complex orthodontic procedures and support long-term stability[4,7].

Anterior crossbites are commonly treated using removable appliances such as the Frankel Functional Regulator III (FR–III), bionator, and activator, as well as fixed appliances, including facemasks and the 2 × 4 appliance system[4]. Recently, considering the growing interest in orofacial musculature in the etiology and progression of malocclusion, the demand for prefabricated functional appliances (PFA) has increased owing to their ease of use and clinical convenience[1].

PFA, developed on the basis of the Functional Matrix Hypothesis, is intended to address fundamental etiological factors of malocclusion by enhancing soft tissue function and normalizing tongue posture[8]. Recent studies have demonstrated that PFAs may promote favorable maxillary arch development and morphological symmetry in growing patients with functional anterior crossbite and mild Class III malocclusion[9]. In addition, owing to their flexible material properties and ease of use, PFAs are considered cost-effective and well-tolerated, rendering them particularly suitable for pediatric clinical practice[10-12].

The Pre-Ortho® Type 3 appliance (OptimaOrtho Korea, Busan, South Korea) is designed to address both myofunctional and skeletal discrepancies in pediatric patients. Primarily indicated for functional anterior crossbite correction and management of oral parafunctional habits, this appliance regulates tongue posture and orofacial muscle activity, thereby supporting favorable dental arch and maxillofacial development.

Various studies have discovered that PFA exhibits a considerable level of therapeutic effectiveness in the treatment of skeletal Class II malocclusion[1,10]. However, evidence on the use and effectiveness of PFA in treating functional anterior crossbites or Class III malocclusion remains limited.

Therefore, this study aimed to investigate the treatment-related outcomes of PFA application in children presenting with functional anterior crossbite during mixed dentition and to assess its potential as an early interceptive treatment modality.

Materials and Methods

The Institutional Review Board (IRB) of the Pusan National University Dental Hospital approved this study (IRB No.: PNUDH 2025-03-004).

1. Study Patients

In this retrospective study, we included patients who underwent orthodontic treatment with PFA exclusively at the Department of Pediatric Dentistry, Pusan National University Dental Hospital, from September 2019 to December 2024. Inclusion and exclusion criteria were applied to analyze patient data from electronic medical records.

The inclusion criteria were as follows: (1) Children in the mixed dentition phase, presenting with one or more incisors in crossbite; (2) Achieving an edge-to-edge incisal relationship upon guided mandibular closure; (3) Hellman's developmental stages ⅡC – ⅢB; (4) Cervical vertebral maturation (CVM) stages 1 – 2 at the initial assessment; (5) Treatment performed solely using Pre-Ortho Type 3 (OptimaOrtho Korea). The exclusion criteria included the following: (1) Systemic conditions affecting the oral and maxillofacial region; (2) History of prior orthodontic treatment; (3) Incomplete or missing records on treatment duration required for crossbite correction; (4) Poor patient compliance, including missed appointments or failure to follow appliance instructions.

Clinical examination and radiographic assessment were used to diagnose an anterior crossbite. The clinical diagnostic criteria included cases in which one or more maxillary incisors were positioned lingually relative to the mandibular incisors in centric occlusion. Furthermore, the evaluation included an assessment of functional mandibular displacement and the presence of occlusal interference. Thirty patients (15 males and 15 females) were included. The patient recruitment and selection process are illustrated (Fig. 1), whereas the sample size, sex distribution, and age profile are summarized in Table 1.

2. Study Methods

Participants were instructed to wear the Pre-Ortho Type 3 (OptimaOrtho Korea) for 1 hour during the day and continuously while sleeping. The principal components of the Pre-Ortho Type 3 (OptimaOrtho

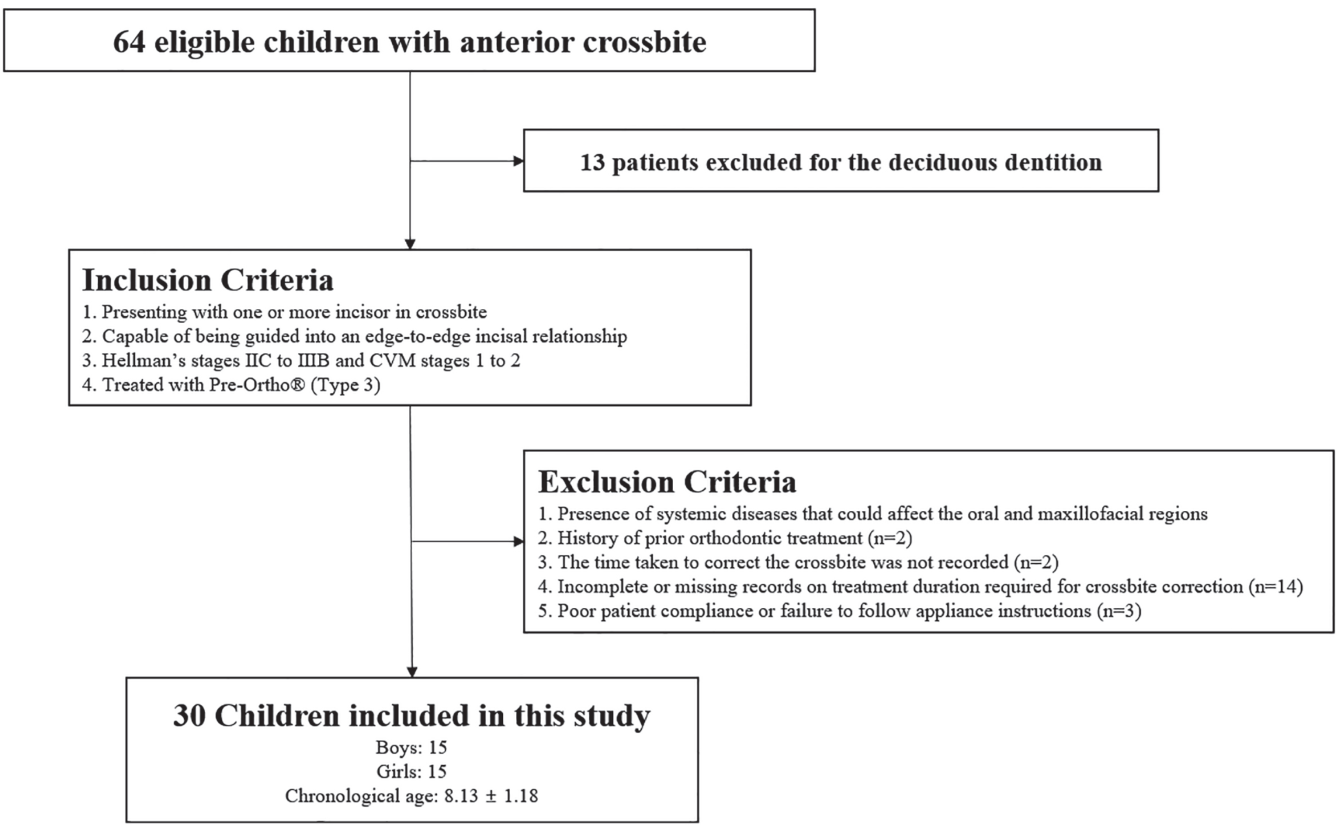

Fig. 1. Flow diagram of this study.

Table 1. The demographic characteristics of this study

Variables	Categories	n (%)
Chronological age	Mean ± SD (years)	8.13 ± 1.18
Sex	Male	15 (50.0)
	Female	15 (50.0)
Hellman's stages	2C	12 (40.0)
	3A	12 (40.0)
	3B	6 (20.0)
CVM stage	CS 1	15 (50.0)
	CS 2	15 (50.0)
Total		30 (100.0)

SD: standard deviation; CVM: cervical vertebral maturation.

Korea) appliance include: (1) The tongue up plate, which facilitates elevation of the tongue toward the palate, encourages a physiological resting tongue posture, and contributes to post-treatment functional stability; (2) The labial flange and lip bumper, which intercept excessive muscular pressure from the upper and lower lips, thereby supporting anterior growth of the maxilla; (3) The buccal shield, which eliminates inward pressure from the buccal mucosa, facilitating transverse arch development and encouraging growth of the underlying basal bone; (4) The lingual flange, which stimulates the anterior palatal region and promotes labial tipping of the maxillary incisors; (5) The occlusal slot, which contributes to proper incisor inclination and guides the overall development of the dental arch; (6) and the level guide facilitates proclination of the maxillary incisors and retroclination of the mandibular incisors. Additionally, it enables selective tooth movement via localized reduction of the guide surface.

The appliance size (S or M) was determined according to the patient's plaster model analysis and the manufacturer's guidelines. To improve patient compliance and reduce discomfort during the initial phase of treatment, a soft-type appliance was preferentially selected. Appliance wear time was monitored and reinforced through caregiver education. Lateral cephalometric radiographs were obtained at pre-treatment (T0) and at post-treatment (T1). T1 was defined as 12 months following the establishment of a positive overjet without anterior crossbite, including the subsequent retention period during which the appliance was worn at night. For patients without a lateral cephalometric radiograph at T0, cephalometric measurements were obtained from cone-beam computed tomography (CBCT) images, as CBCT was performed at the initial diagnosis in some patients. In accordance with the ALARA (as low as reasonably achievable) principle, no additional radiographs were taken solely for study purposes. The reliability and validity of cephalometric measurements derived from CBCT have been supported by previous studies[13]. The same reference points and measurement parameters were applied as in the LCR analysis.

Linear cephalometric measurements were conducted to evaluate changes in skeletal, dental, and soft tissue structures. Angular and linear variables were selected using standard cephalometric analyses proposed by Steiner, Downs, McNamara, and Ricketts. Sixteen cephalometric variables were analyzed using V-Ceph™ 8.0 (Osstem, Seoul, South Korea) and ON3D software (3D ONS Inc., Seoul, Korea). Detailed definitions of the cephalometric measurements are provided in Table 2.

3. Statistical Analysis

An examiner marked measurement points and calculated the distances and angles in 10 randomly selected samples. This was done two weeks later to assess the intra-examiner reliability. The intraclass correlation coefficient demonstrated high stability (r = 0.913). Statistical analysis was performed after testing for normality using the Shapiro-Wilk test. A paired t-test and Wilcoxon signed-rank test compared measurements between T0 and T1. All statistical analyses were carried out using SPSS 29.0 statistical software (IBM Corp., Armonk, NY, USA).

Results

The cephalometric values at T0, T1, and the changes observed (T1 – T0) are presented in Table 3 and Fig. 2. To evaluate the potential influence of skeletal maturation on treatment outcomes, subjects were divided into two groups based on CVM stage 1 and CVM stage 2 (Table 4).

Table 2. Definitions of cephalometric measurements used in this study

Measurements	Definition
SNA (°)	Angle between SN plane and NA plane
SNB (°)	Angle between SN plane and NB plane
ANB (°)	Difference between SNA and SNB
APDI (°)	The anteroposterior dysplasia indicator
A–N⊥ (mm)	Linear distance from A to N-perpendicular line
Pog–N⊥ (mm)	Linear distance from Pog to N-perpendicular line
ODI (°)	The overbite depth indicator
FMA (°)	Angle between FH plane and mandibular plane
Y-axis (°)	Angle between FH plane and S-Gn line
SN-Go-Me (°)	Angle between SN plane and mandibular plane
U1SN (°)	Angle between the long axis of the upper central incisor and SN plane
U1FH (°)	Angle between the long axis of the upper central incisor and FH plane
IMPA (°)	Angle between the long axis of the lower central incisor and mandibular plane
Interincisal angle (°)	Angle between the long axis of the upper and lower central incisors
Upper lip E-plane (mm)	Linear distance from the most anterior point of the upper lip to E-plane
Lower lip E-plane (mm)	Linear distance from the most anterior point of the lower lip to E-plane

Table 3. Comparison of cephalometric measurements pre-treatment and post-treatment

Cephalometric measurements		Pre-treatment (T0) Mean ± SD	Post-treatment (T1) Mean ± SD	T1 – T0 Mean difference	*p* value
Sagittal skeletal	SNA (°)	80.03 ± 2.98	80.04 ± 2.84	0.01	.938
	SNB (°)	79.72 ± 3.19	79.00 ± 2.75	−0.73	.005*
	ANB (°)†	0.30 ± 2.40	1.04 ± 2.04	0.74	< .0001*
	APDI (°)†	87.67 ± 4.81	86.22 ± 4.29	−1.46	< .0001*
	A–N⊥ (mm)	−2.37 ± 2.39	−1.79 ± 2.12	0.58	.083
	Pog–N⊥ (mm)	−5.40 ± 5.35	−5.35 ± 4.25	0.04	.948
Vertical skeletal	ODI (°)	66.24 ± 5.23	66.45 ± 4.19	0.21	.704
	FMA (°)	27.98 ± 3.93	28.61 ± 3.54	0.63	.137
	Y-axis (°)	60.32 ± 3.36	61.07 ± 2.63	0.75	.057
	SN-Go-Me (°)†	33.82 ± 3.68	36.41 ± 3.78	2.59	< .0001*
Dentoalveolar	U1SN (°)	99.20 ± 6.37	105.62 ± 6.47	6.42	< .0001*
	U1FH (°)	108.05 ± 6.40	113.63 ± 6.56	5.58	< .0001*
	IMPA (°)	91.65 ± 5.35	84.76 ± 5.13	−6.89	< .0001*
	Interincisal angle (°)	133.62 ± 9.65	133.00 ± 7.79	−0.62	.566
Soft tissue	Upper lip E-plane (mm)	0.52 ± 1.96	1.40 ± 1.74	0.87	< .0001*
	Lower lip E-plane (mm)†	1.07 ± 2.81	1.84 ± 1.88	0.76	.556

Data are presented as mean ± SD or number, unless otherwise indicated. The Shapiro-Wilk test was employed for the test of the normality assumption. *p* values were derived from a paired t-test or Wilcoxon signed-rank test, depending on the normality of the differences.

*: statistical significance ($p < .01$); †: Wilcoxon signed-rank test.

SNA: Angle between SN plane and NA plane; SNB: Angle between SN plane and NB plane; ANB: Difference between SNA and SNB; APDI: The anteroposterior dysplasia indicator; A–N⊥: Linear distance from A to N-perpendicular line; Pog–N⊥: Linear distance from Pog to N-perpendicular line; ODI: The overbite depth indicator; FMA: Angle between FH plane and mandibular plane; Y-axis: Angle between FH plane and S-Gn line; SN-Go-Me: Angle between SN plane and mandibular plane; U1SN: Angle between the long axis of the upper central incisor and SN plane; U1FH: Angle between the long axis of the upper central incisor and FH plane; IMPA: Angle between the long axis of the lower central incisor and mandibular plane; Interincisal angle: Angle between the long axis of the upper and lower central incisors; Upper lip E-plane: Linear distance from the most anterior point of the upper lip to E-plane; Lower lip E-plane: Linear distance from the most anterior point of the lower lip to E-plane.

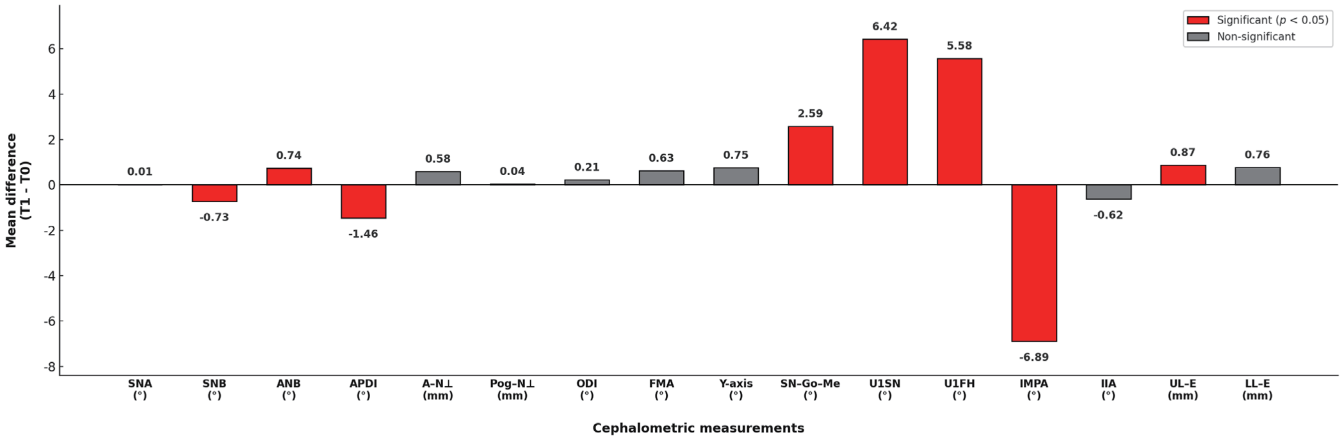

Fig. 2. Mean differences in cephalometric measurements pre-treatment and post-treatment.
SNA: Angle between SN plane and NA plane; SNB: Angle between SN plane and NB plane; ANB: Difference between SNA and SNB; APDI: The anteroposterior dysplasia indicator; A–N⊥: Linear distance from A to N-perpendicular line; Pog–N⊥: Linear distance from Pog to N-perpendicular line; ODI: The overbite depth indicator; FMA: Angle between FH plane and mandibular plane; Y-axis: Angle between FH plane and S-Gn line; SN-Go-Me: Angle between SN plane and mandibular plane; U1SN: Angle between the long axis of the upper central incisor and SN plane; U1FH: Angle between the long axis of the upper central incisor and FH plane; IMPA: Angle between the long axis of the lower central incisor and mandibular plane; IIA: Interincisal angle (Angle between the long axis of the upper and lower central incisors); UL-E: Upper lip E-plane (Linear distance from the most anterior point of the upper lip to E-plane); LL-E: Lower lip E-plane (Linear distance from the most anterior point of the lower lip to E-plane).

1. Treatment durations

The distribution of treatment durations is shown in Fig. 3. In this study, treatment duration was defined as the number of months required to achieve anterior crossbite correction, which was characterized by the establishment of a positive overjet without any anterior crossbite[14,15]. Of the 30 patients, 63.3% (n = 19) of anterior crossbites were corrected within the first three months of treatment. Specifically, 33.3% of the patients were corrected within the first month, whereas 30.0% improved between one and three months.

2. Sagittal Skeletal Changes

The SNB angle decreased by an average of 0.73 ± 1.33° and the ANB angle increased by 0.74 ± 1.02°; both were statistically significant (p = 0.005 and p < 0.0001, respectively). In contrast, changes in the SNA angle were not statistically significant. The A-point to Nasion perpendicular (A–N⊥) distance increased by an average of 0.58 ± 1.77 mm and the Pogonion to Nasion perpendicular (Pg–N⊥) distance increased by an average of 0.04 ± 3.40 mm; however, neither change was statistically significant between pre- and post-treatment.

3. Vertical Skeletal Changes

The SN–Go–Me angle increased by 2.59 ± 3.20° (p < 0.0001). However, no statistically significant changes were observed in the Y-axis, Frankfort-mandibular plane angle (FMA) or overbite depth indicator (ODI) values.

4. Dental Changes

U1-SN and U1-FH angles increased by 6.42 ± 4.93° and 5.58 ± 5.05°, respectively (p < 0.0001). In contrast, the incisor mandibular plane angle (IMPA) decreased by 6.89 ± 4.14°, which was statistically significant (p < 0.0001). There was no significant difference in the interincisal angle.

Table 4. Comparison of cephalometric measurements pre-treatment and post-treatment according to growth stage

Cephalometric measurements		CVM stage 1			CVM stage 2		
		Pre-treatment (T0)	Post-treatment (T1)	T1 – T0	Pre-treatment (T0)	Post-treatment (T1)	T1 – T0
		Mean ± SD	Mean ± SD	Mean diff	Mean ± SD	Mean ± SD	Mean diff
Sagittal skeletal	SNA (°)	80.00 ± 3.64	79.95 ± 3.67	-0.05	80.05 ± 2.26	80.12 ± 1.79	0.08
	SNB (°)	79.86 ± 3.65	78.99 ± 3.47	-0.87*	79.59 ± 2.79	79.00 ± 1.90	-0.59
	ANB (°)	0.15 ± 2.60	0.97 ± 2.18	0.82†**	0.45 ± 2.26	1.12 ± 1.97	0.67*
	APDI (°)	87.65 ± 5.53	85.94 ± 5.00	-1.70†**	87.70 ± 4.17	86.49 ± 3.60	-1.21*
	A–N⊥ (mm)	-2.05 ± 2.66	-1.51 ± 2.25	0.54	-2.68 ± 2.14	-2.06 ± 2.02	0.62
	Pog–N⊥ (mm)	-4.48 ± 5.19	-4.72 ± 4.30	-0.24	-6.31 ± 5.52	-5.99 ± 4.25	0.32
Vertical skeletal	ODI (°)	65.51 ± 4.68	66.05 ± 3.62	0.55	66.97 ± 5.81	66.85 ± 4.78	-0.12
	FMA (°)	27.20 ± 4.09	27.82 ± 3.48	0.61	28.76 ± 3.74	29.40 ± 3.54	0.64
	Y-axis (°)	59.63 ± 3.51	60.32 ± 2.53	0.70	61.01 ± 3.17	61.82 ± 2.60	0.81
	SN-Go-Me (°)	33.55 ± 3.96	35.83 ± 4.36	2.27†*	34.10 ± 3.49	37.00 ± 3.14	2.90**
Dentoalveolar	U1SN (°)	100.11 ± 6.60	105.42 ± 7.59	5.31**	98.30 ± 6.22	105.82 ± 5.40	7.52**
	U1FH (°)	108.05 ± 6.02	113.80 ± 6.94	5.75**	108.05 ± 6.96	113.46 ± 6.39	5.42**
	IMPA (°)	92.01 ± 5.19	84.99 ± 3.21	-7.03**	91.29 ± 5.68	84.54 ± 6.63	-6.76**
	Interincisal angle (°)	132.56 ± 8.79	133.40 ± 6.38	0.84	134.68 ± 10.65	132.60 ± 9.21	-2.08
Soft tissue	Upper lip E-plane (mm)	0.05 ± 2.17	1.10 ± 1.90	1.05**	1.00 ± 1.66	1.70 ± 1.58	0.70
	Lower lipE-plane (mm)	1.10 ± 3.01	1.64 ± 2.28	0.55†	1.05 ± 2.71	2.03 ± 1.42	0.98

Data are presented as mean ± SD or number, unless otherwise indicated. The Shapiro-Wilk test was employed for the test of the normality assumption. *p* values were derived from a paired t-test or Wilcoxon signed-rank test, depending on the normality of the differences.
*: statistical significance ($p < .05$). **: statistical significance ($p < .01$). †: Wilcoxon signed-rank test.
SNA: Angle between SN plane and NA plane; SNB: Angle between SN plane and NB plane; ANB: Difference between SNA and SNB; APDI: The anteroposterior dysplasia indicator; A–N⊥: Linear distance from A to N-perpendicular line; Pog–N⊥: Linear distance from Pog to N-perpendicular line; ODI: The overbite depth indicator; FMA: Angle between FH plane and mandibular plane; Y-axis: Angle between FH plane and S-Gn line; SN-Go-Me: Angle between SN plane and mandibular plane; U1SN: Angle between the long axis of the upper central incisor and SN plane; U1FH: Angle between the long axis of the upper central incisor and FH plane; IMPA: Angle between the long axis of the lower central incisor and mandibular plane; Interincisal angle: Angle between the long axis of the upper and lower central incisors; Upper lip E-plane: Linear distance from the most anterior point of the upper lip to E-plane; Lower lip E-plane: Linear distance from the most anterior point of the lower lip to E-plane.

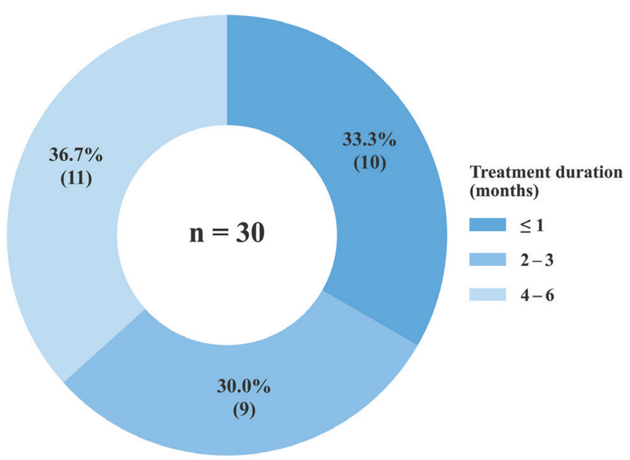

Fig. 3. The distribution of treatment durations.

5. Soft Tissue Changes

The upper lip to E-plane (UL–E plane) increased by 0.87 ± 1.30 mm, which was statistically significant ($p < 0.0001$). In contrast, the lower lip to E-plane (LL–E plane) showed no significant change between pre- and post-treatment.

6. Measurement comparison by growth stage

The overall comparison revealed no statistically significant difference in treatment outcomes between the CVM stage 1 and 2 groups. However, differences were observed in specific variables. The SNB angle and UL–E plane showed statistically significant changes only in the

CVM stage 1 group. The SNB angle decreased by an average of 0.87° and the UL–E plane increased by 1.05 mm (p = 0.014 and p < 0.0001, respectively).

Discussion

PFA use as a potentially viable modality for early orthodontic intervention has been increasingly explored. According to previous studies, applying functional appliances during the mixed dentition phase can facilitate mandibular growth modulation and improve orofacial muscular function[16]. This approach tends to promote the harmonious growth of soft and hard tissues[15]. In light of the existing literature, the optimal time for PFA initiation is during the early intervention phase[17,18]. The timing of anterior crossbite correction was analyzed in this study, serving as an indirect indicator of patient compliance due to the lack of objective wear-time data. Approximately 63% of the patients were corrected within three months of initiating treatment. These findings suggest that functional changes during the initial stages of treatment can be effectively induced with the appropriate implementation of early intervention. Notably, the increased correction outcomes between three and six months are consistent with previous literature, thereby emphasizing the importance of early interventions[5,11].

Furthermore, individual variability in treatment response was observed in some cases, which may be attributed to differences in growth patterns, cooperation, and compliance. The association between the duration required for anterior crossbite correction and both baseline patient characteristics and cephalometric changes was analyzed. However, no distinct trends were observed.

In a randomized controlled trial conducted by Wiedel and Bondemark[19], functional anterior crossbite was successfully corrected in 30 out of 31 patients (96.8%) using removable appliances. This success rate is consistent with the findings of the present study. These results suggest that favorable outcomes may be attainable under appropriate clinical conditions and with timely intervention. Therefore, the 100% correction rate observed in this study should not be interpreted as definitive evidence of the intrinsic efficacy of the PFA alone. Rather, it reflects the favorable clinical outcomes that can be attained when treatment is initiated early and patient compliance is adequately maintained.

Differentiating skeletal from functional Class III malocclusion remains challenging due to overlapping features. However, clinical indicators such as edge-to-edge incisal relationship, normal SNA, retroclination of maxillary incisors, and normal lower incisor angles have been widely used to support the diagnosis of pseudo-Class III. In the present study, baseline cephalometric values were consistent with these characteristics, further validating the selection criteria[20-22].

Borrie and Bearn[3] suggested that the ideal approach to managing anterior crossbite should be noninvasive, involving a short treatment duration and aiming for rapid correction. Therefore, considering these criteria, PFA may be a suitable modality for the early management of anterior crossbites. Wiedel and Bondemark[19] reported that the mean treatment duration was 5.5 and 6.9 months (SD = 1.41 and SD = 2.8, respectively) for fixed and removable appliances. The findings of our study are consistent with those reported in previous studies. They support the notion that functional appliances actively induce occlusal changes during the initial treatment phase, followed by gradual stabilization during the retention period. According to Fichera et al.[11], extended retention after single-phase treatment with an elastodontic device may yield results comparable to the conventional biphasic protocol. The latter consists of functional appliance therapy followed by fixed appliances.

The success of orthodontic treatment is significantly influenced by the practitioner's clinical proficiency. It is also affected by external factors, including the patient's cooperation, the caregiver's active involvement, and continued engagement throughout the treatment duration. Particularly, patient compliance is a critical determinant of success for treatments utilizing removable appliances. Modifying the treatment plan during poor compliance may become necessary. This may potentially result in prolonged treatment duration and reduced predictability of treatment outcomes[23]. In this study, the timing of anterior crossbite correction varied among the patients, which can be attributed to differences in individual compliance and treatment cooperation. Therefore, patient motivation is essential in ensuring successful outcomes, whereby continuous support and involvement from caregivers and clinicians is crucial[24].

In this study, the SNB angle decreased by an average of 0.73° after treatment ($p = 0.005$), whereas the ANB angle increased by 0.74° ($p < 0.0001$). This indicated a statistically significant change in the sagittal skeletal relationships, possibly associated with the therapeutic effects. These findings are consistent with those of the study by Ji et al.[15], which showed a decrease of 0.3° in SNB and an increase of 0.6° in ANB following treatment with an FR–III appliance. Baik et al.[25] demonstrated a similar trend to that observed in this study. According to Sung et al.[26], the A-point to Nasion Perpendicular distance typically increases by 0.2 – 0.7 mm depending on age as part of physiological growth. The 0.58 mm increase observed in the present study falls within the physiological range; however, it did not reach statistical significance. Nevertheless, the increase in A–N⊥ during the correction period may suggest a potential trend. This tendency, albeit inconclusive, could indicate a skeletal environment favorable to anterior maxillary development. Such an effect could have facilitated a favorable environment for normal maxillary forward growth. The SNA angle did not exhibit a statistically significant change. Similarly, Kerr and Tenhave[27] and Park et al.[28] reported no significant change in the SNA angle following FR–III treatment, suggesting a limited skeletal effect on the maxillary complex; however, Yoshida et al.[29] reported a mean increase of 1.7° in SNA and 1.6° in A to Nasion Perpendicular to facemask therapy ($p < 0.05$). These findings suggest that PFA has only a limited effect on Point A, indicating that its mechanism does not primarily involve direct stimulation of maxillary growth. In contrast, it may facilitate posterior repositioning or mandibular growth inhibition, thereby promoting a conducive environment for the anterior development of the maxilla and contributing to the correction of the anterior crossbite.

The modulation of the vertical growth pattern of the mandible is a critical factor in orthodontic treatment. In this study, the SN–Go–Me increased by 2.59° ($p < 0.0001$) following treatment. According to Kilic et al.[30], treatment with FR–III resulted in a 2.28° increase in the SN–Go–Me angle ($p < 0.0001$). In contrast, Sung et al.[26] noted that during physiological growth between the ages of 8 and 16 years, the mandible undergoes counterclockwise rotation, characterized by gradual decreases in both the Y-axis and SN–Go–Me angles relative to the cranial base. Therefore, the opposite rotational pattern observed in our study may indicate a therapeutic intervention effect. This effect may suggest that the therapeutic intervention influenced the natural vertical growth pattern, potentially altering the expected mandibular trajectory. Such vertical skeletal modulation could be associated with both a reduction in mandibular protrusion and an enhancement of sagittal harmony.

In this study, the U1-SN and the U1-FH angles increased by 6.42° ($p < 0.0001$) and 5.58°, respectively. Conversely, IMPA decreased by 6.89° ($p < 0.0001$) following treatment. These outcomes are consistent with those of Ji et al.[15]. They observed a 3.6° increase in U1-SN ($p < 0.01$) and a 2.7° decrease in IMPA ($p < 0.01$). These results suggest that functional appliance use may have contributed to favorable changes in the axial inclination of both maxillary and mandibular incisors, which may reflect dentoalveolar compensation. These dentoalveolar adaptations may support the normalization of the overbite and overjet, which may support long-term occlusal stability[15]. Furthermore, Kilic et al.[30] and Yang et al.[31] reported that the therapeutic effects of the FR–III appliance may be primarily related to clockwise mandibular rotation and alterations in incisor angulation. These findings are consistent with those of this study.

Regarding soft tissue changes, E-plane analysis showed a forward movement of UL–E plane by 0.87 mm ($p < 0.0001$), indicating a partial improvement in lip protrusion. In comparison, Ji et al.[15] observed a marked increase of 2.2 mm ($p < 0.05$). The magnitude of change in the UL–E plane was relatively modest in this current study. However, its early occurrence in the treatment phase and statistical significance suggest a potential clinical relevance. Within the context of early interceptive treatment, these findings indicate that PFA may contribute to dental and skeletal adaptations as well as enhance facial balance and esthetic outcomes.

To evaluate the potential influence of skeletal maturation on treatment outcomes, treatment effects were also compared according to the CVM stage. The overall comparison revealed no statistically significant differences in treatment outcomes between the two groups, indicating that the appliance elicited generally consistent effects across both maturation stages. However, the SNB and UL–E plane values showed statistically significant changes only in the CVM stage 1 group. This suggests that mandibular positional changes may respond more favorably to treatment during the earlier stages of skeletal development.

This study revealed significant skeletal and dentoalveolar changes following PFA treatment. However, clinical consideration is warranted regarding factors that may influence the long-term stability of these effects and the potential for relapse. In particular, the timing of treatment initiation may play a critical role in determining long-term prognosis. Several studies have reported that delaying the correction of functional Class III malocclusion may exacerbate unfavorable growth patterns and increase the likelihood of progression to skeletal Class III malocclusion[32,33]. In addition, once the periodontal ligament matures, greater orthodontic forces are typically required to achieve similar levels of tooth movement. This may in turn extend the treatment duration and increase the risk of root resorption[34]. Reitan[35] suggested that age is a significant factor influencing root resorption, and that precementum and predentine in younger individuals may function as biological barriers, protecting against tissue damage. This implies that early intervention may facilitate safer and more efficient tooth movement.

Although long-term follow-up was not performed in the present study, Wiedel and Bondemark[36] reported that relapse frequently occurs within 2 years following orthodontic treatment. Additionally, Ryu et al.[37] identified a marked increase in mandibular length during the pubertal growth spurt (CS3 and CS4 stages), which could contribute to relapse. Kakali et al.[38] further indicated that residual mandibular growth may be a key factor in relapse. Moreover, male patients carry a higher risk of relapse due to their relatively later skeletal maturation than that observed in females. Previous studies have suggested that combining functional appliances with retainers may enhance long-term impact[16]. In addition, several studies with follow-up periods greater than 5 years indicate that continued use of PFAs during and beyond the active treatment phase contributes to long-term stability. This is particularly true when combined with appropriate retention protocols [34,37,39,40].

This study not only establishes PFA as a practical and minimally invasive therapeutic option for the management of functional anterior crossbite, but also reinforces the scientific rationale for clinical decision-making. Furthermore, by providing empirical data on the optimal timing and duration of treatment, our findings contribute to improved prognostic predictability and evidence-based early intervention strategies.

Collectively, these findings indicate that successful clinical application of PFA requires careful consideration of treatment timing, long-term retention strategies, and patient compliance. Growth-related characteristics such as sex and individual developmental patterns may also contribute to improved treatment stability and prognosis.

This study has some acknowledged limitations. First, the study design itself presents certain inherent limitations. Determining whether the observed changes are due to the intervention or natural craniofacial growth is limited by a retrospective, single-arm design. Establishing a longitudinal, untreated control group during the mixed dentition phase presents some ethical challenges. Therefore, future studies should include controlled, comparative designs to assess PFA's efficacy objectively. Second, there is a lack of long-term data regarding the post-treatment stability of PFA. PFA may show favorable short-term outcomes. However, there is reduced evidence on the long-term stability of occlusal relationships following treatment. Based on these findings, future longitudinal studies should evaluate the durability and sustained efficacy of PFA treatments over time.

Conclusion

This study aimed to evaluate the therapeutic effects of PFA in patients with anterior crossbite during the mixed dentition stage and to assess its feasibility as an interceptive orthodontic approach. These findings indicate that PFA use may be associated with skeletal modifications, dentoalveolar compensation, and changes in soft tissue profile. In addition, the appliance may have elicited a transient skeletal response affecting mandibular position. This response may have supported the correction of maxillomandibular discrepancies during treatment, thereby assisting in anterior crossbite management. Furthermore, the results showed a possible dental compensation promotion by PFA, which may have been important in resolving the crossbites. Moreover, the forward displacement of the upper lip observed after treatment indicates a possible improvement in facial balance. This suggests that functional appliances may influence tooth alignment and support craniofacial structure in growing patients. In conclusion, PFA may be a practical and potentially effective option for early treatment of anterior crossbites in the mixed-dentition phase.

However, it should be emphasized that the success of this approach is highly dependent on appropriate case selection based on accurate diagnosis. Differentiating functional from true skeletal anterior crossbite remains a significant diagnostic challenge, and the injudicious application of this appliance to improperly selected cases may lead to suboptimal or even adverse outcomes. This underscores the necessity of meticulous diagnostic protocols when implementing PFA in pediatric orthodontics.

These findings provide preliminary support for PFA's potential as a clinical modality for the development of early dentofacial treatment strategies, especially during periods of growth. However, considering the short-term nature of this study, further longitudinal studies are required to assess the long-term stability and effectiveness of PFA treatment outcomes.

Acknowledgments

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number : RS-2025-02293109).

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

CRediT authorship contribution statement

Wonbin Seo: Writing – Original Draft, Investigation, Data Curation, Visualization. **Jonghyun Shin:** Conceptualization, Methodology, Supervision, Project administration. **Eungyung Lee, Soyoung Park, Taesung Jung:** Validation, Writing – Review & Editing.

References

1. An SY, Kim EH, Lee HU, Bak SH, Kang HJ, Shim YS : Effects of a prefabricated functional orthodontic appliance on children with Class II division 1 malocclusion. *J Dent Hyg Sci*, 23:112-122, 2023.
2. Macrì M, Ritrovato L, Pisanelli EL, Festa F : Elastodontic therapy with oral bioactivator devices: a review. *Appl Sci*, 13:8868, 2023.
3. Borrie F, Bearn D : Early correction of anterior crossbites: a systematic review. *J Orthod*, 38:175-184, 2011.
4. Ngan P, Moon W : Evolution of Class III treatment in orthodontics. *Am J Orthod Dentofacial Orthop*, 148: 22-36, 2015.
5. Lee SH : Diagnosis and treatment of Class III malocclusion in children. *J Korean Acad Pediatr Dent*, 34:

725-740, 2007.

6. Rhee S, Song JS, Shin TJ, Kim YJ, Kim JW, Jang KT, Hyun HK : Distribution of pediatric malocclusion patients in Seoul National University Dental Hospital. *J Korean Acad Pediatr Dent*, 48:140-150, 2021.
7. Ronsivalle V, Quinzi V, La Rosa S, Leonardi R, Lo Giudice A : Comparative analysis of skeletal changes, occlusal changes, and palatal morphology in children with mild class III malocclusion treated with elastodontic appliances and bimaxillary plates. *Children*, 10:1219, 2023.
8. Chen LR, Lai CL, Chang IT, Hsu CL, Liu JF, Kao CT : Evaluation of skeletal and dentoalveolar changes in class II division I pediatric patients receiving myofunctional appliance therapy: A preliminary study. *J Formos Med Assoc*, 121:2028-2034, 2022.
9. Lo Giudice A, Ronsivalle V, Conforte C, Marzo G, Lucchese A, Leonardi R, Isola G : Palatal changes after treatment of functional posterior cross-bite using elastodontic appliances: a 3D imaging study using deviation analysis and surface-to-surface matching technique. *BMC Oral Health*, 23:68, 2023.
10. Mohammed H, Čirgić E, Rizk MZ, Vandevska-Radunovic V : Effectiveness of prefabricated myofunctional appliances in the treatment of Class II division 1 malocclusion: a systematic review. *Eur J Orthod*, 42:125-134, 2020.
11. Fichera G, Martina S, Palazzo G, Musumeci R, Leonardi R, Isola G, Lo Giudice A : New materials for orthodontic interceptive treatment in primary to late mixed dentition. A retrospective study using elastodontic devices. *Materials*, 14:1695, 2021.
12. Yang X, Lai G, Wang J : Effect of orofacial myofunctional therapy along with preformed appliances on patients with mixed dentition and lip incompetence. *BMC Oral Health*, 22:586, 2022.
13. Jung PK, Lee GC, Moon CH : Comparison of cone-beam computed tomography cephalometric measurements using a midsagittal projection and conventional two-dimensional cephalometric measurements. *Korean J Orthod*, 45:282-288, 2015.
14. Mandall N, Cousley R, DiBiase A, Dyer F, Littlewood S, Mattick R, Nute SJ, Doherty B, Stivaros N, McDowall R, Shargill I, Worthington HV : Early class III protraction facemask treatment reduces the need for orthognathic surgery: a multi-centre, two-arm parallel randomized, controlled trial. *J Orthod*, 43:164-175, 2016.
15. Ji LL, Sun DX, Shi LB, Kyung HM, Bing L, Wu XP : Morphological changes of Frankel functional regulator III in mixed dentition with class III malocclusion. *Int J Morphol*, 38:1053-1059, 2020.
16. Wishney M, Darendeliler MA, Dalci O : Myofunctional therapy and prefabricated functional appliances: an overview of the history and evidence. *Aust Dent J*, 64:135-144, 2019.
17. Perinetti G, Franchi L, Contardo L : Determination of timing of functional and interceptive orthodontic treatment: A critical approach to growth indicators. *J World Fed Orthod*, 6:93-97, 2017.
18. Zhou C, Duan P, He H, Song J, Hu M, Liu Y, Liu Y, Guo J, Jin F, Cao Y, Jiang L, Ye Q, Zhu M, Jiang B, Ruan W, Yuan X, Li H, Zou R, Tian Y, Gao L, Shu R, Chen J, Liu R, Zou S, Li X : Expert consensus on pediatric orthodontic therapies of malocclusions in children. *Int J Oral Sci*, 16:32, 2024.
19. Wiedel AP, Bondemark L : Fixed versus removable orthodontic appliances to correct anterior crossbite in the mixed dentition - a randomized controlled trial. *Eur J Orthod*, 37:123-127, 2015.
20. Li Z, Hung KF, Ai QYH, Gu M, Su YX, Shan Z : Radiographic imaging for the diagnosis and treatment of patients with skeletal Class III malocclusion. *Diagnostics*, 14:544, 2024.
21. Zhou X, Chen S, Zhou C, Jin Z, He H, Bai Y, Li W, Wang J, Hu M, Cao Y, Liu Y, Yan B, Shi J, Guo J, Li Z, Ma W, Liu Y, Li H, Lu Y, Ren L, Zou R, Xu L, Hu J, Wu X, Cui S, Xu L, Wang X, Zhu S, Hu L, Tang Q, Song J, Fang B, Chen L : Expert consensus on early orthodontic treatment of class III malocclusion. *Int J Oral Sci*, 17:20, 2025.
22. Kapur A, Chawla HS, Utreja A, Goyal A : Early class III occlusal tendency in children and its selective management. *J Indian Soc Pedod Prev Dent*, 26:107-113, 2008.

23. Cosgun A, Altan H : Treatment of anterior dental crossbite with different methods in the early mixed dentition period: Report of two cases. *J Pediatr Dent*, 6:61-64, 2020.
24. Ćirgić E, Kjellberg H, Hansen K, Lepp M : Adolescents' experiences of using removable functional appliances. *Orthod Craniofac Res*, 18:165-174, 2015.
25. Baik HS, Jee SH, Lee KJ, Oh TK : Treatment effects of Fränkel functional regulator III in children with class III malocclusions. *Am J Orthod Dentofacial Orthop*, 125:294-301, 2004.
26. Sung JH, Kwon OW, Kyung HM, Park KD : A longitudinal cephalometric study of the craniofacial growth changes of Koreans aged from 8 to 16 years. *Korean J Orthod*, 22:491-507, 1992.
27. Kerr WJ, Tenhave TR : A comparison of three appliance systems in the treatment of Class III malocclusion. *Eur J Orthod*, 10:203-214, 1988.
28. Park JA, Yang KH, Choi NK, Kim SM : Treatment effects of Fränkel functional regulator III in mixed dentition children with anterior crossbite. *J Korean Acad Pediatr Dent*, 35:652-661, 2008.
29. Yoshida I, Shoji T, Mizoguchi I : Effects of treatment with a combined maxillary protraction and chincap appliance in skeletal Class III patients with different vertical skeletal morphologies. *Eur J Orthod*, 29:126-133, 2007.
30. Kilic N, Celikoglu M, Oktay H : Effects of the functional regulator III on profile changes in subjects with maxillary deficiency. *Eur J Orthod*, 32:729-734, 2010.
31. Yang X, Li C, Bai D, Su N, Chen T, Xu Y, Han X : Treatment effectiveness of Fränkel function regulator on the Class III malocclusion: A systematic review and meta-analysis. *Am J Orthod Dentofacial Orthop*, 146:143-154, 2014.
32. Ngan P : Early timely treatment of Class III malocclusion. *Semin Orthod*, 11:140-145, 2005.
33. Kanas RJ, Carapezza L, Kanas SJ : Treatment classification of Class III malocclusion. *J Clin Pediatr Dent*, 33:175-185, 2008.
34. Keski-Nisula K, Hernesniemi R, Heiskanen M, Keski-Nisula L, Varrela J : Orthodontic intervention in the early mixed dentition: A prospective, controlled study on the effects of the eruption guidance appliance. *Am J Orthod Dentofacial Orthop*, 133:254-260, 2008.
35. Reitan K : Initial tissue behavior during apical root resorption. *Angle Orthod*, 44:68-82, 1974.
36. Wiedel AP, Bondemark L : Stability of anterior crossbite correction: A randomized controlled trial with a 2-year follow-up. *Angle Orthod*, 85:189-195, 2015.
37. Ryu HK, Chong HJ, An KY, Kang KH : Short-term and long-term treatment outcomes with Class III activator. *Korean J Orthod*, 45:226-235, 2015.
38. Kakali L, Christopoulou I, Tsolakis IA, Sabaziotis D, Alexiou A, Sanoudos M, Tsolakis AI : Mid-term follow up effectiveness of facemask treatment in class III malocclusion: A systematic review. *Int Orthod*, 19: 365-376, 2021.
39. Janson G, Nakamura A, Chiqueto K, Castro R, de Freitas MR, Henriques JFC : Treatment stability with the eruption guidance appliance. *Am J Orthod Dentofacial Orthop*, 131:717-728, 2007.
40. Levin AS, McNamara JA Jr, Franchi L, Baccetti T, Fränkel C : Short-term and long-term treatment outcomes with the FR-3 appliance of Fränkel. *Am J Orthod Dentofacial Orthop*, 134:513-524, 2008.