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Comparison of patients with different cervical spine bone ages before and after arch expansion treatment based on cone-beam computed tomography

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Abstract. – OBJECTIVE: The changes of maxillary basal arch width, molar angle, palatal suture width and nasal cavity width were analyzed in patients with different cervical bone ages before and after maxillary rapid arch expansion treatment, providing more reference for orthodontic design and treatment in the future.

PATIENTS AND METHODS: A total of 45 patients with maxillary lateral, insufficient development that underwent arch expansion treatment in Jiaxing Second Hospital between February 2021 and February 2022 were selected for the study. Patients were retrospectively grouped based on the cervical vertebra bone age, and divided into the pre-growth (15 cases), mid-growth (15 cases) and post-growth groups (15 cases). All patients had oral cone-beam computed tomography (CBCT) and lateral cranial radiographs taken before and after the treatment. Maxillary basal arch width, palatal suture width, nasal cavity width and molar angle were measured and analyzed using paired samples *t*-test, ANOVA and least significant difference test (LSD-T).

RESULTS: The maxillary basal arch width, palatal suture width, nasal cavity width and molar angle in the three groups were significantly changed after arch expansion treatment ($p<0.05$). There was no statistically significant difference in all measurement indexes between patients in the pre-growth and the mid-growth groups ($p>0.05$), but there was statistically significant difference between patients in the pre-growth and the late-growth groups ($p<0.05$). There were statistically significant differences in all measurement indexes between the middle-growth and the late-growth group ($p<0.05$).

CONCLUSIONS: Rapid expansion of arch can be used to enlarge the width of palatal suture, maxillary basal arch, and nasal cavity in adolescent patients of different bone ages. With the increase of cervical bone age, the bony effect of expansion of arch gradually decreases, while the dental effect increases. Appropriate overcorrection should be made during arch expansion in late growth and excessive tooth tilt should be avoided to conceal bony width irregularities.

Key Words:
Cervical vertebra age, Palatal expansion technique, Width of the nasal cavity, CBCT.

Introduction

Maxillary transverse deficiency (MTD) is a common problem in clinical practice that is characterized not only by a transverse deficiency, but also by vertical and sagittal deficiency. Several studies[1] have shown a variation in prevalence rates ranging from 8% to 23% in adolescents and up to about 10% in adult orthodontic patients due to differences in study samples and study calculation methods. Patients with narrow maxillary arches often present with clinical manifestations such as malocclusion, high arches of the palatal cover, unilateral and bilateral posterior retrusions, bilateral buccal corridor enlargement, and changes in the clinical crown axis inclination of the teeth[2]. Deviation in the sagittal relationship of the maxilla and the mandible can lead to skeletal Class III and Class II deformities, and in severe cases of mandibular recession in skeletal Class II patients can even cause obstructive sleep apnea and hypopnea syndrome (OSAHS)[3] that negatively affect the patient's quality of life. Clinically, tooth-supported expansion devices are used for growing patients with narrow maxillary arches. The use of teeth as support inevitably results in a buccal tilt of the teeth. Literature has shown that the bony effect of arch expansion decreases with age. However, due to the wide variability in individual growth and development, it is not suffi-

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cient to judge the effectiveness of arch expansion solely based on age. Gao and Gu[4] used cone-beam computed tomography (CBCT) in 1,076 Chinese children and adolescents and founds a high correlation between cervical spine bone age and the midpalatal suture. However, only few scholars[5] focused on the relationship between the efficiency of midpalatal suture dilation and the amount of screw spring opening with the amount of midpalatal suture dilation during arch dilation in patients with different cervical spine skeletal ages.

This retrospective study compares the effects of arch expansion in patients at different stages of growth according to Baccetti's modified cervical vertebral staging method[6] to provide some insights for better clinical treatment of MTD.

Patients and Methods

Research Subjects

Medical records of 45 patients (16 males and 29 females), with an average age of 10.33±2.04 years (the oldest being 15 years old and the youngest 7 years old), who attended the orthodontic department of Jiaxing Second Hospital and required arch expansion treatment between September 2020 and December 2021, were selected for the study. The Ethical Committee of the Second Affiliated Hospital of Jiaxing University approved this study with No. JXEY-2017024, date 16/10/2017.

Inclusion Criteria

(1) Narrow upper dental arch, laterally underdeveloped, with the width of the maxillary basal arch being 2 mm wider than the mandible as the normal standard; (2) juvenile patients at various stages of cervical vertebral maturation (CVM) staging; (3) patients with incomplete ossification of the mid-palatal suture as judged by CBCT; (4) no history of orthodontic treatments.

Based on the results of the Baccetti's modified cervical staging method, patients were retrospectively divided into 3 groups: 1) pre-growth group – cervical vertebral maturation stage (CVMS) I, 15 cases (7 males and 8 females, mean age 9.13±1.36 years); 2) mid-growth group – CVMS II-CVMS III, 15 cases (3 males and 12 females, mean age 9.47±0.92 years); 3) post-growth group – CVMS IV-CVMS VI, 15 cases (6 males and 9 females, mean age 13.07±1.28 years) (Figure 1).

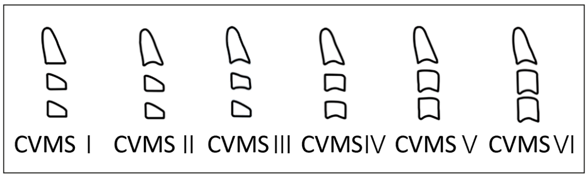

Figure 1. Baccetti's modified cervical staging method.

Exclusion Criteria

(1) Patients with severe mouth breathing, temporomandibular joint (TMJ) symptoms; (2) patients with cleft lip and palate and congenital dysplasia; (3) patients with a history of jaw trauma and surgery; (4) patients with severe periodontal tissue disease or dental tissue disease.

Research Methods

The Hyrax spiral arch expander was used as the treatment device, with the first premolar and the first molar as the supporting teeth or, if the first premolar has not erupted, the first deciduous molar and the first molar were used for retention. The imported glass ionomer (GC II) was used to bond the expansion device to the retained teeth and the patient's parents were taught the correct way to expand the maxilla arch. The patient's parents were instructed to dilate the maxilla every morning and evening with a quarter turn each time. Patients were instructed to follow up on a weekly basis. According to the difference in maxillary and mandibular widths measured on cone-beam computed tomography (CBCT) before the treatment, all three groups of patients stopped the arch expansion when the maxillary width was 2 mm more than the mandibular width, and the screw spring was fixed with a ligature wire to prevent it from springing back. All patients completed the arch expansion within one month and then maintained it for more than 3 months to ensure that the bone formation at the mid-palatal suture was intact and the arch shape was stable. All patients had regular follow-up appointments as prescribed by their doctors and no patients were lost on the follow-up. All patients were treated by the same primary care physician.

Measurement Methods

All patients had oral CBCT, and lateral cranial radiographs taken before and after the treatment by the same physician in the radiology department of Jiaxing Second Hospital. The original CBCT images were converted to 3D images using Romexis 3D software (Software, Planmeca, Helsinki, Finland; Device, Sirona, Bensheim, Germany). The CBCT data measurements and the depiction of the lateral cranial slices were done by

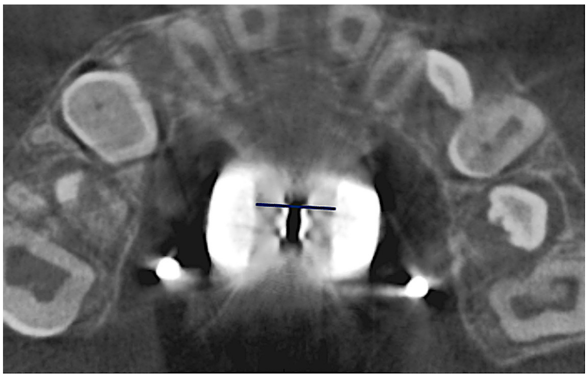

Figure 2. Maxillary basal bone width (MBBW).

two investigators and the final results were averaged. If there was a large difference between the two sets of measurements, the decision was made by a third investigator after retesting.

Measurements

CBCT measurement

- Axial plane: through the orbital-ear plane.
- Sagittal plane: through the line between the point of the nasal root and the anterior chin point and perpendicular to the axial plane.
- Coronal plane: perpendicular to the axial and sagittal planes.
- Coronal plane of the maxillary first molar: through the coronal plane of the cusps of the palatal roots of the bilateral first molars or, if the two cusps are not in the same plane, the plane of the anterior-posterior intermediate position of the two roots.

Measurement indicators

- Maxillary bone width (MBBW): the width of the palatal plane where the line connecting the bifurcation points of the roots of the maxillary first molars are located on the coronal plane (Figure 2). If the bilateral root bifurcation points are not in the same coronal plane, the intermediate position is taken, and the first premolar is taken on the coronal plane in line with the central position of the pulp chamber in the palatal plane where the maximum area is located buccolingually.
- Spiral spring opening quantity (SSOQ): the amount of spiral spring opening was measured in the plane of the spiral spring of the bow expander (Figure 3).
- Tooth inclination of upper first molar (TI-M1): the angle formed by the line through the lowest point of the ipsilateral nasal floor and the line between the palatal cusp and the central fossa of the maxillary first molar, selected on the coronal surface of the maxillary first molar (Figure 4 and Figure 5).
- Suture expansion (SE): the width of the palatal suture at the coronal plane of the maxillary first molar.
- Nasal width (NW): the distance between the widest point of the nasal pear-shaped foramen in the coronal plane of the maxillary first molar.

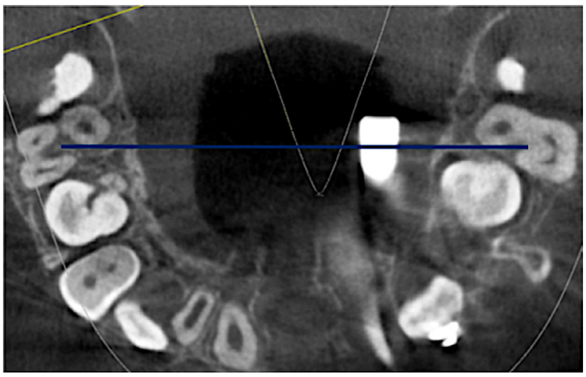

Figure 3. Spiral spring opening quantity (SSOQ).

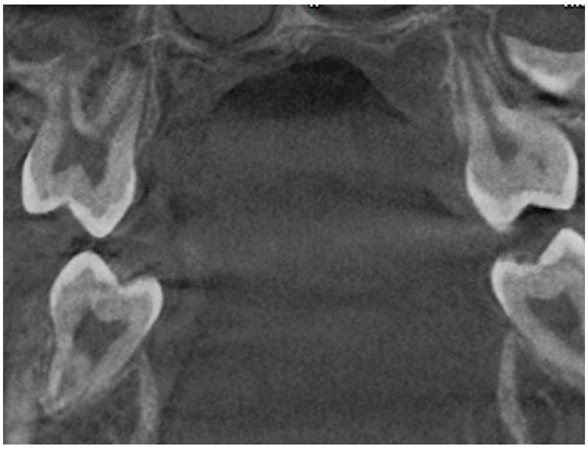

Figure 4. Coronal plane of the first molar.

Statistical Analysis

Statistical analysis was done using the SPSS 26.0 statistical software (IBM Corp., Armonk, NY, USA). Three groups of patients with different growth periods were analyzed by the paired samples *t*-test before and after the dilation treatment, and the percentage increase in each measure before and after the dilation treatment was analyzed by ANOVA. LSD-T test was used at the level of two-sided $\alpha = 0.05$. A *p*-value lower than 0.05 was considered to be statistically significant.

Table I. Comparison of pre- and post-arch expansion measurements in the pre-growth group ($\bar{\chi} \pm s$).

Time	Case number	MBBW_P1 (mm)	MBBW_M1 (mm)	T1_M1R (°)	T1_M1L (°)	SE (mm)	NW (mm)
Pre-arch expansion	15	36.07±1.96	43.76±1.99	118.25±7.39	115.38±6.02	0.81±0.25	29.10±2.00
Post-arch expansion	15	41.51±2.28	48.34±2.07	121.71±6.71	118.22±6.46	2.56±0.50	31.47±1.90
t-value		-14.945	-17.055	-5.666	-5.731	-15.168	-11.092
p-value		0.000	0.000	0.000	0.000	0.000	0.000

MBBW_P1: first premolar or first milk molar basal bone arch width. MBBW_M1: first molar basal bone arch. T1_M1R: angle of the right first molar. T1_M1L: angle of the left first molar. SE: midpalatal suture width. NW: nasal cavity width. A *p*-value lower than 0.05 is considered to be statistically significant.

Table II. Comparison of pre- and post-arch expansion measurements in the mid-growth group ($\bar{\chi} \pm s$).

Time	Case number	MBBW_P1 (mm)	MBBW_M1 (mm)	T1_M1R (°)	T1_M1L (°)	SE (mm)	NW (mm)
Pre-arch expansion	15	36.06±1.42	44.60±1.94	117.70±5.96	116.81±6.70	0.78±0.16	28.89±2.51
Post-arch expansion	15	41.17±2.03	49.23±2.57	121.52±5.41	119.91±7.00	2.26±0.47	31.03±2.71
t-value		-18.624	-17.986	-6.418	-10.197	-11.436	-10.958
p-value		0.000	0.000	0.000	0.000	0.000	0.000

A *p*-value lower than 0.05 is considered to be statistically significant.

Results

Comparison of the three groups of patients before and after the arch expansion treatment is summarized in Tables I-III, respectively. Compared to the pre-arch expansion treatment, there were statistically significant changes in maxillary basal arch width, maxillary first molar inclination, suture expansion and nasal cavity width measurements ($p<0.05$) in all three groups after the rapid maxillary expansion.

Comparison of the growth volume ratios before and after the arch expansion in three groups is shown in Tables IV and V, respectively. A pairwise comparison study found statistically significant differences in the percentage increase in each measure between the pre-growth and mid-growth groups compared to the patients in the late growth group after rapid maxillary expansion treatment ($p<0.05$). There was no statistically significant difference in the percentage increase in each measure between the pre-growth and mid-growth groups, (all $p>0.05$). There was a statistically significant difference in the ratio of maxillary basal and midpalatal suture width to screw spring spread between the pre-growth and mid-growth groups compared to the late growth group ($p<0.05$). There was no statistically significant difference between the pre-growth and mid-growth groups in the ratio of maxillary palatal suture and basal suture width to screw spring spread ($p>0.05$).

Table III. Comparison of pre- and post-arch expansion measurements in the post-growth group ($\bar{\chi} \pm s$).

Time	Case number	MBBW_P1 (mm)	MBBW_M1 (mm)	T1_M1R (°)	T1_M1L (°)	SE (mm)	NW (mm)
Pre-arch expansion	15	36.60±1.99	45.94±2.72	113.79±4.91	115.55±5.74	0.69±0.14	30.21±1.53
Post-arch expansion	15	39.81±1.98	49.00±2.61	119.59±6.41	120.62±6.04	1.42±0.13	31.22±1.49
t-value		-283.761	-59.656	-8.667	-13.075	-30.615	-20.893
p-value		0.000	0.000	0.000	0.000	0.000	0.000

A *p*-value lower than 0.05 is considered to be statistically significant.

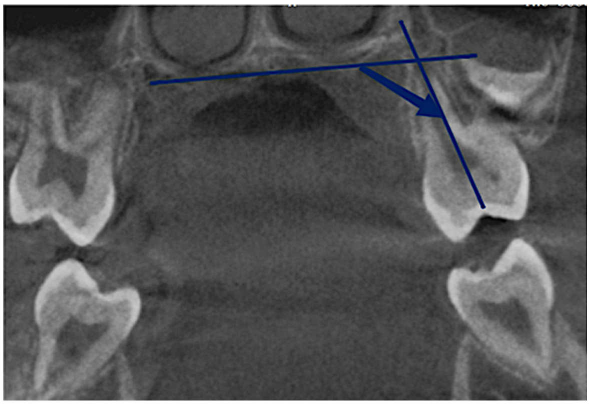

Figure 5. Tooth inclination of upper first molar (TI-M1).

Discussion

In this retrospective study, pre- and post-operative CBCT data were collected and comparatively analyzed in patients with different cervical spine bone age stages that underwent fixed rapid expansion treatment. We report that this method of analysis shows high accuracy and feasibility.

Since Dr. Angel[7] introduced the maxillary expansion technique in 1860, this orthodontic treatment has gradually become the most common treatment for MTD. There are various methods of expanding the maxillary arch, such as rapid expansion, slow expansion, implant and surgical assisted expansion[8]. Rapid maxillary arch expansion is used in adolescent patients during their growth spurt. By applying lateral orthopedic forces to the palatal suture, the palatal suture tissue degenerates, old connective tissue is gradually replaced by the new connective tissue, and bone matrix is deposited in the palatal suture area, eventually causing the maxillary arch to widen[9]. This is also consistent with the findings of Gautam et al[10], showing that when greater stresses are applied to the midpalatal suture, cells within the suture will produce osteoclastic and osteogenic responses, and that the suture changes caused by different stresses will be different.

There is still no consensus on the age of ossification of the mid-palatal suture. Angelieri et al[11,12] analyzed CBCT images of patients of different ages and found that the midpalatal suture

Table IV. Comparison of measurements growth ratio before and after bow expansion in the three groups ($\bar{\chi} \pm s$).

Time	Case number	MBBW_P1 (mm)	MBBW_M1 (mm)	T1_M1R (°)	T1_M1L (°)	SE (mm)	NW (mm)
Pre-growth	15	0.15±0.04	0.11±0.02	0.03±0.22	0.02±0.02	2.36±0.87	0.08±0.03
Mid-growth	15	0.14±0.03	0.10±0.02	0.03±0.02	0.03±0.01	2.00±0.79	0.07±0.03
Post-growth		0.09 ± 0.01^{ab}	0.07 ± 0.01^{ab}	0.05 ± 0.02^{ab}	0.04 ± 0.01^{ab}	1.10 ± 0.33^{ab}	0.03 ± 0.01^{ab}
f value		17.766	19.019	4.042	9.329	12.601	18.641
p-value		0.000	0.000	0.000	0.000	0.000	0.000

Measurements growth ratio refers to the difference between post-treatment measurements and pre-treatment measurements as [a]percentage of initial measurements. [a]represents $p<0.05$ compared to patients in the pre-growth group, [b]represents $p<0.05$ compared to patients in the mid-growth group. A *p*-value lower than 0.05 is considered to be statistically significant.

Table V. Comparison of the ratio of measurements to the width of the screw spring after arch expansion in the three groups ($\bar{\chi} \pm s$).

Group	Case number	MBBW_P1/SSOQ	MBBW_M1/SSOQ	SE/SSOQ
Pre-growth	15	0.91±0.16	0.82±0.12	0.31±0.07
Mid-growth	15	0.91±0.12	0.82±0.10	0.26±0.07
Post-growth		0.65 ± 0.13^{ab}	0.62 ± 0.10^{ab}	0.15 ± 0.04^{ab}
f value		14.677	17.825	28.772
p-value		0.000	0.000	0.000

MBBW_P1/SSOQ: ratio of the increase in the width of the first premolar jaw to the opening of the screw spring; MBBW_M1/SSOQ: ratio of the increase in the width of the first premolar jaw to the opening of the screw spring; SE/SSOQ: ratio of the increase in the width of the palatal septum to the opening of the screw spring. [a]represents $p<0.05$ compared to patients in the pre-growth group, [b]represents $p<0.05$ compared to patients in the mid-growth group. A *p*-value lower than 0.05 is considered to be statistically significant.

was unfused in approximately 12% of adults and that there was no significant relationship between age and gender and the ossification of the midpalatal suture. Gao and Gu[4] found a high correlation between cervical spine bone age staging and midpalatal suture staging, and Persson and Thilander[13] reported results consistent with this study. Age is not an accurate predictor of actual growth and development, and cervical spine bone age should be used for more accurate staging[14].

Bone Effect

There was a significant change in the width of the midpalatal suture and maxillary basal arch in all three groups before and after the treatment ($p<0.05$), indicating that rapid maxillary expansion was effective in patients with incomplete closure of the midpalatal suture at all bone ages, which is consistent with the findings of Angelieri et al[11]. Li et al[5] found that, after rapid maxillary expansion, a significant widening of the midpalatal suture was observed on CBCT. There was a statistically significant difference between patients in the pre-growth group and those in the mid-growth group in terms of changes in the width of the mid-palatal suture and maxillary basal arch compared to those in the post-growth group. This is consistent with the findings of Xiong et al[15], who showed that patients with narrow dental arches had more bone effect when they underwent rapid maxillary expansion in the pre-growth and mid-growth periods. This is closely related to the unique structure of the palatal suture itself. The midpalatal suture is a fusion line between the horizontal part of the palate and the palatal eminence of the maxilla. As the bone ages, this fusion line gradually changes from fibrous to osseous union, making the bone structure of the midpalatal suture more rigid and producing a different midpalatal suture response for the same large value of arch expansion force[16]. Li et al[17] found that the amount of midpalatal suture expansion decreases gradually with increasing age and bone age when performing maxilla arch expansion on rats of different ages, which is consistent with our findings. Table V shows that there is a statistically significant difference in the ratio of the expanded width of the maxillary arch to the opening of the screw spring and the ratio of the midpalatal suture to the opening of the screw spring between the pre-growth and mid-growth patients compared to the late growth patients. Therefore, for patients in the later stages of growth, some overcorrection may be appropriate at the time of maxilla arch expansion in order to obtain more bony effect, as a substitute for the lack of maxillary width that is created again when the buccally inclined molars are set upright in the second stage of fixed orthodontics.

Teeth Effect

Patients in the pre-growth, mid-growth and post-growth groups all showed significant buccal tilting of the supporting molar after rapid maxillary expansion treatment ($p<0.05$), and the tilting occurred on both the right and the left sides. This is mainly due to the fact that the rapid expansion of the maxilla arch not only acts on the palatal mesial suture but also exerts a greater orthodontic force on the supporting molars, resulting in a buccal inclination of the supporting teeth[18]. Liu et al[19] studied the way the teeth moved after maxilla arch expansion treatment and found that a certain amount of tilt movement occurred after rapid maxillary expansion. In this study, a statistically significant change ($p<0.05$) in the inclination of the molars was found in the late growth phase compared to the pre-growth and mid-growth patients after the maxilla arch expansion treatment, suggesting that as the bone ages, the odontogenic effect becomes more pronounced, and the supporting teeth develop more buccal inclination. Domann et al[20] used CBCT to show that rapid maxillary arch expansion treatment resulted in a reduction in the thickness and height of the buccal alveolar bone of the maxillary posterior teeth, especially in the premolar, molar teeth. The force applied in a short period of time during rapid maxillary expansion can be very high, up to 2,000-3,000 g. However, the rate of bone deposition in the alveolar bone lags behind the rate of expansion, which greatly increases the chance of bone fractures and bone openings. Garib et al[21] therefore recommend that the presence of a thin buccal bone plate should be watched for on CBCT before performing rapid maxillary expansion treatment. In patients in the later stages of growth, extra care should be taken when expanding the maxilla arch to prevent the occurrence of bone dehiscence due to the large amount of expansion. In patients with a thin buccal bone plate, a prior cortectomy or periodontal accelerated osteogenic orthodontics (PAOO) may be considered to prevent osteoclastic fractures and osteoclastic windows.

Nasal Cavity Width

All three groups of patients at different growth stages exhibited significant changes in nasal cavity width ($p<0.05$) after the treatment with arch expansion. These results are consistent with the findings of Erdur et al[22], who found a significant increase in nasal cavity width in both adolescent and late adolescent patients after rapid maxillary expansion treatment. The increased nasal cavity width may be related to the specific structure of the maxilla. During the arch expansion treatment, as the screw spring continues to open, the mid-facial structures expand, resulting in an increase in the width of the nasal maxillary complex, thus promoting a significant increase in the total volume of the nasal cavity, including the supra-nasal region, and the width of the nasal cavity. In a study of 35 patients with maxillary arch stenosis, Li et al[23] found that the width of the pyriform foramen increased by about 2 mm at the end of the expansion treatment, indicating that rapid expansion treatment had an overall arch expansion effect on the nasomaxillary complex. Guo et al[24] found that maxillary expansion treatment increased the volume of the upper airway in patients with malocclusion with mouth breathing, improved mouth breathing symptoms and helped patients to establish normal nasal breathing. It has been shown that rapid maxillary expansion plays an important role in improving nasal structure and promoting nasal ventilation and thus relieving nasal congestion[25]. Therefore, in patients with OSAHS who also a narrow maxillary arch have, clinical orthodontic treatment with arch expansion can be considered after excluding organic nasal disease. A two-by-two comparison of the three groups of patients with different growth spurts showed that the increase in nasal width gradually decreased with bone age, with statistically significant differences between patients in the pre-growth and late growth spur groups and between patients in the mid-growth and late growth spur groups ($p<0.05$). This may be related to the specific structure of the cranio-maxillary complex. Scholars[26] have shown that the elastic modulus of the sutures in growing patients is much smaller than that of the cortical and cancellous bones and is more likely to deform when subjected to external forces. The cranial maxillary sutures gradually ossify as the bones grow older, usually completely ossifying by the age of 16 years.

Conclusions

We showed that after the rapid maxillary expansion treatment, the maxilla, mid-palatal suture and nasal cavity width of the three groups of patients of different bone ages were enlarged to different degrees. This indicates that the width of the cranio-maxillary complex could be enlarged by the use of the rapid arch expander in patients at different stages of growth and with incomplete closure of the mid-palatal suture. There were statistically significant differences between the pre-growth and post-growth groups and between the mid-growth and post-growth groups, indicating that the increase in maxilla, mid-palatal suture and nasal width gradually decreases with increasing bone age, while the inclination of the supporting teeth gradually increases, as the bone suture between the maxilla and the surrounding bones gradually ossifies with increasing bone age. For patients in pre-growth and mid-growth, more significant bone effects are achieved, while for patients in late growth, more dental effects are obtained. This not only demonstrates a good treatment effect of the rapid maxillary expansion treatment in pre-growth and mid-growth patients, but also shows that it has certain advantages for improving nasal function[3]. Therefore, it is beneficial to treat patients in pre-growth and mid-growth period with rapid maxillary expansion. Since only recent changes were observed in this study, further observational studies are needed to evaluate long-term stability and effects of the treatment.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Ethics Approval

The Ethical Committee of the Second Affiliated Hospital of Jiaxing University approved this study with No. JX-EY-2017024, date 16/10/2017.

Availability of Data and Materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Authors' Contributions

WZ conceptualized the study. YC and XY acquired the data and performed the analyses. YC and WZ wrote the draft manuscript. All authors read and approved the final draft of the manuscript.

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Informed Consent

Not applicable, due to the retrospective nature of the study.

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