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ORIGINAL RESEARCH

Is maxillary protraction the earlier the better? A retrospective study on early orthodontic treatment of Class III malocclusion with maxillary deficiency

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Abstract

To investigate the optimal timing of maxillary protraction in children with Class III malocclusion to aid comprehension of this still non-consensual topic. In all, the data of 97 children with Class III malocclusion treated by using the Delaire facemask with maxillary expansion were collected retrospectively and divided into three groups according to their dentition stages; those subjects in the mixed dentition group were further divided into three subgroups. All patients were regrouped by the cervical vertebral maturation index (CVMI) and observed closely by cephalograms at the beginning of treatment (T0) and after facemask removal (T1). Comparisons between subgroups, within groups, and the final evaluation of the increment of maxillary length were performed by different statistical methods. Similar favorable maxillary traction effects were achieved in all stages. Intragroup comparisons showed changes without significance in aspect ratio during the mixed dentition stage, while there was a significant decrease during the deciduous and permanent dentition stages. The largest increment of maxillary length was obtained when the maxillary protraction began at Cervical Stage (CS)2. However, no significant difference was found in all skeletal measurements among the three groups (deciduous, mixed and permanent dentition stages) and the three subgroups with mixed dentition. The univariable linear regression analysis also showed that CVMI and dentition stage at T1 did not have a significant impact on the increment of maxillary length. In our center, Class III malocclusion patients treated with the Delaire facemask achieved similar skeletal changes in short term, when they began the treatment at different dentition stages or CVMI stages. Starting the maxillary protraction at CS2 was likely a reliable choice for those who desired more maxillary advancement.

Keywords

Treatment timing; Class III malocclusion; Orthodontic treatment; Maxillary protraction

1. Introduction

The prevalence of Class III malocclusion reportedly varies in different populations, ranging from 0% to 26.7%, impairing a child's aesthetic and psychological development [1, 2]. Class III malocclusion with maxillary deficiency in children and adolescents is commonly addressed through maxillary protraction, which applies a forward and downward force to the maxilla [3]. This force can widen the bone sutures around the maxilla, prompting bone deposition in response to the traction force, ultimately resulting in maxillary advancement [4, 5]. In the context of treatment for children and adolescents, maxillary protraction *via* facemask is the preferred approach. This preference arises from the fact that bone-anchored appliances are often not well-received in growing children because of factors such as bone density, bone mass and the potential for greater surgical trauma [6]. Extensive researches have established the therapeutic efficacy of maxillary protraction *via* facemask, prompting a growing interest in studying the optimal timing of treatment for this demographic [7].

Some researchers advocated early intervention for children with skeletal Class III malocclusion, as younger patients typically exhibit less deformity and greater growth potential, allowing for more substantial maxillary advancement through protraction [8–10]. Studies by Kapust *et al.* [11] showed more significant treatment effects and shorter treatment duration when facemask/expansion therapy was administered to patients aged 4–7 years and 7–10 years with Class III malocclusion, as opposed to those aged 10–14 years. Similarly, research by Saadia *et al.* [12] yielded comparable results, indicating that patients aged 3–9 years experienced more pronounced effects in a shorter timeframe than those aged 9–12 years with facemask expansion therapy. Kajiyama *et al.* [13] reported that greater skeletal and dento-alveolar changes occurred when patients were treated with the maxillary protractor bow appliance during deciduous dentition. However, some researchers contended that the timing of treatment had minimal impact on treatment outcomes in adolescents with Class III malocclusion [14–16]. Baik *et al.* [14] divided patients aged 8–13 years into three age groups for comparison and found no statistically significant differences in the treatment effects of maxillary protraction. Merwin *et al.* [16] observed similar skeletal changes in patients aged both under and above 8 years.

Of note, it was proved chronological age is an inappropriate predictor of skeletal growth [17]. Luckily, the cervical vertebral maturation index (CVMI), a method used to trace the C2, C3 and C4 vertebrae respectively, allows accurate determination of skeletal maturity by lateral cephalometric analysis [18]. A recent study concluded that similar results could be achieved in adolescents at various stages of cervical vertebral maturation (CVM) [19]. Baccetti *et al.* [20] revealed that the growth spurt of the mandible occurred after Cervical Stage (CS)3 and recommended starting maxillary protraction treatment at CS1 or CS2. Moreover, the dentition stage has attracted attention as another indicator for assessing the maturity of the maxilla and mandible. However, based on the existing evidence [8, 9, 13, 21–23]. There remains no consensus on the optimal treatment timing in terms of dentition stage. Therefore, to better understand this non-consensus issue, the present study evaluated the optimal timing of maxillary protraction in children with class III malocclusion by a retrospective method according to the CVMI and dental stage.

2. Materials and methods

2.1 Subjects

All subjects were 3–14 years old and met the following inclusion and exclusion criteria: (1) skeletal Class III malocclusion with maxillary deficiency (the angle formed by the point A, the point N and the point B, ANB $<0°$ or A-Nperp distance, A-Nperp <0 mm); (2) subjects treated by Delaire facemask with maxillary expander, but without skeletal anchorage; (3) qualified cephalometric lateral radiographs before and after the treatment; (4) no other dento-maxillofacial deformities or systemic diseases, such as cleft lip and palate, cleidocranial dysostosis, ectodermal deficiency and hypophosphatasia; (5) no history of orthodontic or orthognathic treatment.

A total of 97 children who met the above criteria and underwent maxillary protraction in our hospital were included in the present study. According to the classification method based on the dentition stage (Table 1) [23], all subjects were divided into the following three groups: group 1 with 37 patients in stage IIA–IIC (17 boys and 20 girls, mean age: 5.91 $\pm$ 1.73 years); group 2 with 40 patients in stage IIIA–IIIB (19 boys and 21 girls, mean age: 9.05 $\pm$ 1.15 years); and group 3 with 20 patients in stage IIIC–IVA (10 boys and 10 girls, mean age: 10.60 $\pm$ 1.39 years).

The subjects with mixed dentition were then divided into three subgroups: 10 boys and 10 girls with early mixed dentition (stage IIC, mean age: 7.30 $\pm$ 0.86 years) in subgroup 1; 10 boys and 10 girls with mid-mixed dentition (stage IIIA, mean age: 8.60 $\pm$ 0.94 years) in subgroup 2; and 9 boys and 11 girls with late mixed dentition (stage IIIB, mean age: 9.50 $\pm$ 1.19 years) in subgroup 3. Besides, all patients were regrouped by the CVMI method [20].

Two authors (AA and YL) independently assessed the risk of bias. Any disagreement was resolved through consultation with a third author (YP).

2.2 Treatment protocol

All subjects were photographed before treatment to record their morphology and occlusion (Fig. 1A–F). The removal expander was applied to the maxillary palate. Two arrowhead clasps were placed on each side, one clasping on the canine or first premolar and the other on the second deciduous molar or first permanent molar (Fig. 1G). The patient was asked to activate the expansion screw twice a week (0.25 mm each time) for 1–3 months until the required expansion was achieved. Besides, maxillary protraction using the Delaire facemask (also called reverse headgear) was carried out. The Delaire face mask consists of a forehead pad and chin cup connected by a square-shaped bilateral framework with a connecting wire for elastic attachment. The elastics were attached to the metal hooks in the canine region in a direction of 25–30° downward and forward from the occlusal plane, generating a force of 300–500 g on each side (Fig. 1H,I). The patients were instructed to wear their facemasks for at least 14 hours a day and to wear intraoral appliances throughout the day.

2.3 Cephalometric analysis

Cephalometric lateral radiographs were taken at the beginning of the treatment (T0) and after facemask removal (T1). All lateral radiographs were traced and analyzed by the same investigator using computerized software. Nineteen cephalometric points were oriented on every radiograph (the detailed information is provided in **Supplementary Fig. 1**). Changes to the cephalometric measurements represented the dental and skeletal changes after treatment. All radiographs were retraced 4 weeks after the first measurement to evaluate the method error.

2.4 Statistical analysis

Cephalometric measurements were described as the arithmetic mean difference (MD) and standard deviation (SD). The SPSS (version 25.0 for Windows, IBM Corporation, Armonk, NY, USA) and R (v3.6.3, Alcatel-Lucent S.A., Boulogne-Billancourt, France) software were used for all statistical analyses. (1) The normality of the distribution of variables and the homogeneities of group variances were checked by the Shapiro-Wilks test and the Levene test, respectively; (2) Inter-subgroup comparisons of the measurements were conducted using one-way analysis of variance (ANOVA) with Tukey's *post-hoc* test or the Kruskal-Wallis test with Steel-Dwass test; (3) Intragroup comparisons were evaluated by paired t-test or Wilcoxon signed-rank test. (4) The effect of treatment timing on the increment of maxillary length was evaluated by univariable linear regression analysis. The significance levels were set at $p < 0.05$, $p < 0.01$ and $p < 0.001$ for all statistical analyses.

TABLE 1. Classical development stage [23].

Timing	Stage
Completion of deciduous dentition	IIA
Beginning of eruption of permanent first molars	IIC
Completion of eruption of all permanent first molars and some or all permanent incisors	IIIA
Shedding of deciduous canines and molars and eruption of successors	IIIB
Beginning of eruption of permanent second molars	IIIC
Completion of eruption of permanent second molars	IVA
Beginning of eruption of third molars	IVC
Completion of eruption of third molars	VA

FIGURE 1. Intra and extraoral appliances for maxillary protraction. (A–F) An extraoral and intraoral view of patient before treatment; (G,H) Extraoral view of patient with Delaire facemask with elastics during treatment process; (I) Intraoral view of a removable maxillary expander.

3. Results

A total of 106 children with Class III malocclusion were initially included in the study. Of these, nine were excluded because of poor quality of images, loss of follow-up, and combined treatment methods; therefore, 97 children were finally included (46 boys and 51 girls; age range: 3–14 years). The cephalometric results of the 97 children and the differences within and between groups were carefully analyzed. Table 2 shows the differences in skeletal morphology between patients at stage IIA–IIC, stage IIIA–IIIB and stage IIIC–IVA. Most significant differences were found between group 1 and either group 2 or group 3, or both, which largely resulted from the craniofacial development.

There were statistically significant differences in most parameters when comparing the pre- and post-cephalometric measurements (Table 3). Notably, the maxillary length (Ptm-A) and the distance between the Ptm point and sella were both significantly increased ($p < 0.001$) after treatment in each group. Besides, significant increments of the ANB angle ($p < 0.001$) were observed in each group.

The results of intergroup comparisons of cephalometric measurement variations are presented in Table 4. No significant difference was found in all skeletal measurements among the three groups. However, the changes of the U1-SN angle ($p < 0.001$) and U1-L1 angle ($p < 0.01$), the dental parameters, both showed significant differences among the three groups. The increase in the U1-SN angle and decrease in the U1-L1 angle observed in group 1 were greater than in group 2 and group 3. However, in terms of the post-treatment parameters, the U1-SN angle in group 1 patients remained smaller than in group 2 and group 3 patients. In addition, patients in group 3 presented the largest increment in Ptm-S distance, MP-FH angle and ANB angle.

To further investigate the dental and skeletal changes in patients with mixed dentition, the mixed dentition group was divided into three subgroups corresponding to the early, mid and late mixed dentition. Patients with early mixed dentition yielded more increase in the U1-SN angle and more decrease in the U1-L1 angle than those with mid- and late-mixed dentition, and this difference was significant. No significant difference was found among subgroups in other cephalometric measurement variations. The results of the inter-subgroup comparisons of cephalometric measurement variations are detailed in Table 5.

When the subjects were regrouped by the CVMI method, only changes in maxillary length (Ptm-A) showed statistically significant differences (Table 6). The results of the multiple comparisons showed that the largest increment was achieved by maxillary protraction when beginning at CS2. However, the univariable linear regression analysis showed that CVMI and dentition stage did not have a statistically significant impact on the increment of maxillary length (Ptm-A) (**Supplementary Table 1**).

4. Discussion

Given that it remains a difficult task to provide an accurate prediction of the craniofacial development for adolescents with Class III malocclusion, there is no consensus on the optimal timing of maxillary protraction. In previous studies, chronological age was commonly used to assess the optimal treatment timing of maxillary protraction [24]. However, among children with the same chronological age, osseous maturation varied to a large extent, indicating that chronological age might not be an accurate assessment of the developmental potential of the maxilla for every patient [12]. Of note, in addition to chronological age, CVMI and dentition stage were both considered as main indicators of the treatment timing [25]. Therefore, the subjects in this study were grouped by the dentition stage and CVMI method. As a result, we found that patients with class III malocclusion treated by Delaire facemasks at different stages of dentition or at the beginning of treatment at the CVMI stage obtained similar skeletal changes in the short term.

Our data showed that regardless of the dentition stage, maxillary protraction could effectively improve the maxillomandibular relationship by producing dentoskeletal changes, including forward displacement and counterclockwise rotation of the maxilla, clockwise backward rotation of the mandible, retroclination of the maxillary incisors, and the proclination of the mandibular incisors, which were consistent with previous studies [10, 26].

Regarding the dental effects, a significant difference was found in the changes of the U1-SN angle. Although more increase in the U1-SN angle was found in group 1 (stage IIA–IIC) than in group 2 (stage IIIA–IIIB) and group 3 (stage IIIC–IVA), the U1-SN angle in group 1 remained smaller than those in group 2 and group 3 after treatment. This result could be explained possibly by the fact that the maxillary deciduous central incisors erupted more lingually than the maxillary central incisors, which was reported in a previous study [13].

As for the skeletal effects, all groups gained significant forward increment of the maxilla after maxillary protraction, with increased SNA and ANB angles. Among all subjects, the most increase in maxillary length (Ptm-A) was achieved in patients with stage IIC malocclusion. The patients in stage IIIC–IVA presented the largest increment of the Ptm-S distance, MP-FH angle and ANB angle, indicating that the increase in the ANB angle resulted both from the maxillary advancement and the mandibular clockwise rotation. The outcome may be in line with the suggestion by Jiang *et al.* [27] and favorable results could be achieved in Class III malocclusion patients when maxillary protraction began at permanent dentition (stage IIIC–IVA). However, the Ptm-S, a distance from the point of the pterygomaxillary fissure to the sella turcica, represents a segment of structure including the length of maxillary tuberosity which will grow to a certain extent during peak growth and the permanent dentition [28]. Therefore, further investigation should be conducted to prove maxillary protraction in the subjects with a Ptm-S increment.

This study suggested that similar results could be achieved when maxillary protraction began at different dentition stages before CS4, which was partially inconsistent with Kajiyama *et al.* [13] Baccetti *et al.* [8] and Franchi *et al.* [21, 22]. However, a retrospective study by Lee *et al.* [24] and a meta-analysis by Zhang *et al.* [29] suggested that maxillary protraction could

TABLE 2. Intergroup comparisons of cephalometric measurements at the beginning of the treatment.

Cephalometric measurements	Group 1 (n = 37) Stage IIA–IIC	Group 2 (n = 40) Stage IIIA–IIIB	Group 3 (n = 20) Stage IIIC–IVA	*p*	Multiple comparison		
					1 *vs.* 2	1 *vs.* 3	2 *vs.* 3
SNA (°)	78.29 ± 3.49	77.93 ± 3.06	76.76 ± 2.29	0.204			
SNB (°)	79.36 ± 3.57	80.19 ± 3.38	80.73 ± 3.17	0.314			
ANB (°)	−1.06 ± 2.38	−2.27 ± 1.83	−3.96 ± 2.57	***	*	*	*
SGn-FH (°)	58.36 ± 3.33	57.99 ± 3.29	57.04 ± 3.98	0.385			
PP-FH (°)	−0.79 ± 3.10	−0.56 ± 2.32	−1.25 ± 3.07	0.669			
MP-FH (°)	25.10 ± 4.03	25.23 ± 4.95	22.84 ± 5.07	0.140			
NPo-FH (°)	88.28 ± 3.45	90.64 ± 3.20	91.31 ± 3.24	**	*	*	
U1-SN (°)	92.56 ± 8.92	104.53 ± 7.72	107.70 ± 5.17	***	*	*	
L1-MP (°)	83.74 ± 7.56	87.63 ± 7.27	87.58 ± 5.76	**	*		
U1-L1 (°)	149.29 ± 14.53	132.31 ± 9.33	131.76 ± 7.90	***	*	*	
Ptm-A (mm)	37.31 ± 2.10	37.97 ± 2.14	39.30 ± 2.23	**		*	
Ptm-S (mm)	16.46 ± 2.02	17.55 ± 1.79	17.24 ± 2.23	*	*		
Co-Gn (mm)	90.36 ± 6.24	99.17 ± 4.63	103.59 ± 5.65	***	*	*	*
N-ANS (mm)	42.45 ± 3.89	46.77 ± 2.76	48.47 ± 3.08	***	*	*	
S-Go (mm)	59.74 ± 4.38	63.95 ± 3.52	67.19 ± 3.95	***	*	*	*
S-Go/N-Me (%)	63.49 ± 3.01	62.59 ± 3.42	64.10 ± 3.18	0.198			
ANS-Me/N-Me (%)	54.96 ± 1.84	54.29 ± 2.03	53.79 ± 2.21	0.091			

$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

SNA, the angle formed by the point S, the point nasion (N) and the point subspinable (A); SNB, the angle formed by the point S, the point N and the point supramental (B); ANB, the angle formed by the point A, the point N and the point B; L1-MP, the angle formed by the lower incisor axis and the mandibular plane (Go-Me); SGn-FH, the angle formed by the mandibular point (Gn) and the Sella point (S) to the Frankfort horizontal line (FH); PP-FH, the angle formed by the pterygomaxillary fissure (Ptm) and point P (Porion) to the Frankfort horizontal line (FH); MP-FH, the angle formed by the mandibular plane (Go-Me) to the Frankfort horizontal line (FH); NPo-FH, the angle formed by the nasion point (N) and point P (Porion) to the Frankfort horizontal line (FH); U1-SN, the angle formed by the upper incisor axis and the nasal spine line (SN); L1-MP, the angle formed by lower incisor axes and mandibular plane (Go-Me); U1-L1, the angle formed by the intersection of upper incisor and lower incisor axes; Ptm-A, the distance between the perpendicular projections from the point Ptm and the point A onto the FH plane; Ptm-S, the distance between the perpendicular projections from the point pterygomaxillary fissure (Ptm) and point S onto the Frankfort horizontal (FH) plane; Co-Gn, the distance between the most anterior point on the chin (Gn) and the most inferior point on the chin (Co); N-ANS, the distance between the nasion (N) and the anterior nasal spine (ANS); S-Go, the distance between the subspinale (S) and the gonion (Go); S-Go/N-Me, the ratio of the S-Go distance to the distance between the nasion (N) and the menton (Me); ANS-Me/N-Me, the ratio of the distance between the anterior nasal spine (A).

yield similar dental and skeletal effects at different dentition stages, which was consistent with our results. It should be noted that relevant clinical studies are varied in sample size, treatment appliance and observation period. In addition, differences in grouping methods should also not be overlooked. Zhang *et al.*'s [29] meta-analysis pooled the outcomes of five studies [9, 13, 22, 30]. Subjects in the study by Yüksel *et al.* [30] which proved that late facemask therapy could achieve similar outcomes to early treatment therapy were grouped by age; whereas in the other four studies, they were grouped by stage of dentition [9, 13, 22]. As a result, the conclusions of previous studies may also vary. Furthermore, we found that patients who were treated by maxillary protraction at CS2, presented the largest increment in the maxillary length (Ptm-A). A probable explanation is that CS2 is an indicator of the approaching growth spurt [20]. The detailed information of the six studies evaluating the relationship between the timing (dentition stage) of maxillary protraction and the treatment effects are summarized in **Supplementary Table 2**.

Interestingly, CS2 included deciduous dentition and early mixed dentition. After regrouping the subjects, the results of CS2 agreed with the stage IIC, which proved the mutual accuracy of this experiment. Moreover, our findings were in line with Nucci *et al.*'s [19] results, in which growing patients

TABLE 3. Intragroup comparisons of cephalometric measurement variations.

Cephalometric measurements	Group 1 (n = 37) Stage IIA–IIC			Group 2 (n = 40) Stage IIIA–IIIB			Group 3 (n = 20) Stage IIIC–IVA		
	T0	T1	*p*	T0	T1	*p*	T0	T1	*p*
SNA (°)	78.29 ± 3.49	80.01 ± 3.59	***	77.93 ± 3.06	79.70 ± 3.24	***	76.76 ± 2.29	78.58 ± 3.49	***
SNB (°)	79.36 ± 3.57	78.29 ± 3.48	**	80.19 ± 3.38	79.48 ± 3.74	*	80.73 ± 3.17	79.34 ± 3.08	**
ANB (°)	−1.06 ± 2.38	1.72 ± 1.71	***	−2.27 ± 1.83	0.22 ± 1.77	***	−3.96 ± 2.57	−0.77 ± 2.40	***
SGn-FH (°)	58.36 ± 3.33	59.76 ± 2.97	***	57.99 ± 3.29	59.16 ± 3.54	***	57.04 ± 3.98	58.95 ± 3.45	***
PP-FH (°)	−0.79 ± 3.10	−1.49 ± 2.96	0.091	−0.56 ± 2.32	−1.42 ± 3.25	*	−1.25 ± 3.07	−1.98 ± 3.63	0.174
MP-FH (°)	25.10 ± 4.03	26.09 ± 3.79	*	25.23 ± 4.95	25.86 ± 5.02	0.059	22.84 ± 5.07	24.73 ± 5.06	***
NPo-FH (°)	88.28 ± 3.45	87.30± 3.19	**	90.64 ± 3.20	89.98 ± 3.26	0.053	91.31 ± 3.24	89.83 ± 2.75	**
U1-SN (°)	92.56 ± 8.92	101.98 ± 7.62	***	104.53 ± 7.72	110.24 ± 7.48	***	107.70 ± 5.17	111.51 ± 6.36	***
L1-MP (°)	83.74 ± 7.56	83.72 ± 7.41	0.988	87.63 ± 7.27	85.62 ± 8.89	*	87.58 ± 5.76	85.30 ± 9.59	0.059
U1-L1 (°)	149.29 ± 14.53	138.98 ± 14.12	**	132.31 ± 9.33	127.84 ± 9.57	**	131.76 ± 7.90	128.47 ± 12.11	0.341
Ptm-A (mm)	37.31 ± 2.10	39.15 ± 2.48	***	37.97 ± 2.14	39.97 ± 2.09	***	39.30 ± 2.23	41.09 ± 1.78	***
Ptm-S (mm)	16.46 ± 2.02	17.31 ± 1.82	***	17.55 ± 1.79	18.56 ± 2.15	***	17.24 ± 2.23	18.52 ± 2.22	***
Co-Gn (mm)	90.36 ± 6.24	93.28 ± 6.96	***	99.17 ± 4.63	102.63 ± 5.15	***	103.59 ± 5.65	106.59 ± 6.16	***
N-ANS (mm)	42.45 ± 3.89	43.79 ± 4.09	***	46.77 ± 2.76	48.28 ± 3.06	***	48.47 ± 3.08	49.62 ± 3.15	**
S-Go (mm)	59.74 ± 4.38	61.37 ± 4.54	***	63.95 ± 3.52	66.52 ± 4.16	***	67.19 ± 3.95	69.33 ± 4.94	***
S-Go/N-Me (%)	63.49 ± 3.01	62.70 ± 2.90	**	62.59 ± 3.42	62.23 ± 3.79	0.116	64.10 ± 3.18	63.16 ± 3.47	**
ANS-Me/N-Me (%)	54.96 ± 1.84	55.35 ± 1.73	*	54.29 ± 2.03	54.89 ± 1.81	**	53.79 ± 2.21	54.80 ± 2.22	**

**p* < 0.05; ***p* < 0.01; ****p* < 0.001.

SNA, the angle formed by the point S, the point nasion (N) and the point subspinable (A); SNB, the angle formed by the point S, the point N and the point supramental (B); ANB, the angle formed by the point A, the point N and the point B; L1-MP, the angle formed by the lower incisor axis and the mandibular plane (Go-Me); SGn-FH, the angle formed by the mandibular point (Gn) and the Sella point (S) to the Frankfort horizontal line (FH); PP-FH, the angle formed by the pterygomaxillary fissure (Ptm) and point P (Porion) to the Frankfort horizontal line (FH); MP-FH, the angle formed by the mandibular plane (Go-Me) to the Frankfort horizontal line (FH); NPo-FH, the angle formed by the nasion point (N) and point P (Porion) to the Frankfort horizontal line (FH); U1-SN, the angle formed by the upper incisor axis and the nasal spine line (SN); L1-MP, the angle formed by lower incisor axes and mandibular plane (Go-Me); U1-L1, the angle formed by the intersection of upper incisor and lower incisor axes; Ptm-A, the distance between the perpendicular projections from the point Ptm and the point A onto the FH plane; Ptm-S, the distance between the perpendicular projections from the point pterygomaxillary fissure (Ptm) and point S onto the Frankfort horizontal (FH) plane; Co-Gn, the distance between the most anterior point on the chin (Gn) and the most inferior point on the chin (Co); N-ANS, the distance between the nasion (N) and the anterior nasal spine (ANS); S-Go, the distance between the subspinale (S) and the gonion (Go); S-Go/N-Me, the ratio of the S-Go distance to the distance between the nasion (N) and the menton (Me); ANS-Me/N-Me, the ratio of the distance between the anterior nasal spine (A).

TABLE 4. Intergroup comparisons of cephalometric measurement variations.

Cephalometric measurements	Group 1 (n = 37) Stage IIA–IIC	Group 2 (n = 40) Stage IIIA–IIIB	Group 3 (n = 20) Stage IIIC–IVA	*p*	Multiple comparison		
					1 *vs.* 2	1 *vs.* 3	2 *vs.* 3
SNA (°)	1.72 ± 1.60	1.78 ± 1.90	1.82 ± 2.24	0.896			
SNB (°)	−1.07 ± 1.76	−0.71 ± 1.84	−1.40 ± 1.80	0.360			
ANB (°)	2.79 ± 1.73	2.49 ± 1.56	3.19 ± 2.09	0.334			
SGn-FH (°)	1.40 ± 1.83	1.17 ± 1.75	1.91 ± 1.78	0.193			
PP-FH (°)	−0.70 ± 2.45	−0.86 ± 2.46	−0.73 ± 2.29	0.911			
MP-FH (°)	0.99 ± 2.27	0.64 ± 2.07	1.89 ± 1.94	0.102			
NPo-FH (°)	−0.98 ± 2.13	−0.66 ± 2.08	−1.48 ± 2.10	0.364			
U1-SN (°)	9.42 ± 5.11	5.72 ± 5.17	3.81 ± 3.92	***	**	***	
L1-MP (°)	−0.02 ± 7.42	−2.02 ± 5.78	−2.28 ± 6.04	0.269			
U1-L1 (°)	−10.31 ± 8.55	−4.47 ± 7.87	−3.29 ± 8.65	**	**	**	
Ptm-A (mm)	1.84 ± 1.71	1.99 ± 1.28	1.79 ± 1.18	0.582			
Ptm-S (mm)	0.85 ± 0.86	1.02 ± 1.32	1.28 ± 1.19	0.401			
Co-Gn (mm)	2.92 ± 2.42	3.46 ± 2.73	3.00 ± 2.56	0.626			
N-ANS (mm)	1.34 ± 1.23	1.52 ± 1.93	1.15 ± 1.54	0.646			
S-Go (mm)	1.64 ± 2.22	2.58 ± 2.25	2.15 ± 1.73	0.163			
S-Go/N-Me (%)	−0.79 ± 1.66	−0.36 ± 1.71	−0.94 ± 1.40	0.344			
ANS-Me/N-Me (%)	0.39 ± 0.92	0.61 ± 1.22	1.01 ± 1.25	0.163			

***$p < 0.01$; ***$p < 0.001$.*

SNA, the angle formed by the point S, the point nasion (N) and the point subspinable (A); SNB, the angle formed by the point S, the point N and the point supramental (B); ANB, the angle formed by the point A, the point N and the point B; L1-MP, the angle formed by the lower incisor axis and the mandibular plane (Go-Me); SGn-FH, the angle formed by the mandibular point (Gn) and the Sella point (S) to the Frankfort horizontal line (FH); PP-FH, the angle formed by the pterygomaxillary fissure (Ptm) and point P (Porion) to the Frankfort horizontal line (FH); MP-FH, the angle formed by the mandibular plane (Go-Me) to the Frankfort horizontal line (FH); NPo-FH, the angle formed by the nasion point (N) and point P (Porion) to the Frankfort horizontal line (FH); U1-SN, the angle formed by the upper incisor axis and the nasal spine line (SN); L1-MP, the angle formed by lower incisor axes and mandibular plane (Go-Me); U1-L1, the angle formed by the intersection of upper incisor and lower incisor axes; Ptm-A, the distance between the perpendicular projections from the point Ptm and the point A onto the FH plane; Ptm-S, the distance between the perpendicular projections from the point pterygomaxillary fissure (Ptm) and point S onto the Frankfort horizontal (FH) plane; Co-Gn, the distance between the most anterior point on the chin (Gn) and the most inferior point on the chin (Co); N-ANS, the distance between the nasion (N) and the anterior nasal spine (ANS); S-Go, the distance between the subspinale (S) and the gonion (Go); S-Go/N-Me, the ratio of the S-Go distance to the distance between the nasion (N) and the menton (Me); ANS-Me/N-Me, the ratio of the distance between the anterior nasal spine (A).

were divided based on different CVMI (CS1–2 *vs.* CS3–4) to detect the ideal timing of intervention for the treatment of Class III malocclusion with a modified SEC III (Splints, Elastic and Chincup) protocol. The modified early protocol produced favorable sagittal outcomes in both groups, whereas no statistically significant changes of T1–T2 were found in any angular and linear measurements between the CS1–2 and CS3–4 groups. However, the study lacked metrics to measure the length and position of the maxilla, so it was difficult to determine the treatment effect on maxillary growth and development. Therefore, the findings of our study can be used as a complement to previous studies and provide a reference for clinicians to determine the optimal timing of maxillary protraction.

This study concentrates on the optimal treatment timing for children with class III malocclusion, while also innovatively introducing the method of CVMI for grouping. Supported by an organized scientific method, the results show critical clinical significance. Some limitations of the current study are as follows. The sample size of 97 patients was relatively small, and the effects of treatment timing on the treatment efficacy were evaluated only in the short term. Hence, results from long-term post-treatment follow-up are still needed. Additionally, the blank control groups of untreated patients

TABLE 5. Inter-subgroup comparisons of cephalometric measurement variations.

Cephalometric measurements	Subgroup 1 (n = 20) Stage IIC	Subgroup 2 (n = 20) Stage IIIA	Subgroup 3 (n = 20) Stage IIIB	*p*	Multiple comparison		
					1 *vs.* 2	1 *vs.* 3	2 *vs.* 3
SNA (°)	1.72 ± 1.57	1.69 ± 1.89	1.87 ± 1.95	0.945			
SNB (°)	−0.85 ± 1.71	−0.93 ± 1.82	−0.49 ± 1.88	0.712			
ANB (°)	2.58 ± 1.97	2.63 ± 1.74	2.35 ± 1.39	0.860			
SGn-FH (°)	1.01 ± 1.81	1.02 ± 1.95	1.32 ± 1.55	0.822			
PP-FH (°)	−1.05 ± 2.70	−1.14 ± 2.78	−0.58 ± 2.13	0.759			
MP-FH (°)	0.63 ± 2.27	0.21 ± 2.35	1.07 ± 1.69	0.445			
NPo-FH (°)	−0.49 ± 2.25	−0.61 ± 2.54	−0.71 ± 1.56	0.949			
U1-SN (°)	9.73 ± 6.08	3.81 ± 5.56	7.63 ± 4.04	**	**		
L1-MP (°)	−0.97 ± 5.41	−2.45 ± 5.58	−1.59 ± 6.07	0.714			
U1-L1 (°)	−9.61 ± 8.79	−1.91 ± 6.69	−7.03 ± 8.28	*	**		
Ptm-A (mm)	2.27 ± 2.06	1.89 ± 1.35	2.10 ± 1.24	0.746			
Ptm-S (mm)	0.96 ± 0.86	1.05 ± 1.38	0.99 ± 1.29	0.974			
Co-Gn (mm)	3.51 ± 2.88	2.72 ± 3.16	4.21 ± 2.03	0.234			
N-ANS (mm)	1.64 ± 1.27	1.10 ± 1.92	1.94 ± 1.89	0.298			
S-Go (mm)	2.05 ± 2.20	2.28 ± 2.58	2.87 ± 1.88	0.493			
S-Go/N-Me (%)	−0.82 ± 1.40	−0.31 ± 2.08	−0.42 ± 1.30	0.579			
ANS-Me/N-Me (%)	0.40 ± 1.05	0.74 ± 1.04	0.48 ± 1.40	0.641			

$*p < 0.05$; $**p < 0.01$.
SNA, the angle formed by the point S, the point nasion (N) and the point subspinable (A); SNB, the angle formed by the point S, the point N and the point supramental (B); ANB, the angle formed by the point A, the point N and the point B; L1-MP, the angle formed by the lower incisor axis and the mandibular plane (Go-Me); SGn-FH, the angle formed by the mandibular point (Gn) and the Sella point (S) to the Frankfort horizontal line (FH); PP-FH, the angle formed by the pterygomaxillary fissure (Ptm) and point P (Porion) to the Frankfort horizontal line (FH); MP-FH, the angle formed by the mandibular plane (Go-Me) to the Frankfort horizontal line (FH); NPo-FH, the angle formed by the nasion point (N) and point P (Porion) to the Frankfort horizontal line (FH); U1-SN, the angle formed by the upper incisor axis and the nasal spine line (SN); L1-MP, the angle formed by lower incisor axes and mandibular plane (Go-Me); U1-L1, the angle formed by the intersection of upper incisor and lower incisor axes; Ptm-A, the distance between the perpendicular projections from the point Ptm and the point A onto the FH plane; Ptm-S, the distance between the perpendicular projections from the point pterygomaxillary fissure (Ptm) and point S onto the Frankfort horizontal (FH) plane; Co-Gn, the distance between the most anterior point on the chin (Gn) and the most inferior point on the chin (Co); N-ANS, the distance between the nasion (N) and the anterior nasal spine (ANS); S-Go, the distance between the subspinale (S) and the gonion (Go); S-Go/N-Me, the ratio of the S-Go distance to the distance between the nasion (N) and the menton (Me); ANS-Me/N-Me, the ratio of the distance between the anterior nasal spine (A).

were not included in the present research owing to ethical considerations. Cone-beam computed tomography (CBCT) is required for better visualization of the results, rather than relying only on two-dimensional scans [31]. Of note, factors affecting treatment timing are complex, as the time of treatment is influenced by cost, willingness, and health condition. Overall, additional large-scale clinical studies to investigate the long-term effects of treatment timing on the treatment of maxillary protraction are needed. In particular, other types of masks such as traction masks with forehead straps (PFFS) or Pettit-type masks (PTF) should be considered in such studies to assess differences in optimal timing when using different mask types [32–34].

According to the latest research hotspot, the effect of maxillary retraction appliances on the improvement of pharyngeal airway dimensions in patients with maxillary retraction growth class III suggests that pharyngeal parameters can also be used as one of the evaluation factors [35, 36]. Furthermore, in a recent study, Yilmaz *et al.* [36] even took into account the development of the dental roots when evaluating the effect of the mask, which suggests that further studies should enrich the indicators considered and not be limited only to skeletal indicators.

TABLE 6. Comparisons of cephalometric measurement variations among Class III malocclusion patients at different CVMI.

Cephalometric measurements	CVMS 1 (n = 59)	CVMS 2 (n = 25)	CVMS 3&4 (n = 13)	p	Multiple comparison		
					1 *vs.* 2	1 *vs.* 3&4	2 *vs.* 3&4
SNA (°)	1.71 ± 1.82	1.80 ± 1.44	1.94 ± 2.66	0.918			
SNB (°)	−0.93 ± 1.97	−1.28 ± 1.35	−0.68 ± 1.83	0.582			
ANB (°)	2.64 ± 1.66	3.09 ± 1.66	2.58 ± 2.26	0.526			
SGn-FH (°)	1.33 ± 1.90	1.74 ± 1.54	1.16 ± 1.73	0.551			
PP-FH (°)	−0.95 ± 2.36	−0.48 ± 2.70	−0.54 ± 2.04	0.674			
MP-FH (°)	0.87 ± 2.29	1.32 ± 1.88	1.18 ± 2.08	0.663			
NPo-FH (°)	−0.83 ± 2.33	−1.39 ± 1.61	−0.64 ± 1.91	0.467			
U1-SN (°)	7.20 ± 5.60	7.03 ± 4.67	4.03 ± 5.02	0.147			
L1-MP (°)	−0.91 ± 6.77	−1.72 ± 5.99	−2.33 ± 6.67	0.730			
U1-L1 (°)	−7.17 ± 8.82	−6.82 ± 7.67	−2.48 ± 10.07	0.213			
Ptm-A (mm)	1.61 ± 1.14	2.60 ± 1.78	1.84 ± 1.51	*	**		
Ptm-S (mm)	1.04 ± 1.15	0.79 ± 0.87	1.27 ± 1.48	0.438			
Co-Gn (mm)	3.15 ± 2.62	3.36 ± 2.61	2.81 ± 2.36	0.825			
N-ANS (mm)	1.28 ± 1.73	1.84 ± 1.16	0.89 ± 1.66	0.181			
S-Go (mm)	2.04 ± 2.37	2.24 ± 2.07	2.30 ± 1.22	0.888			
S-Go/N-Me (%)	−0.57 ± 1.78	−0.94 ± 1.38	−0.42 ± 1.43	0.561			
ANS-Me/N-Me (%)	0.58 ± 1.10	0.43 ± 1.11	1.04 ± 1.29	0.288			

*CVMI: cervical vertebral maturation index; *$p < 0.05$; **$p < 0.01$.*
SNA, the angle formed by the point S, the point nasion (N) and the point subspinable (A); SNB, the angle formed by the point S, the point N and the point supramental (B); ANB, the angle formed by the point A, the point N and the point B; L1-MP, the angle formed by the lower incisor axis and the mandibular plane (Go-Me); SGn-FH, the angle formed by the mandibular point (Gn) and the Sella point (S) to the Frankfort horizontal line (FH); PP-FH, the angle formed by the pterygomaxillary fissure (Ptm) and point P (Porion) to the Frankfort horizontal line (FH); MP-FH, the angle formed by the mandibular plane (Go-Me) to the Frankfort horizontal line (FH); NPo-FH, the angle formed by the nasion point (N) and point P (Porion) to the Frankfort horizontal line (FH); U1-SN, the angle formed by the upper incisor axis and the nasal spine line (SN); L1-MP, the angle formed by lower incisor axes and mandibular plane (Go-Me); U1-L1, the angle formed by the intersection of upper incisor and lower incisor axes; Ptm-A, the distance between the perpendicular projections from the point Ptm and the point A onto the FH plane; Ptm-S, the distance between the perpendicular projections from the point pterygomaxillary fissure (Ptm) and point S onto the Frankfort horizontal (FH) plane; Co-Gn, the distance between the most anterior point on the chin (Gn) and the most inferior point on the chin (Co); N-ANS, the distance between the nasion (N) and the anterior nasal spine (ANS); S-Go, the distance between the subspinale (S) and the gonion (Go); S-Go/N-Me, the ratio of the S-Go distance to the distance between the nasion (N) and the menton (Me); ANS-Me/N-Me, the ratio of the distance between the anterior nasal spine (A).

5. Conclusions

Dental and skeletal changes occurred in almost all patients with Class III malocclusion who were treated by the Delaire facemask, when these changes are related to the timing of initiating treatment. Though statistical significance has not been found among groups at different dentition stages or cervical vertebral maturation index in the short term, we recommend starting treatment at CS2 for patients who desire large maxillary increment.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

YP and YL—designed the research study. YL—performed the research. AA—analyzed the data. YL and AA—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The design of this study was approved by the ethics committee of West China Hospital (No. WCHSIRB-D-2020-254). Informed consent was obtained from both patients and their parents.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at `https://oss.jocpd.com/files/article/1852224908720783360/attachment/Supplementary%20material.docx`.

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