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Comparative analysis of rapid expansion combined with maxillary protraction therapy in patients at different growth phases: A retrospective study

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Abstract. The best timing for treating adolescent patients with skeletal class III malocclusion is still unclear. The present study aimed to explore variations in the efficacy of rapid expansion combined with maxillary protraction therapy in patients with skeletal class III malocclusion at different growth and development stages. Clinical records of 45 patients with skeletal class III malocclusion who underwent rapid expansion combined with maxillary protraction therapy from January 2019 to June 2022 were included in the present study. Based on the cervical vertebral maturation method (CVM), the patients were retrospectively divided into three groups: Pre-pubertal (CVM stages I-II, n=15), pubertal (CVM stage III, n=15) and post-pubertal (CVM stages IV-VI, n=15). Lateral head radiographs before and after the treatment and various bone, dental and soft tissue measurements were compared between groups to assess the differences in treatment effects. The results of the intra-group comparison before and after the treatment showed that the dental and bone indicators, such as A Point-Nasion-Point B angle, sella-nasion-A point angle, sella-nasion-B point angle, mandibular plane angle, A Point-VR plane and anterior Nasal-VR plane (ANS-VR) were significantly different compared with those before treatment in all three groups of patients ($P<0.05$). The posterior Nasal-VR plane (PNS-VR) changed significantly in the pre-pubertal and pubertal groups ($P<0.05$), but there was no significant change in the post-pubertal group. The Glabella-Pronasale-Pogonion of soft tissue and Sella-Nasion-Nasion-Bs Point angle decreased significantly post-treatment in the three groups, while the Sella-Nasion-Nasion-Sn Point angle increased ($P<0.05$). Intergroup comparisons before and after treatment showed that there was no significant difference in the post-treatment indexes between the pre-pubertal and pubertal groups. The changes in ANS-VR and PNS-VR values before and after treatment were statistically significant between the post-pubertal and the other two groups ($P<0.05$). In conclusion, rapid expansion combined with maxillary protraction therapy has the best treatment effects in patients in the pre-pubertal and pubertal stages and is associated with significant skeletal effects and less alveolar response. Although the skeletal treatment effects are less favorable in patients in the post-pubertal stage with more pronounced alveolar responses, the treatment can still provide appropriate compensation for facial deformities and reduce the likelihood of orthognathic surgery.

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Introduction

Skeletal class III malocclusion is highly prevalent in China, with an incidence of ~15.67%, and maxillary sagittal deficiency accounts for 42-67% of all class III malocclusion cases (1). Malocclusion has been associated with clinical changes of masticatory muscles or the temporomandibular joint and temporomandibular disorders that are accompanied by joint and muscle pain, and limitations of mouth opening (2). Studies suggest that the management of class III malocclusion improves temporomandibular joint conditions (3,4). It is well-established that malocclusion symptoms associated with maxillary sagittal deficiency, such as malocclusion itself, midfacial depression and nasal collapse, significantly impact the physical and mental wellbeing of adolescent patients with skeletal class III malocclusion (5,6). Therefore, early intervention is typically recommended for such patients.

Rapid expansion combined with maxillary protraction has emerged (7) as an effective approach for treating skeletal class III malocclusion. While maxillary protraction efficiently improves facial aesthetics and occlusion in younger patients (8), there is a lack of sufficient research on the effects of anterior distraction in patients during the post-pubertal stage. The development of the micro-implant anchorage has increased the use of maxillary skeletal expansion combined with protraction in post-pubertal patients and improved the overall treatment effect. By comparing bone anchorage and dental anchorage in class III patients, Seiryu *et al* (9) found that facemask therapy and a miniscrew provided more orthopedic force and controlled the side effects of alveolar bone. However, based on clinical observations by our group, certain post-pubertal patients still refuse this invasive procedure and choose to use dental anchorage protraction, which is associated with a potential risk of recurrence (10,11). Therefore, it is crucial to determine whether post-pubertal patients would benefit from dental anchorage-forward distraction therapy. Various factors influence growth and development, and even individuals of the same age may exhibit varying degrees of skeletal maturity (12-15). In recent years, the prevalence of precocious puberty in children has increased, rendering physiological age an insufficient criterion for assessing their growth and development status (16-18). Jang *et al* (19) used cone beam computed tomography (CBCT) and confirmed a correlation between the cervical vertebral bone age stage and the maturity of multiple maxillary sutures. The cervical vertebral maturation (CVM) method offers higher accuracy compared to physiological age and greater convenience compared to carpal bone age in determining children's growth and development stage (20). In a previous publication by our group that provided a research basis for the current study (21), patients with maxillomandibular transverse width incoherence who were treated with rapid maxillary expansion were examined, and they were grouped according to cervical vertebral maturation. The results showed that the effect of maxillary transverse expansion was different in patients with different bone ages, and the effect of skeletal expansion decreased gradually with the increase of bone age.

Therefore, in the present study, the CVM method was also used to group skeletal class III patients and investigate whether the treatment effect of maxillary sagittal distraction differed in patients with different bone ages. In addition, the present study aimed to assess the feasibility of maxillary protraction in a specific population of patients in the later stage of growth and development to provide favorable evidence for using rapid expansion combined with maxillary protraction therapy in post-pubertal patients.

Patients and methods

Patients. According to the pre-determined eligibility criteria (listed later), clinical records of skeletal class III patients who underwent rapid expansion combined with maxillary protraction at the Department of Orthodontics of the Second Hospital of Jiaxing (Jiaxing, China) from January 2019 to June 2022 were retrospectively screened. Records of 45 eligible skeletal class III adolescent patients were retrospectively collected and grouped according to the cervical spine bone age shown by their lateral cephalograms.

Inclusion criteria. Patients were included if they met the following criteria: i) Skeletal class III malocclusion based on the A point to B point to nasion; the angle that relates the anterior limit of the maxillary bone (A point) and mandibular bone (B point) with the anterior limit of the nasofrontal suture (N point) (ANB) as -3°<ANB<0°; ii) facial profile exhibiting midfacial depression, with maxillary sagittal deficiency, maxillary prominence [distance from the point of the A point to the Nasion perpendicular (ANP) <1 mm (McNamara analysis) (22)]; iii) the mandibular growth pattern was defined as average or horizontal growth, mandibular plane angle (MPA) <32°; iv) lateral cephalograms indicating the growth and development stage of the cervical spine; v) rapid palatal expansion treatment combined with anterior distraction was performed for more than 1 year.

Exclusion criteria. Patients were included if the following applied: i) Patients did not cooperate; ii) temporomandibular joint disease; iii) cleft lip and palate and maxillofacial or growth and development defects; iv) a previous history of surgery, trauma, orthodontic treatment, maxillofacial defects or growth defects; v) a family history of mandibular hyperdevelopment [patients with overgrowth of the mandible were excluded, according to Jaraback's analysis (23)].

Grouping. According to the CVM method, 45 patients who met the inclusion and exclusion criteria were divided into three groups. The pre-pubertal group consisted of 15 patients (8 males and 7 females; mean age, 7.3 years) with CVM stages I-II; the pubertal group included 15 patients (6 males and 9 females; mean age, 9.4 years) with CVM stage III; and the post-pubertal group had 15 patients (5 males and 10 females; mean age, 12.2 years) with CVM stages IV-VI (24).

Therapeutic method. As previously described (25), lateral cephalograms and CBCT were taken before the treatment to examine the sagittal and transverse imbalance of the upper and lower jaw. CBCT was used to measure the width of each patient's maxillary and mandibular basal bone arches (the width of the connection between the root furcations of the bilateral first molars) prior to treatment (Fig. 1A and B, respectively) (26). Rapid maxillary expansion was first used for each patient included in the study (Fig. 2) with an occlusal pad for maxillary rapid expansion. The coil spring was required to be opened 0.5 mm (2 revolutions/day) daily. The width of the upper and lower jaws was adjusted to make the width of the maxillary base bone arch 2 mm larger than that of the mandibular base bone arch. After completing the maxillary expansion, the Petit-type facemask (Hangzhou West Lake Biological Material Co., Ltd.) (Fig. 3) was implemented with a force of 450 g on each side at an angle of 20-30° downward to the maxillary plane. Traction lasted for 14 h per day (27). Lateral cephalograms were taken after about one year of traction.

Measurements and collected indexes. Tracing and lining segment measurements were performed on lateral cephalograms of each patient prior to treatment and at the one-year follow-up visit. Based on previous studies (28,29), the following measurement indicators were selected (Fig. 4): The relatively stable horizontal reference (HR) plane (7° downward rotation of the line connecting the sellar point and nasion point) and vertical reference (VR) plane (sellar point perpendicular to the HR plane) were used as horizontal and vertical reference axes, respectively. The following were measured: Sella-Nasion-A Point angle (SNA angle), Sella-Nasion-B Point angle (SNB angle), A Point-Nasion-Point B angle (ANB angle), Upper Anterior Teeth-Palatal Plane angle (U1-PP angle), Mandibular Plane Angle (MPA angle), Sella-Nasion-Nasion-Sn Point angle (S-Ns-Sn angle), Sella-Nasion-Nasion-Bs Point angle (S-Ns-Bs angle), Glabella-Pronasale-Pogonion of soft tissue angle [Angle of convexity (G-Prn-Pos angle)], Anterior Nasal-VR

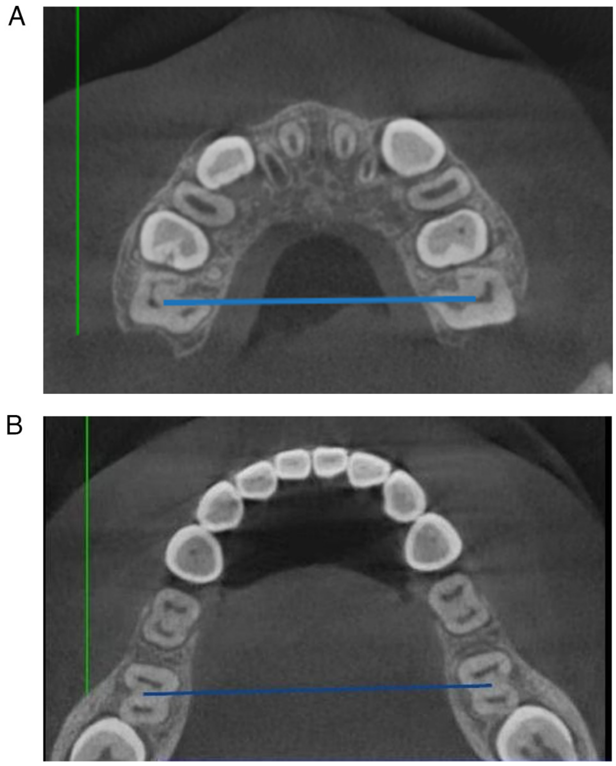

Figure 1. (A) Example of the pre-treatment CBCT measurement of the width of maxillary basal bone arches; (B) Pre-treatment CBCT measurement of the width of mandibular basal bone arches. CBCT, cone beam computed tomography.

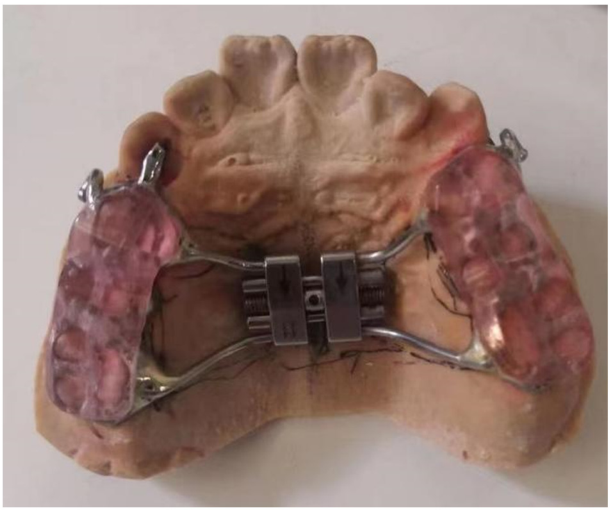

Figure 2. Rapid maxillary expansion expander.

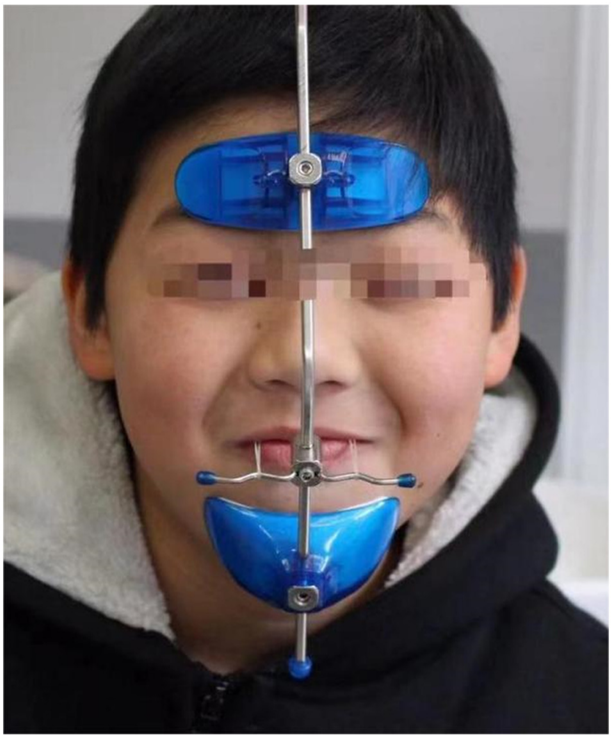

Figure 3. Petit-type facemask.

plane (ANS-VR), Posterior Nasal-VR plane (PNS-VR), A Point-VR plane (A-VR), Labial Superior-VR (Ls-VR) and Upper Anterior Teeth-VR plane (U1-VR).

The same orthodontic doctor positioned and measured the patients' lateral cephalograms (pre- and post-treatment cephalograms of the same patient were measured on the same day) to minimize errors to get a more accurate comparison. The measurements were performed three times, with the final results presented as the average of the three measurements.

Statistical analysis. Statistical analysis was conducted using SPSS 25.0 software (IBM Corp.). Measurement data following a normal distribution were expressed as the mean ± standard deviation. A paired-samples t-test was used for within-group comparisons and one-way ANOVA for multiple groups, with the least-significant differences post hoc t-test for pairwise comparisons between groups, and a 95% confidence interval was selected. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Intra-group comparison of bone indexes in the three groups before and after treatment. As shown in Table I, in all three groups, the treatment was associated with a significant increase in the ANB and SNA angles, a decrease in the SNB angle and an increase in the MPA ($P<0.05$). The results indicated that maxillary anteriorization occurred at the same time as mandibular anteriorization after treatment, which made certain data reach the normal level after treatment, like the ANB angle reaches a positive value in most patients after treatment. The position of the upper anterior teeth (U1-VR) increased after treatment.

In the pre-pubertal and the pubertal groups, treatment led to significantly increased indexes of ANS-VR, PNS-VR and A-VR ($P<0.05$), indicating that the maxilla grew forward and moved forward in these two groups. In the post-pubertal group, the ANS-VR and A-VR increased significantly. By contrast, no such increase was observed for the PNS-VR [an increase of only 0.54±1.21 mm ($P>0.05$)], indicating that in the post-pubertal group, the alveolar bone grew and the maxilla did not move forward. In addition, the post-pubertal and pubertal groups had a significantly larger change in the

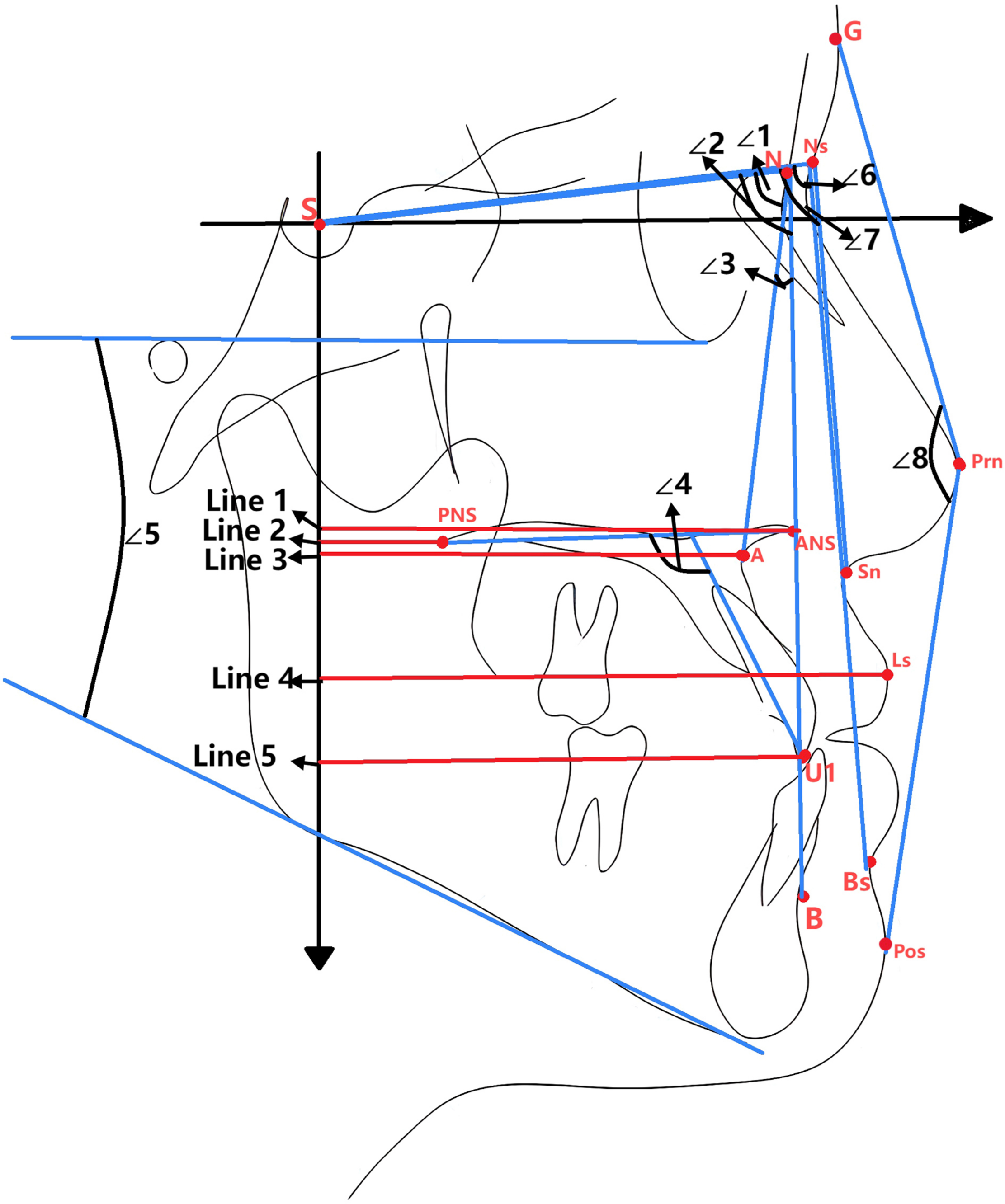

Figure 4. An example of the lateral cephalogram measurement. ∠1, SNA angle; ∠2, SNB angle; ∠3, ANB angle; ∠4, U1-PP angle; ∠5, MPA; ∠6, S-Ns-Sn angle; ∠7, S-Ns-Bs angle; ∠8: G-Prn-Pos angle; line segment 1, ANS-VR; line segment 2, PNS-VR; line segment 3, A-VR; line segment 4, Ls-VR; line segment 5, U1-VR. SNA, Sella-Nasion-Apoint; SNB, Sella-Nasion-B point; ANB, A Point-Nasion-Point B; U1-PP, Upper Anterior Teeth Palatal Plane; MPA, Mandibular Plane Angle; S-Ns-Sn, Sella-Nasion-Nasion-Sn Point; S-Ns-Bs, Sella-Nasion-Nasion-Bs Point; Angle of convexity (G-Prn-Pos), Glabella-Pronasale-Pogonion of soft tissue; VR, Vertical Reference; ANS-VR, Anterior Nasal-VR plane; PNS-VR, Posterior Nasal VR plane; A-VR, A Point VR plane; Ls-VR, Labial Superior VR; U1-VR, Upper Anterior Teeth VR plane.

U1-PP Angle than the prepubertal group, suggesting that lip inclination of the upper anterior teeth occurred in these two groups due to the action of dental anchorage (9).

Intra-group comparison of soft tissue indexes in the three groups before and after treatment. As summarized in Table I, the G-Prn-Pos angle in the pre-pubertal, pubertal and post-pubertal groups decreased significantly after the treatment. In addition, there was a significant increase in the S-Ns-Sn angle of the upper lip. Furthermore, the S-Ns-Bs angle decreased significantly (P<0.05). This indicated that the mid-facial depression was improved and the nasal base position was moved forward. The Ls-VR, as the index representing the position of the upper lip, increased significantly, suggesting that the upper lip had moved forward substantially after treatment (30).

Intergroup comparisons before and after treatment. There was no statistically significant difference in any of the indexes between the pre-pubertal and the pubertal groups. The changes

Table I. Changes in dental and bony parameters before and after treatment in the three groups.

	Pre-pubertal group			Pubertal group			Post-pubertal group		
Angle	T1	T2	P-value	T1	T2	P-value	T1	T2	P-value
ANB angle	-2.25±1.97	0.95±1.43	<0.001	-1.97±0.46	1.25±0.32	<0.001	-2.04±0.59	-0.19±0.51	<0.001
SNA angle	80.35±3.19	82.57±3.35	0.007	78.67±0.89	80.49±0.98	0.001	79.35±0.83	80.27±0.76	<0.001
SNB angle	82.75±2.79	81.08±2.54	0.003	80.65±1.09	79.26±1.00	0.003	81.39±1.06	80.47±1.00	0.005
U1-PP angle	115.15±1.58	116.14±1.18	0.475	114.93±1.72	117.11±1.28	0.042	117.84±1.24	119.63±1.27	0.049
MPA angle	27.46±1.46	31.23±0.97	0.012	30.32±1.19	32.29±1.07	0.005	30.18±0.99	31.69±1.08	0.011
A-VR	59.35±1.15	61.54±1.19	0.001	60.91±1.69	63.19±2.00	0.015	60.52±1.25	61.89±1.22	0.001
ANS-VR	65.47±1 24	67.89±1.16	0.001	66.78±1.78	69.11±2.14	0.018	66.05±1.12	66.59±1.18	0.049
PNS-VR	17.89±0.79	19.29±0.79	<0.001	19.64±0.94	20.77±1. 00	0.030	17.69±0.81	18.23±0.76	0.108
U1-VR	60.98±2.36	63.20±2.41	0.001	61.89±2.12	66.28±2.04	0.00 3	64.67±1.79	67.23±1.89	0.001
Ls-VR	77.09±1.79	80.39±1.74	<0.001	79.23±2.21	81.82±2.39	0.0 09	79.29±1.35	81.24±1.31	0.002
G-Prn-Pos angle	144.89±2.25	139.94±1.65	0.002	147.64±2.38	143.53±2.15	<0.001	153.89±1.32	150.49±1.61	0.001
S-Ns-Sn angle	88.31±0.72	90.32±0.87	0.002	85.80±1.76	88.42±1.80	0.002	84.72±1.69	86.19±1.58	0.029
S-Ns-Bs angle	85.07±2.88	83.66±3.39	0.011	85.10±1.09	82.69±1.04	0.003	82.91±1.39	81.87±1.43	0.023

$P<0.05$ was considered to indicate statistical significance before and after treatment in the same group. T1, before rapid expansion combined with protraction; T2, rapid expansion combined with protraction; SNA, Sella-Nasion-A Point; SNB, Sella-Nasion-B Point; ANB, A Point-Nasion-Point B; U1-PP, Upper Anterior Teeth-Palatal Plane; MPA, Mandibular Plane Angle; S-Ns-Sn, Sella-Nasion-Nasion-Sn Point; S-Ns-Bs, Sella-Nasion-Nasion-Bs Point; Angle of convexity (G-Prn-Pos), Glabella-Pronasale-Pogonion of soft tissue; VR, Vertical Reference; ANS-VR, Anterior Nasal-VR plane; PNS-VR, Posterior Nasal-VR plane; A-VR, A Point-VR plane; Ls-VR, Labial Superior-VR; U1-VR, Upper Anterior Teeth-VR plane.

Table II. Intergroup comparison of differences before and after treatment in the three groups (T2-T1).

Angle	Pre-pubertal group	Pubertal group	Post-pubertal group	P-value
ANB angle	3.21±1.93	3.22±1.84	1.85±1.01	>0.05
SNA angle	2.21±2.69	1.82±1.78	0.92±0.77	>0.05
SNB angle	-1.66±1.76	-1.39±1.48	-0.93±1.08	>0.05
U1-PP angle	0.99±5.22	2.17±3.77	1.79±3.21	>0.05
MPA angle	3.77±5.09	1.97±2.27	1.51±2.00	>0.05
A-VR	2.18±1.91	2.27±3.18	1.37±1.19	>0.05
ANS-VR	2.43±2.11	2.33±3.35	0.55±0.98[a,b]	<0.05
PNS-VR	1.40±1.19	1.13±1.81	0.54±1.21[c,d]	<0.05
U1-VR	2.87±2.56	4.39±4.84	2.56±2.46	>0.05
Ls-VR	3.29±2.56	2.59±3.32	1.95±1.92	>0.05
G-Prn-Pos	-4.95±5.19	-4.11±3.21	-3.40±3.25	>0.05
S-Ns-Sn angle	2.01±2.03	2.61±2.68	1.47±2.35	>0.05
S-Ns-Bs angle	-1.41±1.88	-2.41±2.65	-1.04±1.58	>0.05

T2-T1, the difference before and after rapid expansion combined with protraction. [a]The ANS-VR changes in the post-pubertal group were significantly different from those in the pre-pubertal group [b]The ANS-VR changes in the post-pubertal group were significantly different from those in the pubertal group. [c]The PNS-VR changes in the post-pubertal group were significantly different from those in the pre-pubertal group. [d]The PNS-VR changes in the post-pubertal group were significantly different from those in the prepubertal group. SNA, Sella-Nasion-A Point; SNB, Sella-Nasion-B Point; ANB, A Point-Nasion-Point B; U1-PP, Upper Anterior Teeth-Palatal Plane; MPA, Mandibular Plane Angle; S-Ns-Sn, Sella-Nasion-Nasion-Sn Point; S-Ns-Bs, Sella-Nasion-Nasion-Bs Point; Angle of convexity (G-Prn-Pos), Glabella-Pronasale-Pogonion of soft tissue; VR, Vertical Reference; ANS-VR, Anterior Nasal-VR plane; PNS-VR, Posterior Nasal-VR plane; A-VR, A Point-VR plane; Ls-VR, Labial Superior-VR; U1-VR, Upper Anterior Teeth-VR plane.

in the ANS-VR and PNS-VR in the post-pubertal group were significantly different from and the change in the post-pubertal group was significantly lower than that in the other two groups. There was no significant difference in the changes in facial soft tissue among the three groups (Table II).

Discussion

Skeletal class III malocclusion can be classified into maxillary sagittal deficiency, mandibular overgrowth and mixed types (31). However, the length of the mandible is mainly determined by genetics and the mandibular growth of patients with class III malocclusion has a longer duration (32). In addition, clinical studies have shown that chincap appliances therapy for patients with mandibular overgrowth is not effective in inhibiting mandibular growth (33). Therefore, the early treatment of skeletal class III malocclusion mainly focuses on the sagittal deficiency of the maxilla to stimulate its growth and development (25), and the treatment of rapid expansion combined with maxillary protraction is the most common.

Patients with overgrowth of the mandible were excluded from the present study. The results of this study showed that rapid maxillary expansion combined with protraction could improve the sagittal imbalance of the upper and lower jaws, correct the malocclusion of the anterior teeth and improve the facial profile of the patients in three different growth and development stages within ~1 year. However, the bone and dental effects differ in patients of various ages after treatment. The results revealed that the ANB angles of the pre-pubertal and pubertal patients reached normal values after the treatment. By contrast, the ANB angles of patients in the post-pubertal group significantly increased after rapid expansion combined with maxillary protraction therapy for ~1 year. However, certain patients did not attain the normal range. In this study, the sagittal changes of the A point were significant in all three groups. The changes in the A-VR were 2.18±1.91, 2.27±3.18 and 1.37±1.19 mm in the pre-pubertal, pubertal and post-pubertal groups, respectively. The change in the SNA angle in the three groups was 2.21±2.69, 1.82±1.78 and 0.92±0.77°, respectively, and the differences before and after treatment within each of the groups were statistically significant ($P<0.05$). Baccetti *et al* (34) observed untreated patients with class III malocclusion and demonstrated that the change value of point A was only 0.5±2.1 mm during the natural growth (from CVM stage I to stage VI). This indicates that even after removing the effects of growth and development, the A point of all three groups experienced a growth promotion after protraction treatment. However, the forward movement of point A does not match the forward movement of the maxilla, and point A represents the alveolar effect rather than the bone effect (35). A previous study compared 26 patients with class III malocclusion treated with forward distraction with 15 patients with class III malocclusion without the treatment and concluded that the most significant change in the movement of the maxillary complex after forward distraction treatment was the movement of the posterior nasal spine and pterygomaxillary fissure points (36). This parameter represented the overall movement of the maxilla, which was the expected bone effect of forward distraction treatment. In the present study, the PNS-VR changed significantly after the treatment in the pre-pubertal (1.40±1.19 mm) and the pubertal group (1.13±1.81 mm). At the same time, the U1-VR value, representing the dental changes, also considerably changed in the two groups. Comparison of the changes in PNS-VR, A-VR and U1-VR revealed an order of magnitude of U1-VR > A-VR > PNS-VR in the pre-pubertal and pubertal groups. These results indicate that the forward traction treatment led to the maxilla moving forward and caused a certain degree of alveolar reaction due to the forward movement of the upper anterior teeth. In addition, a study provided a 3D finite element analysis of tooth-anchored maxillary protraction and bone-anchored maxillary protraction, showing that both dental and bony anchorage have forces on the position of the bonded fixed molar and the occurrence of dental effects is difficult to avoid (37). In the present study, the treatment led to a slight insignificant change in the PNS point in the post-pubertal group (0.54±1.21 mm), while the A and the ANS points changed significantly [1.45±0.87 and 0.72±0.55 mm, respectively]. The results suggest that there was only small maxillary movement in the post-pubertal group, but the alveolar response was larger. Cha (38) also found that 84.0% of bone remodeling and 16.0% of alveolar remodeling were observed in patients at the growth peak. By contrast, in the late stages of growth, 63.6% of the patients had bone remodeling and 36.4% had alveolar remodeling. The results of comparisons among the three groups of patients showed that the PNS-VR of the patients in the post-pubertal group was significantly smaller than that in the other two groups (P<0.05), further indicating that the bone effect of the treatment in the post-pubertal group was worse than that in the other two groups.

Previously, a U1-SN angle was used to reflect the labial inclination effect of the upper anterior teeth. However, both the palatal plane rotation and the labial inclination of the upper anterior teeth caused a change in the U1-SN angle (27). Therefore, in the present study, the U1-PP angle was selected to remove the influence of the palatal plane rotation and better represent the labial inclination of the upper anterior teeth. The present results showed that the U1-PP angle increased by 2.17+3.77 and 1.79±3.21° in the pubertal and the post-pubertal groups, respectively (P<0.05). However, no significant change was observed in the pre-pubertal group of patients, which differed from previous studies (39). There are several possible reasons for this discrepancy. First, most patients in the pre-pubertal group of this study were in the early mixed dentition stage. Furthermore, the bone effect of rapid maxillary expansion was more significant in the early stage of growth and development (40), and more space was obtained in the upper anterior tooth area, which reduced the crowding of the upper anterior teeth and caused the self-retraction of the upper anterior teeth that initially compensated for lip inclination. Combined with the bone and dental effects, for the patients in the pre-pubertal group, the bone effect was obvious and the dental effect was small after treatment; for the patients in the pubertal group, a good bone effect was obtained after treatment, but the phenomenon of dental compensation also occurred; for the patients in the post-pubertal group, the treatment produced a small amount of bone effect but a significant dental effect. Therefore, for post-pubertal patients whose upper anterior teeth have been compensated by lip inclination, measures such as bone anchorage or alternate rapid maxillary expansion and contraction should still be selected to increase the bony effect (29,41).

As the maxillary complex moves, the overlying midface soft tissue changes accordingly (42). Regarding concave profile changes, G-Prn-Pos angle, which represents facial prominence, was significantly reduced in all three groups, indicating that midface depression was improved after forward traction, and the profile gradually tended toward the type I facial profile. The present results were consistent with the conclusions of most previous studies. A study by Pavoni *et al* (43) included untreated skeletal class III malocclusion patients as a control group. It showed that the facial process angle of the untreated class III patients increased, indicating that the concave facial pattern would become more serious if left untreated. This study found that following the treatment, the upper lip position of patients moved forward due to the movement of the naso-maxillary complex and the upper front teeth, resulting in a gradual coordination between the upper and lower lips. This is similar to the conclusion of Li *et al* (30). Çelebi and Çelikdelen (44) found that rapid expansion combined with anterior distraction can lead to maxillary and dental changes in skeletal class III patients, and changes in bone bring changes in soft tissue. Forward and downward movement of the maxilla is helpful to improve class III facial type. In contrast to the skeletal parameters, no significant treatment-related differences were found in the soft tissue parameters between the post-pubertal, the pre-pubertal and the pubertal groups, indicating that the skeletal advancement and the dental compensation had similar effects on the improvement of the facial profile after the traction treatment.

The current study has significant clinical implications. It is inevitable to encounter skeletal class III malocclusion patients in the late stage of growth and development in clinical practice. However, certain patients and their families may decline combined orthodontic-orthognathic treatment in adulthood due to various reasons, such as the high cost of the treatment. Such patients may prefer non-invasive treatment to improve their facial shape and occlusion. This study contributes to a better understanding of whether traditional treatment methods can be used for such patients to achieve patient satisfaction, reduce pain to a certain extent and avoid orthognathic surgery in adulthood. The results of the present comprehensive study showed that, although the skeletal effect of the patients in the post-pubertal group was not as good as that of the patients in the pre-pubertal and pubertal groups, their class III malocclusion was also significantly improved (ANB angle increased by 1.85±1.01° after treatment, and the ANB angle after treatment was-0.19±0.51°). At the same time, a good treatment effect was achieved from the soft tissue point of view (the G-Prn-Pos Angle increased by 3.40±3.25°), which was acceptable for the patients. Therefore, if invasive treatments such as bone anchorage rapid expansion and traction or orthodontic treatment are not considered, rapid expansion combined with maxillary protraction therapy can also mask the facial defects of patients with mild maxillary deficiency in the post-pubertal stage.

Of note, the present study has certain limitations. It is a retrospective study with a small sample size. Additionally, the study lacked a control group of untreated class III malocclusion patients, and the influence of growth and development could not be fully excluded, highlighting the need for further research.

In conclusion, treating patients with skeletal class III malocclusion at different growth stages using protraction combined with rapid maxillary expansion could efficiently correct the sagittal jaw imbalance, improve unfavorable facial profiles and achieve favorable therapeutic outcomes. Of note, substantial bone effects were observed in the pre-pubertal and pubertal groups. By contrast, the bone effects were diminished, and alveolar and dental reactions were prominent after the growth peak period. Nevertheless, improved facial aesthetics still benefit patients' physical and mental health.

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Availability of data and materials

The datasets used and/or analyzed during the current study may be requested from the corresponding author.

Authors' contributions

XY conceived and designed the study. YC collected the data. CM and WZ performed the analysis. XY was involved in writing the manuscript. XY and YC confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of the Second Affiliated Hospital of Jiaxing University (Jiaxing, China; approval no. JXEY-2022JYT006; date, 9th October 2022). Each patient's legal guardian provided written informed consent before the treatment.

Patient consent for publication

The legal guardian of the patient depicted in Fig. 3 provided written consent for publication of the patient image.

Competing interests

The authors declare that they have no competing interests.

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