Submitted: 10 November, 2023 Accepted: 20 December, 2023 Published: 03 September, 2024 DOI:10.22514/jocpd.2024.105

Journal of Clinical Pediatric Dentistry

ORIGINAL RESEARCH

Mandibular response after rapid maxillary expansion in mixed dentition children with different vertical growth patterns: a retrospective study

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Abstract

This study evaluated the mandibular development induced by rapid maxillary expansion (RME) therapy in mixed dentition patients with different vertical growth patterns through long-term observation. The research utilized a retrospective design that included two cohorts: a control group consisting of pediatric subjects with individualized malocclusions, and an experimental group received RME therapy. A total of 60 subjects were included; 37 in the RME group (17 males and 20 females) and 23 in the control group (13 males and 10 females). Based on mandibular plane angles, 19 pertinent cephalometric variables were quantified with Dolphin Imaging software, and participants were subclassified into high-angle and normal-angle subgroups. Changes in the groups during the observation period were statistically analyzed with a *t*-test. Compared to the control group, both sagittal parameters tended to decrease after treatment in the RME group ($p < 0.05$), and none of the vertical correlations were statistically different ($p > 0.05$). Within the normal-angle experimental subgroup, sagittal parameters markedly decreased when contrasted with their normal-angle control group ($p < 0.05$). Notably, a substantive decrease in overjet was solely observable in the sagittal dimension among the high-angle expansion subgroup when compared to the high-angle control subgroup ($p < 0.05$). In the vertical dimension, neither the normal-angle nor high-angle subgroups exhibited any statistically significant differences from their respective control cohorts ($p > 0.05$). Based on long-term observation, RME therapy promotes mandible sagittal growth of the mandible in subjects with normal-angle vertical growth patterns. A similar tendency was not observed in subjects with high-angle vertical growth patterns. In addition, the mandibular plane angle did not increase after RME in children with high-angles.

Keywords

Rapid maxillary expansion; Vertical growthpatterns; Mandibular response

1. Introduction

Maxillary transverse deficiency constitutes a pervasive clinical malocclusion that affects not only maxillary dentition alignment and occlusal interrelationships, but also the mandible's sagittal orientation [1]. Rapid Maxillary Expansion (RME) is a cornerstone treatment for pediatric transverse deficiencies based on the principle of expanding the incompletely ossified mid-palatal suture in the pediatric population. This intervention involves the exertion of mechanical forces upon the mid-palatal suture over a delimited temporal window, thereby facilitating a harmonious intermaxillary dimensional congruence [2].

While the inception of RME primarily focused on the rectification of transverse deficiencies and enhancement of arch perimeter, more possible indications for this technique have been proposed [3]. Once the mid-palatal suture is expanded and space is created, the blocked occlusion between the upper and lower dentition is relieved, enables unfettered three-dimensional mandibular growth [4].

Skeletal Class II malocclusion patients frequently have pronounced constrictions in the maxillary dimension [5]. Spontaneous anterior repositioning of the mandible has been reported following maxillary arch expansion [6]. McNamara identified salutary improvements in dental Class II malocclusion during the retention phase of RME treatment in early mixed dentition cohorts [7]. Caprioglio found that children with shorter mandibles and an acute superior gonial angle have a higher chance of improving molar Class II after RME [8]. However, a systematic review asserts that there is only a modicum of moderate-quality evidence exists to support statistically and clinically significant alterations in sagittal parameters [9].

Despite RME's purported sagittal benefits, existing literature demonstrates downward and posterior mandibular rotation following RME, particularly in high-angle patients [10]. RME in high-angle patients is discouraged by this undesirable vertical dimensional repercussion. Yet, longitudinal skeletal assessment studies indicate that the elevation of the mandibular plane angle may merely be a transient epiphenomenon [11]. Matthew argues that RME remains viable in patients with elevated vertical dimensions without untowardly affecting vertical skeletal relationships [12].

Collectively, existing systematic reviews proffer inconclusive evidence regarding the sagittal efficacy of RME on Class II malocclusions [13]. This ambiguity derives from prior studies due to heterogeneity, truncated study durations, insufficient sample sizes, and, most pertinently, the absence of robust controls. Hence, this study aims to examine the long-term evaluation of mandibular development—both in sagittal and vertical dimensions—induced by RME therapy in mixed dentition patients with divergent vertical growth patterns.

2. Materials and methods

2.1 Study design

The study encompassed children aged 6–12 with mixed dentition malocclusions who sought clinical intervention at Shanghai Stomatological Hospital from January 2018 to December 2020. Having meticulously reviewed clinical electronic health records, patients fulfilling explicit inclusion and exclusion criteria were assimilated into the final cohort for analytical scrutiny.

Inclusion criteria were as follows: (i) aged 6–12 years; (ii) narrow maxillary arch width (maxillomandibular skeletal transverse discrepancy of 3 mm or greater) and the treatment included RME only; (iii) normative maxillary arch width and edgewise treatment only (not more than two malaligned teeth); and (iv) the possession of comprehensive and accurate medical records, including baseline (T1) and two-year follow-up period (T2) lateral cephalometric radiographic data.

Exclusion criteria were as follows: (i) patients with mandibular advancement due to severe mandibular retrusion; (ii) requiring orthopedic intervention for maxillary deficiencies, such as maxillary protraction, or those associated with craniofacial syndromes or clefts; (iii) history of craniofacial surgery or multiple rounds of orthodontic treatment.

Patients were then categorized into facial types based on their pretreatment mandibular plane angles (MP-FH). Consequently, the study cohort was divided into two main subgroups: the normal-angle group (mandibular plane angle $>20°$ and $<27°$) and the high-angle group (mandibular plane angle $\geq 27°$).

2.2 Treatment protocol

For the RME group, treatment commenced with the activation of an *in-situ* Hyrax expander screw (Shanghai Stomatological Hospital, China). Bi-daily activation of the expansion screw, at a rate of 0.25 mm per activation, persisted until overcorrection was achieved, defined as the palatal cusps of the maxillary posterior teeth approaching the buccal cusps of the mandibular posterior teeth. After this phase, the RME apparatus remained *in situ* for at least six months as a passive retentive function to stabilize the expansional gains accrued during the active phase. No additional removable appliances were placed post-removal of the RME device up to T2.

The control group received a treatment regimen exclusively using 2×4 edgewise techniques. Due to focusing on not more than two misaligned teeth, like individual tooth misalignment, the treatment duration for the control group typically falls within 6 months. Up to T2, no functional appliances were used in this group.

2.3 Cephalometric analysis

T1 and T2 lateral cephalograms were systematically procured for each patient in the study cohort. Radiographic images were digitized and meticulously traced using Dolphin Imaging Software (version 19.0; Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). Two investigators, blinded to the specific group affiliations, delineated anatomical contours and identified of salient landmarks. Any extant discrepancies concerning the precise localization of landmarks were arbitrated by a tertiary, experienced investigator; the resultant mean value was integrated into the study's analysis. Cephalometric analysis included 19 variables that combined established landmarks and reference planes, drawn from Steiner's, Ricketts', McNamara's, and Jarabak's cephalometric analyses [14–17]. These are illustrated in Table 1 and Fig. 1.

2.4 Statistical analysis

The sample size was determined based on previous literature [8], with a statistical power of 0.80 and a significance level of 0.05. The calculated sample size for the multi-comparison analysis test was 10 subjects in each group. Initial measurements were taken by one operator (Y.G.), then independently repeated by a second operator (XH.X.), and the final results were obtained by averaging the measurements. Across all measurements, the intraclass correlation coefficient was 0.91–0.94, indicating repeated agreement.

Data were analyzed by IBM SPSS Statistics 26.0 (IBM Corp, Armonk, NY, USA). Continuous data were presented as mean $\pm$ standard deviation (SD). Statistics are expressed as frequency (n) and percentage (%). Comparisons between groups of normal and chi-square measures were made using the independent samples t-test, with the correction t-test used instead for non-chi-square measures and the paired samples t-test used for intra-group comparisons. A Mann-Whitney U test for independent samples was used to compare two non-normal measures, and a Wilcoxon Z rank sum test for paired samples was used to compare within groups. Statistical significance was determined at the levels of $p < 0.05$, $p < 0.01$ and $p < 0.001$.

3. Results

Patient demographics and relevant parameters are summarized in Table 2. The RME group consisted of 37 patients, 17 males and 20 females, with T1 and T2 ages averaging 8.6 ± 1.1 years and 11.1 ± 1.3 years, respectively. By contrast, the control group included 23 patients, 13 males and 10 females,

TABLE 1. Definitions of cephalometric measurements.

Measurement	Definition
Sagittal items	
Angle formed by sella, nasion, and point A (SNA), °	Representing the anteroposterior position of the maxilla
Angle formed by sella, nasion, and point A (SNB), °	Representing the anteroposterior position of the mandible
Angle formed by point A, nasion, and point B (ANB), °	Representing the anteroposterior relationship between maxilla and mandible
Wits (mm)	The linear distance between A and B points on the occlusal plane, representing the anteroposterior relationship between maxilla and mandible
Overjet (mm)	Distance between incisal edges of maxillary and mandibular central incisors, parallel to the occlusal plane
Vertical items	
Mandible plane-Frankfort horizontal plane (MP-FH), °	Representing the the inclination of the mandible in relation to Frankfort's horizontal plane
N-me (mm)	Nasion to Menton distance, representing the anterior height of the face
S-Go (mm)	Sella to Gonion distance, representing the posterior height of the face
S-Go/N-Me (%)	Ratio between the posterior (S-Go) and the anterior (N-Me) height of the face, multiplied by 100
Overbite (mm)	Distance between incisal edges of maxillary and mandibular central incisors, perpendicular to the occlusal plane
Skeletal items	
Co-A (mm)	Condylion to A-point distance, representing the length of the maxillary base
Co-Gn (mm)	Condylion to Gnathion distance, representing the total mandibular length
Ar-Go (mm)	Articulare to Gonion distance, representing the lower posterior face height
Go-Me (mm)	Gonion to Menton distance, representing the lower anterior face height
Dentoalveolar	
Upper Incisor to SN Plane Angle (U1-SN), °	Representing maxillary incisor inclination
Incisor Mandibular Plane Angle (IMPA), °	Representing mandibular incisor inclination
Upper Incisor to Lower Incisor Angle (U1-L1), °	Representing interincisal angle
Soft tissue	
Upper lip-Esthetic plane (UL-EP, mm)	Distance from the upper lip to the esthetic plane of Ricketts, representing upper lip protrusion
Lower lip-Esthetic plane (LL-EP, mm)	Distance from the lower lip to the esthetic plane of Ricketts, representing lower lip protrusion

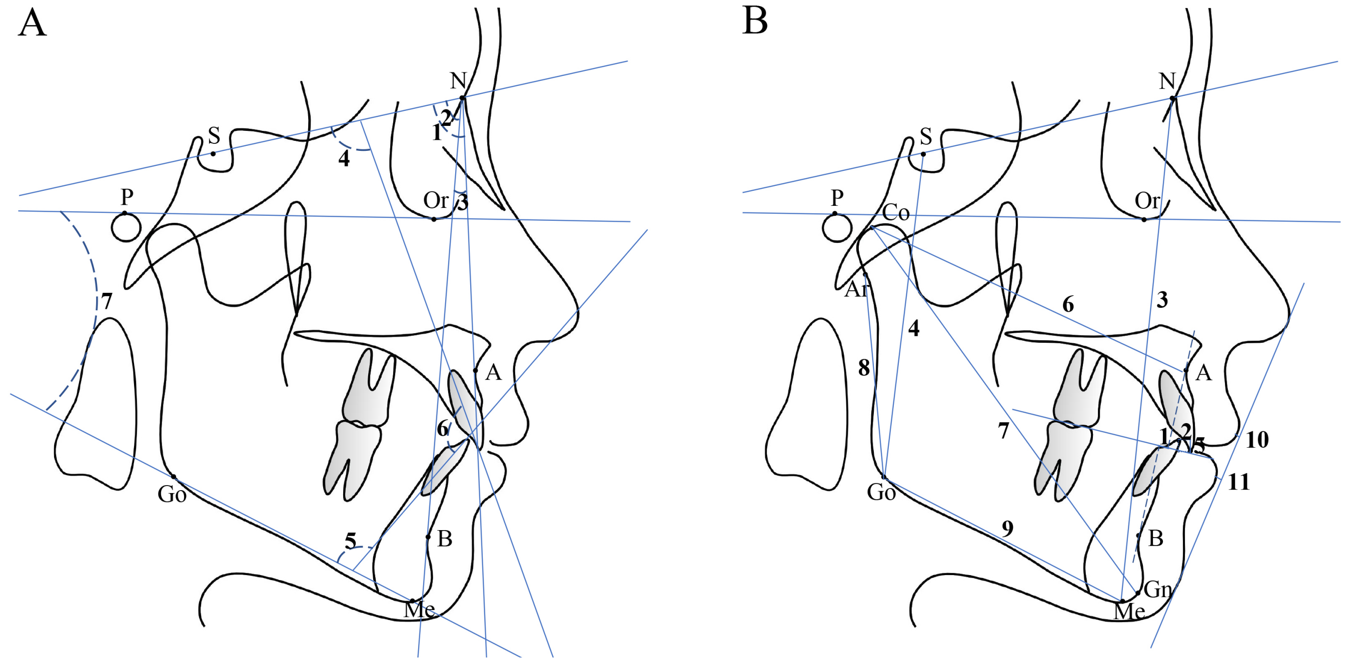

FIGURE 1. Cephalometric points, lines, and angles used in analysis. (A) Cephalometric angular variables: 1, SNA; 2, SNB; 3, ANB; 4, U1-SN; 5, IMPA; 6, U1-LI; 7, MP-FH. (B) Cephalometric linear variables: 1, Wits; 2, Overjet; 3, N-Me; 4, S-Go; 5, Overbite; 6, Co-A; 7, Co-Gn; 8, Ar-Go; 9, Go-Me; 10, UL-EP; 11, LL-EP.

TABLE 2. Basic information of the population.

Group	T1 age (yr)		T2 age (yr)		T2–T1 (yr)	
	Mean	SD	Mean	SD	Mean	SD
RME (n, 37)	8.6	1.1	11.1	1.3	2.5	0.7
Normal-angle (n, 16)	8.9	1.0	11.4	1.2	2.5	0.6
High-angle (n, 21)	8.5	1.1	10.9	1.3	2.5	0.8
Control (n, 23)	8.4	1.2	10.9	1.6	2.5	0.9
Normal-angle (n, 12)	8.9	1.0	11.4	1.2	2.6	1.1
High-angle (n, 13)	7.9	1.3	10.3	1.8	2.3	0.8

Note. Data are shown as mean and SDs. RME: rapid maxillary expansion; SD: standard deviation.

with T1 and T2 ages of 8.4 ± 1.2 years and 10.9 ± 1.6 years, respectively.

Table 3 presents descriptive statistics and comparative analyses of cephalometric variables between the RME and control group. In the analysis of cephalometric indices at T1, the RME group exhibited a statistically larger Overjet compared to the control group. There were no significant differences in any other metric between the two groups ($p > 0.05$).

Substantial alterations were observed in 14 cephalometric variables between T1 and T2 in the RME and control groups ($p < 0.05$), as shown in Table 4. Wits, overbite and LL-EP did not vary significantly in either group ($p > 0.05$). Comparatively, in the sagittal direction, both groups trended towards a decrease in ANB values, with the RME group showed a change of −0.9° ± 1.5° and the control group a change of −0.1° ± 1.5° ($p < 0.05$). While Wits values remained similar between the groups, Overjet presented a divergent trend, decreased by −1.0 ± 2.4 mm in the RME group and increased by 1.5 ± 1.7 mm in the control group ($p < 0.01$). No significant differences were found between the groups in any of the vertical or skeletal parameters.

In the realm of dental indicators, the U1-SN angular shift approximated 2.6° ± 7.3° in the RME group compared to 7.3° ± 5.5° in the control group ($p < 0.05$), suggesting the control group encapsulates sporadic anterior crossbite cases. In the category of soft tissue parameters, UL-EP demonstrated a contraction of nearly −1.0 ± 1.3 mm in the RME group compared to a marginal expansion of 0.2 ± 1.0 mm in the control group ($p < 0.01$).

The cohort was divided into two subgroups based on MP-FH angles, as shown in Table 5. Post-RME intervention, there was statistically significant attenuation in sagittal parameters in the normal-angle subgroup (ANB, $p < 0.01$; Wits, $p < 0.05$; Overjet, $p < 0.001$) compared to the control group. Remarkably, Overjet alterations (−0.4/1.9 mm, $p = 0.014$) were the only significantly differences between the RME high-angle and Control high-angle subgroups. Additionally, the Wits value (−1.9/0.0 mm, $p = 0.016$) exhibited more pronounced

TABLE 3. Comparison of T1 forms: RME group *vs.* Control group.

Cephalometric measurement	RME group (n = 37)		Control group (n = 23)		*p*
	Mean	SD	Mean	SD	
Sagittal items					
SNA, °	80.0	3.0	79.8	3.1	0.939
SNB, °	75.8	3.0	77.0	3.6	0.186
ANB, °	3.9	1.5	2.8	2.6	0.199
Wits (mm)	0.6	3.1	−0.8	3.4	0.151
Overjet (mm)	5.4	2.8	3.1	2.8	0.003†
Vertical items					
MP-FH, °	29.2	4.3	29.2	3.9	0.949
N-me (mm)	103.6	4.4	102.6	5.3	0.518
S-Go (mm)	65.5	4.3	65.1	3.7	0.710
S-Go/N-Me (%)	62.5	3.9	62.8	2.9	0.779
Overbite (mm)	2.0	1.5	1.5	1.5	0.191
Skeletal items					
Co-A (mm)	71.3	3.4	71.6	3.5	0.774
Co-Gn (mm)	95.0	4.0	95.1	3.8	0.945
Ar-Go (mm)	37.1	2.9	37.4	2.3	0.612
Go-Me (mm)	61.5	4.2	60.4	3.7	0.308
Dentoalveolar					
U1-SN, °	105.5	7.3	103.8	6.5	0.199
IMPA, °	90.4	5.6	90.5	6.4	0.948
U1-L1, °	125.8	8.8	128.1	9.0	0.329
Soft tissue					
UL-EP (mm)	2.3	2.2	1.9	1.3	0.455
LL-EP (mm)	3.0	2.4	3.1	1.7	0.797

Note. Data are shown as mean and SDs. †$p < 0.01$.

decline in the RME normal-angle subgroup relative to the RME high-angle subgroup, indicating that the normal-angle subgroup exhibited more marked shifts in the sagittal dimension after RME intervention.

Neither vertical nor skeletal parameters differed significantly from T1 to T2. The RME high-angle group experienced a change in mandibular plane angel of −1.1° ± 2.6°, similar to the growth pattern of the control high-angle group (−1.0° ± 1.8°). Neither the normal nor the high-angle subgroups of the RME cohort showed statistical differences from the control group in terms of Co-A, Co-Gn, N-Me, Go-Me, S-Go and Ar-Go (Re *vs.* Ce, $p > 0.05$; Rh *vs.* Ch, $p > 0.05$).

U1-SN angle was the only dental metric to be significantly divergent, increasing markedly in the control high-angle subgroup (10.0° ± 4.7°) (Rh *vs.* Ch, $p = 0.033$). As for soft tissue indices, the upper lip retracts to a greater extent in the RME normal-angle subgroup (−1.4/−0.1 mm, $p = 0.003$) than it does in the RME high-angle subgroup (−0.6/0.6 mm, $p = 0.021$), when compared to the control group, whereas lower lip retractions remained uniform across both treatment groups.

4. Discussion

Along with the existing empirical evidence showing how RME affects maxillary structures [18], scholarly literature has also suggested RME could have short-term effects on mandibular alterations, such as spontaneous Class II corrections or clockwise mandibular rotations [19]. However, the latter phenomenon, primarily manifested in dental relationships and compounded by skeletal variations engendered by natural growth, remains speculative without a comprehensive control group for comparative analysis [9].

Due to ethical constraints, we were unable to include a natural growth control group without any orthodontic intervention. Consequently, patients only undergoing edgewise treatment were selected as the control. The edgewise group patients, restricted to no more than two malaligned teeth, underwent minor dental realignments. As a result of their minimal skeletal changes, we believe they approximate a naturally growing control group closely. Therefore, this retrospective study was to compare the mandibular development of patients with varying vertical growth patterns induced by RME to a natural growth group with over two years of follow-up data.

TABLE 4. Comparison of T2–T1 change: RME group *vs.* Control group.

Cephalometric measurement	RME (n = 37)							Control (n = 23)							*p* (change)
	T1		T2		Change		*p*	T1		T2		Change		*p*	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD		
Sagittal items															
SNA, °	80.0	3.0	81.3	2.6	1.6	2.4	<0.001	79.8	3.1	81.5	3.1	1.7	2.0	0.001†	0.875
SNB, °	75.8	3.0	78.4	2.7	2.6	1.8	<0.001	77.0	3.6	78.6	3.9	1.6	1.8	<0.001	0.047*
ANB, °	3.9	1.5	3.0	1.9	−0.9	1.5	0.001†	2.8	2.6	2.7	1.8	−0.1	1.5	0.841	0.046*
Wits (mm)	0.6	3.1	−0.2	2.9	−0.9	2.6	0.053	−0.8	3.4	−1.1	3.1	−0.3	2.3	0.479	0.372
Overjet (mm)	5.4	2.8	4.4	1.4	−1.0	2.4	0.012*	3.1	2.8	4.6	2.3	1.5	1.7	<0.001	<0.001
Vertical items															
MP-FH, °	29.2	4.3	28.5	4.1	−0.7	2.4	0.063	29.2	3.9	27.9	4.2	−1.2	2.0	0.006†	0.403
N-me (mm)	103.6	4.4	109.2	5.1	5.6	3.7	<0.001	102.6	5.3	108.3	5.4	5.7	3.5	<0.001	0.997
S-Go (mm)	65.5	4.3	70.4	5.4	4.9	3.5	<0.001	65.1	3.7	69.9	4.3	4.8	2.8	<0.001	0.772
S-Go/N-Me (%)	62.5	3.9	64.0	3.8	1.4	2.0	<0.001	62.8	2.9	64.1	3.3	1.3	1.5	<0.001	0.743
Overbite (mm)	2.0	1.5	2.2	1.6	0.1	1.6	0.599	1.5	1.5	2.0	1.7	0.5	1.3	0.106	0.456
Skeletal items															
Co-A (mm)	71.3	3.4	75.2	3.9	3.9	3.5	<0.001	71.6	3.5	76.1	3.1	4.5	2.5	<0.001	0.509
Co-Gn (mm)	95.0	4.0	101.9	5.0	6.9	4.0	<0.001	95.1	3.8	102.5	4.1	7.5	3.5	<0.001	0.720
Ar-Go (mm)	37.1	2.9	39.9	4.1	2.8	2.5	<0.001	37.4	2.3	40.2	3.2	2.8	2.3	<0.001	0.867
Go-Me (mm)	61.5	4.2	66.4	4.2	5.0	3.1	<0.001	60.4	3.7	66.5	3.4	6.2	3.6	<0.001	0.230
Dentoalveolar															
U1-SN, °	105.5	7.3	108.1	7.5	2.6	7.3	0.037*	103.8	6.5	111.1	5.8	7.3	5.5	<0.001	0.010*
IMPA, °	90.4	5.6	91.7	5.7	1.3	3.7	0.033*	90.5	6.4	91.8	5.9	1.3	3.1	0.049*	0.913
U1-L1, °	125.8	8.8	122.0	9.9	−3.8	8.2	0.008†	128.1	9.0	123.0	6.7	−5.1	6.0	0.001†	0.502
Soft tissue															
UL-EP (mm)	2.3	2.2	1.3	1.9	−1.0	1.3	<0.001	1.9	1.3	2.1	1.1	0.2	1.0	0.283	0.001†
LL-EP (mm)	3.0	2.4	2.6	2.0	−0.4	1.7	0.174	3.1	1.7	3.1	2.0	−0.1	1.6	0.832	0.481

Note. Data are shown as mean and SDs. **p* < 0.05; †*p* < 0.01.

TABLE 5. Statistical comparison of the changes (T1 to T2) during treatment between the groups.

Cephalometric measurement	RME normal-angle (n = 16)		RME high-angle (n = 21)		Control normal-angle (n = 12)		Control high-angle (n = 11)		*p* (Statistical comparisons)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Re/Rh	Ce/Ch	Re/Ce	Rh/Ch
Sagittal items												
SNA, °	1.4	1.1	1.7	3.1	1.7	1.5	1.6	2.6	0.751	0.990	0.634	0.992
SNB, °	2.4	1.6	2.7	1.9	1.2	1.5	2.0	2.0	0.664	0.249	0.052	0.402
ANB, °	−1.1	0.9	−0.7	1.8	0.4	1.4	−0.6	1.5	0.466	0.160	0.002†	0.772
Wits (mm)	−1.9	1.9	0.0	2.8	0.2	2.6	−0.9	2.0	0.016*	0.219	0.011*	0.336
Overjet (mm)	−1.8	2.3	−0.4	2.4	1.5	2.0	1.9	1.6	0.084	0.878	<0.001	0.014*
Vertical items												
FMA, °	−0.3	2.0	−1.1	2.6	−0.8	1.6	−1.0	1.8	0.290	0.118	0.053	0.535
N-me (mm)	6.4	2.9	4.9	4.3	5.8	4.1	6.4	2.7	0.137	0.928	0.515	0.656
S-Go (mm)	5.2	3.1	4.8	3.9	5.4	3.1	4.9	2.3	0.497	0.372	0.874	0.719
S-Go/N-Me (%)	1.0	1.9	1.7	2.1	1.7	1.5	1.1	1.5	0.483	0.225	0.472	0.292
Overbite (mm)	−0.1	1.4	0.4	1.7	0.7	1.4	0.1	1.2	0.326	0.415	0.135	0.775
Skeletal items												
Co-A (mm)	4.0	2.0	3.8	4.4	5.2	2.4	3.7	2.5	0.769	0.151	0.194	0.95
Co-Gn (mm)	7.7	3.1	6.3	4.5	7.5	3.9	7.4	3.3	0.122	0.921	0.639	0.493
Ar-Go (mm)	3.3	2.2	2.4	2.8	3.0	2.3	2.6	2.2	0.189	0.658	0.531	0.883
Go-Me (mm)	4.9	2.3	5.0	3.7	6.4	3.6	5.9	3.7	0.781	0.765	0.307	0.505
Dentoalveolar												
U1-SN, °	1.1	6.5	3.7	7.7	5.4	5.5	10.0	4.7	0.367	0.086	0.096	0.033*
IMPA, °	0.5	2.8	2.0	4.3	2.0	3.0	0.9	3.0	0.130	0.331	0.129	0.342
U1-L1, °	−2.6	7.3	−4.7	8.9	−3.7	6.0	−7.5	5.8	0.451	0.244	0.675	0.511
Soft tissue												
UL-EP (mm)	−1.4	1.2	−0.6	1.4	−0.1	0.8	0.6	1.1	0.084	0.119	0.003†	0.021*
LL-EP (mm)	−0.9	1.6	0.0	1.7	−0.7	1.3	0.7	1.6	0.259	0.034*	0.995	0.245

Note. Data are shown as mean and SDs. Re: RME normal-angle; Rh: RME high-angle; Ce: Control normal-angle; Ch: Control high-angle; *$p < 0.05$; †$p < 0.01$.

The pre-treatment and post-treatment temporal parameters revealed no statistically significant differences between the RME and control groups (Table 2), confirming the homogeneity of the cohorts. Cephalometric measurements at T1 corroborated this observation, except for the Overjet measurement (Table 3). Notably, the control group had a reduced initial Overjet value of 3.1 mm, compared to 5.4 mm in the RME group. Although dentoalveolar compensations are limited by variances in initial Overjet measurements, skeletal modifications remain valid comparisons.

In our study, sagittal measurements of the mandible were analyzed using angular indices, including SNB, ANB, and linear metrics such as Wits, Co-Gn, Go-Me and Overjet. The ANB angle serves as the predominant cephalometric indicator for describing discrepancies between skeletal bases; however, the method is susceptible to variations associated with the Nasion point's position, particularly as children grow and develop [20]. Wits values, which use linear measurements to gauge jaw sagittal relationships, mitigated the influence exerted by cranial base reference points. However, the parameter remains susceptible to occlusal plane fluctuations [21]. Both ANB and Wits metrics have been recommended to diagnose anteroposterior discrepancies in skeletal bases [22, 23]. The metric of Overjet, delineating the horizontal distance between the upper and lower incisor tips, is significantly affected by dentoalveolar compensations and thus may not serve as a precise indication of skeletal alterations; it is merely considered a reference for sagittal relationships.

We found that, in comparison to the control group, the RME cohort manifested a statistically significant decrement in both the ANB angle (−0.9°/−0.1°, $p = 0.046$) and Overjet (−1.0/1.5 mm, $p < 0.001$). A diminishing trend was also noted in Wits values, although not statistically significant (−0.9/−0.3 mm, $p = 0.372$). SNB angle quantified mandibular advancement in the RME group at 1.0° ($p = 0.047$) compared to the control group. Measurements of mandibular length, as measured by Co-Gn and Go-Me metrics, showed significant growth across both groups; however, the RME cohort did not display an amplified trajectory of mandibular growth relative to the control group.

Comparing facial growth pattern groups with mandibular plane angles reveals fascinating observations. RME normal-angle group, significant decrements were noted in ANB (−1.1°, $p = 0.002$), Wits (−1.9 mm, $p = 0.011$), and Overjet (−1.8 mm, $p < 0.001$), whereas SNB (2.4°, $p = 0.053$) manifested an increment when compared to the control normal-angle group. Conversely, only Overjet (−0.4 mm, $p = 0.014$) demonstrated a retraction in the RME high-angle group compared with the control normal-angle group. The RME normal-angle cohort showed more pronounced sagittal transformations than the RME high-angle cohort, as substantiated by a greater trend of decrement in Wits (−1.9/0.0 mm, $p = 0.016$). Statistically significant impacts of maxillary expansion interventions on mandibular body growth were not found in subgroup analyses. This study is corroborating the findings of Susan *et al.* [24], they demonstrated that bonded rapid maxillary expanders employed in early mixed dentition Class II Division 1 subjects could mitigate Class II malocclusion as a secondary consequence.

The effect of RME therapy on mandibular growth has been debated. According to the prevailing hypothesis, RME alleviates maxillary constriction, enabling natural three-dimensional mandibular growth [25]. Alternative conjectures suggest functional shifts as the result of occlusal disruptions; with RME, the existing occlusion could be disrupted, allowing the patient to reposition the mandible anteriorly into a more ergonomic alignment. Subsequent condylar remodeling and stabilization of the mandibular position occur over time [26, 27]. In our study, mandibular body growth was not augmented in the RME group relative to the control group. This was possibly due to the study's observational timeframe, which was confined to a two-year follow-up period.

To assess vertical skeletal modifications in the mandible, relative angular measurements such as FH-MP, and linear metrics like N-Me, S-Go, S-Go/N-Me and Ar-Go were examined. Several short-term studies have suggested that RME can induce buccal inclinations of molars, resulting in an inadvertent elevation of vertical height [28, 29]. Post-treatment mandibular plane angles in this investigation were −0.7° ± 2.4° and −1.2° ± 2.0° for the RME and control groups, respectively, with no significant differences ($p = 0.403$). Explicitly, both the high-angle and normal-angle expansion cohorts recorded post-treatment mandibular plane angles of −1.1° ± 2.6° and −0.3° ± 2.0°, which were not statistically different from their corresponding control groups ($p > 0.05$). Based on longitudinal observations, the mandibular plane angle growth decreased, in agreement with Garib *et al.* [11] and Chang *et al.* [30], who observed physiological contractions in the mandibular plane angle in long-term evaluations of normative samples, recording average contractions of −0.7° and −0.9°, respectively.

When scrutinizing longitudinal alterations across other vertical dimensions—N-Me, S-Go, FHI and Ar-Go—no statistical variance emerged among any of the cephalometric variables. In accordance with such observations, patients with high mandibular angles who undergo RME treatment show similar chances of experiencing alterations in mandibular plane angles to those with normal-angle.

Similarly, current long-term studies collectively assert an absence of substantial modifications in the mandibular plane angle after RME [30, 31]. Matteo Rozzi *et al.* [28] found that, immediately following RME, subjects with elevated mandibular angles underwent clockwise rotation of the mandible. There may be lower muscle strength in high-angle subjects, which leads to lower dental anchorage and greater buccal inclination. Nonetheless, no significant vertical transformations were discernible between the two groups one year post-RME treatment cessation. Corroboratively, Matthew W *et al.* [12], in a long-term study of hyperdivergent subjects who underwent RME, found no adverse effects on vertical skeletal relationships in either the short- or long-term continuum.

Although our study did not directly observe clockwise rotation in the vertical direction within the high-angle RME group, there was also no significant evidence of mandibular remodeling in the sagittal direction, as seen in the normal-angle RME group. This suggests that the tendency for clockwise rotation may offset the anterior mandibular positioning remodeling, further studies conducted with larger sample size are necessary to confirm present results.

In the soft tissue comparison, it can be observed that the normal-angle RME group retruded more than the high-angle RME group. Both groups showed statistically significant retruding compared to their respective control groups. These observations may be explained by alterations in maxillary width; namely, transverse stretching effects on the lips can significantly decrease the upper lip's thickness [32, 33].

The current study is limited by the selective inclusion of cases. Incorporating skeletal Class II cases (ANB >4°) who had only undergone long-term RME treatment was challenging due to database constraints. Additionally, the control group's composition, which may include a subset of anterior crossbite cases, may influence the comparison of dental items to some extent. To mitigate this, we focused our analysis on inter-maxillary positioning and mandibular growth metrics. Cone Beam Computed Tomography examination and Ultra Low Frequency Transcutaneous Electrical Nerve Stimulation were unavailable to us as well [34]. Including such technologies in future studies could provide a comprehensive understanding of the interplay between maxillary expansion and mandibular response, thereby enhancing the depth and accuracy of findings in this field.

5. Conclusions

1. RME facilitates sagittal mandibular growth and optimizes the intermaxillary relationship long-term.

2. Comparative analyses reveal that the RME normal-angle cohort shows more pronounced sagittal transformations, as evidenced by significantly improved maxillomandibular differentials.

3. Longitudinal assessments revealed no significant differences in vertical skeletal morphology between the respective cohorts. Therefore, RME therapy is not contraindicated in cases of high mandibular angle.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

YHL and YYL—conception and design. GY and XQT—methodology. GY—writing article. GY and XHX—data collected and analyzed. All authors have read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was conducted in accordance with relevant guidelines and regulations. The study was protocol approved by the Research Ethics Committee of Shanghai Stomatological Hospital of Fudan University (approval number 2023/006). In alignment with ethical committee directives and given the use of radiographic images for treatment or prior clinical studies, informed consent from patients was waived.

ACKNOWLEDGMENT

We extend our sincere gratitude to the participants of this study for their contributions. We also wish to express our appreciation to the anonymous reviewers for their constructive feedback and suggestions.

FUNDING

This study was supported by Shanghai Municipal Health Commission (202340147 and 2023ZZ02009); Shanghai Science and Technology Commission, Shanghai Sailing Program (21YF1439800).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Gang Yang, Xianhua Xiang, Xianqin Tong, Yuanyuan Li, Yuehua Liu. Mandibular response after rapid maxillary expansion in mixed dentition children with different vertical growth patterns: a retrospective study. Journal of Clinical Pediatric Dentistry. 2024; 48(5): 69-78. doi: 10.22514/jocpd.2024.105.