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Skeletal, dental, periodontal, and upper airway changes after Hyrax rapid maxillary expansion with different premolar anchorage: a retrospective CBCT study

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Abstract

Background: To compare skeletal, dental, periodontal, and upper airway changes after tooth-borne Hyrax rapid maxillary expansion (RME) with first-premolar/first-molar anchorage (group 46) or second-premolar/first-molar anchorage (group 56), and to explore associations among dentoskeletal changes.

Methods: This single-center retrospective study included 52 patients aged 12–15 years treated at Lanzhou University Stomatological Hospital between 2021 and 2025 (26 per group). Cone-beam computed tomography (CBCT) scans obtained before expansion (T0) and after 3–6 months of retention (T1) were used to assess skeletal, dental, periodontal, and upper airway measures. Paired tests assessed within-group changes, and independent-samples tests compared change scores between groups. Correlation and exploratory multivariable linear regression analyses assessed associations among transverse skeletal and dentoalveolar changes.

Results: Both groups showed increases in maxillary basal width and midpalatal suture opening (all $P < 0.05$). Group 56 showed greater basal expansion (2.01 vs 1.48 mm, $P = 0.007$) and anterior, middle, and posterior suture opening (0.89 vs 0.45, 1.02 vs 0.47, and 0.78 vs 0.54 mm, respectively; all $P < 0.05$). Most maxillary dental expansion measures did not differ significantly between groups, except for

greater second-premolar interapical expansion in group 56 (P = 0.01). Second-premolar buccal bone thinning was greater in group 56, whereas palatal bone thickening at some first-premolar sites was greater in group 46 (P < 0.05). Oropharyngeal and nasopharyngeal volumes increased in group 46 (0.99 and 0.68 cm^3; P = 0.02 and 0.004, respectively), but airway changes did not differ significantly between groups. Correlation and exploratory multivariable regression analyses identified positive associations among basal, alveolar, and sutural changes.

Conclusions: Both anchorage configurations produced marked transverse maxillary expansion. In this sample, group 56 showed greater maxillary basal expansion and midpalatal suture opening, whereas overall dental expansion was similar to that in group 46. Periodontal remodeling occurred predominantly around the respective anchor teeth. Changes in airway volumes and minimum cross-sectional areas did not differ significantly between groups. Correlation and exploratory multivariable regression analyses identified positive associations among maxillary basal expansion, alveolar expansion, and sutural opening.

Keywords: Rapid maxillary expansion; Hyrax expander; Tooth anchorage; Cone-beam computed tomography; Midpalatal suture; Alveolar bone; Periodontal tissue; Upper airway

Background

Maxillary transverse deficiency (MTD) is a common transverse orthodontic problem that may present as a narrow maxillary arch, unilateral or bilateral posterior crossbite, crowding, or a transverse discrepancy between the maxillary and mandibular arches. A cross-sectional study of 794 children and adolescents reported an MTD prevalence of 31.1% [1]. Transverse discrepancies may affect periodontal health and the stability of dental compensation [2]. Midpalatal suture maturation does not correspond exactly to chronological age [3]. Expansion options can therefore be selected in light of individual suture maturation and include slow or rapid maxillary expansion (RME), miniscrew-assisted expansion, and surgically assisted expansion. Conventional tooth-borne RME remains commonly used in patients with remaining growth potential [4–6].

Previous studies have reported buccal tipping of anchor teeth, reduced buccal alveolar bone thickness and height, and root resorption after RME [7,8]. Maxillary first and second premolars differ in root position and surrounding alveolar bone anatomy. A CBCT anatomical study found thicker buccal alveolar bone around the second than the first premolars at the measured levels in untreated patients; another found that first-premolar roots were more frequently positioned buccally and had a thinner buccal bone plate [9,10]. Because expansion forces from tooth-borne RME are transmitted through the anchor teeth and their periodontium to the surrounding bone, different premolar anchorage positions may produce different dentoskeletal responses. The position of the anterior anchor teeth may thus be associated with both expansion and local periodontal remodeling.

Clinical tooth-borne Hyrax expanders commonly use premolars and first molars as anchorage units, with the first premolars and first molars forming a common configuration. Previous studies have compared tooth-borne, bone-borne, and hybrid expanders, as well as two-band and four-band appliances [11–13]. By contrast, three-dimensional clinical comparisons of anterior anchor teeth within the same tooth-borne Hyrax system remain limited.

We therefore used CBCT to compare skeletal, dental, periodontal, and upper airway changes after RME with first-premolar and first-molar anchorage (group 46) versus second-premolar and first-molar anchorage (group 56). We focused on maxillary basal width, midpalatal suture opening, bone around the anchor teeth, and airway dimensions, and explored associations among transverse changes to help inform individualized anchorage selection for conventional tooth-borne RME.

Methods

Study design and participants

This was a single-center retrospective observational study. Records from patients treated in the Department of Orthodontics, Lanzhou University Stomatological Hospital, between 2021 and 2025 were screened using prespecified eligibility criteria. Fifty-two patients aged 12–15 years were included. All had permanent dentition, and the maxillary first premolars, second premolars, and first permanent molars had erupted and were suitable as potential anchor teeth. According to the anchorage used during

treatment, 26 patients were assigned to the first-premolar/first-molar group (group 46) and 26 to the second-premolar/first-molar group (group 56). The study was approved by the Clinical Scientific Research Ethics Committee of the School of Stomatology, Lanzhou University (LZUKQ-2025-111). Parental informed consent was obtained for all patients.

Inclusion criteria were: (1) permanent dentition with fully erupted maxillary first premolars, second premolars, and first permanent molars; (2) clinically diagnosed maxillary arch narrowing or transverse discrepancy, manifested by inadequate maxillary arch width, uncoordinated maxillary and mandibular transverse arch relationships, and/or posterior crossbite, with an indication for maxillary expansion after comprehensive assessment; and (3) complete CBCT data at T0 and T1. Exclusion criteria were previous maxillary expansion or other orthodontic treatment that substantially affected transverse arch form; cleft lip or palate, craniofacial syndromes, or marked facial asymmetry; systemic disease affecting bone metabolism or craniofacial growth; severe periodontal disease; or image quality inadequate for measurement.

Expander and treatment protocol

All patients received a tooth-borne Hyrax screw expander (Chongqing Jingmei Medical Technology Co., Ltd., Chongqing, China). The basic appliance design and expansion screw were the same in both groups; the main difference was the anterior anchorage position. Group 46 used the bilateral maxillary first premolars and first permanent molars, whereas group 56 used the bilateral maxillary second premolars and first permanent molars.

After appliance placement, patients or their guardians received standardized activation instructions. The expansion screw was activated once daily by one-quarter turn, corresponding to approximately 0.25 mm of expansion per day. Patients attended regular reviews during active expansion, and the degree of expansion was assessed from the clinical occlusion. Activation stopped when moderate posterior overcorrection was achieved, with the palatal cusps of the maxillary posterior teeth contacting or approaching the corresponding buccal cusps of the mandibular posterior teeth. The expander was then

left in situ for passive retention for 3–6 months, removed, and followed by T1 CBCT imaging. The two anchorage configurations are shown in Fig. 1.



Fig. 1 Hyrax expanders with two premolar anchorage configurations. Left: group 56; right: group 46.

CBCT acquisition and three-dimensional standardization

All patients underwent CBCT before expansion (T0) and at the end of the post-expansion retention period (T1). Images were acquired by the Department of Oral Radiology at Lanzhou University Stomatological Hospital using a KaVo 3D eXam CBCT scanner under the same exposure settings at both time points: 120 kV, 5 mA, scan time 14.7 s, and voxel size 0.25 mm. Patients were seated upright with the head stabilized and the Frankfort horizontal plane parallel to the floor. Teeth were in maximum intercuspation, facial muscles were relaxed, and lips were gently closed. Patients were instructed to avoid swallowing or pronounced tongue movement and to breathe quietly during scanning. The scan extended inferiorly to the lower border of the fourth cervical vertebra. Original images were stored in DICOM format.

T0 and T1 DICOM datasets were imported into InVivo 7 (Anatomage, San Jose, CA, USA) for three-dimensional reconstruction, head-position standardization, and measurement. A common reference plane was constructed using the anterior nasal spine (ANS), posterior nasal spine (PNS), and nasion (N). Pretreatment and postretention images were standardized to reduce the influence of head-position differences. This procedure is illustrated in Fig. 2.

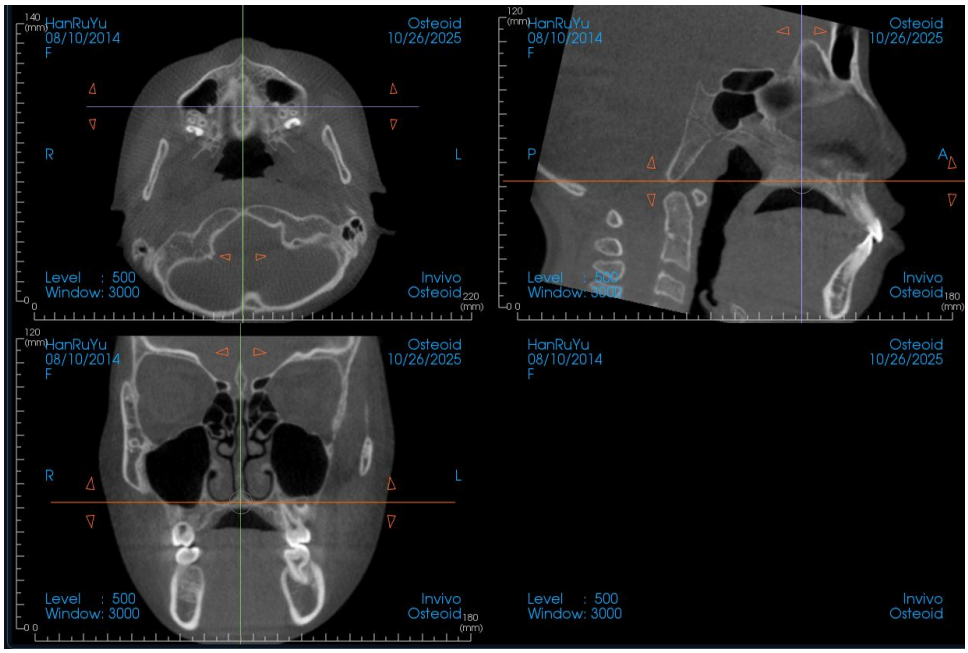


Fig. 2 Three-dimensional head-position standardization of CBCT images.

CBCT measurements

Standardized T0 and T1 CBCT images were measured using InVivo 7. Treatment change was defined as $\Delta = T1 - T0$.

Skeletal measurements comprised maxillary and mandibular basal widths (MxBW and MdBW); alveolar bone widths in the maxillary and mandibular first-premolar, second-premolar, and first-molar regions (MxABW4, MxABW5, MxABW6, MdABW4, MdABW5, and MdABW6); palatal depth (PD); anterior, middle, and posterior midpalatal suture opening (RANS–LANS, RMS–LMS, and RPNS–LPNS); interincisive foramen width (IIFW); distance between the posterior borders of the greater palatine foramina (PGPFW); nasal width (NW); right and left frontozygomatic angles (RFZA and LFZA); and width between the superior margins of the zygomaticomaxillary sutures (I-SZSW).

Dental measurements comprised intercusp widths at the buccal cusps of the maxillary and mandibular first premolars, second premolars, and first molars (MxBCW4–6 and MdBCW4–6); maxillary palatal cusp widths (MxPCW4–6); mandibular lingual cusp widths (MdLCW4–6); maxillary intercanine cusp width (MxBCW3); maxillary canine and posterior interapical widths (MxAW3–6); mandibular posterior interapical widths (MdAW4–6); and the corresponding tooth inclinations (Incl).

Periodontal measurements comprised buccal bone plate thickness (BBPT), palatal bone plate thickness (PBPT), and buccal alveolar crest level (BACL) bilaterally at the maxillary first premolars, second premolars, and first molars. At the first molars, the buccal bone plate was measured separately at the mesiobuccal (BBPT6M) and distobuccal (BBPT6D) roots. Bone plate thickness was defined as the shortest distance from the root surface to the outer border of the corresponding cortical bone. Examples of skeletal and dental measurements appear in Figs. 3–9.

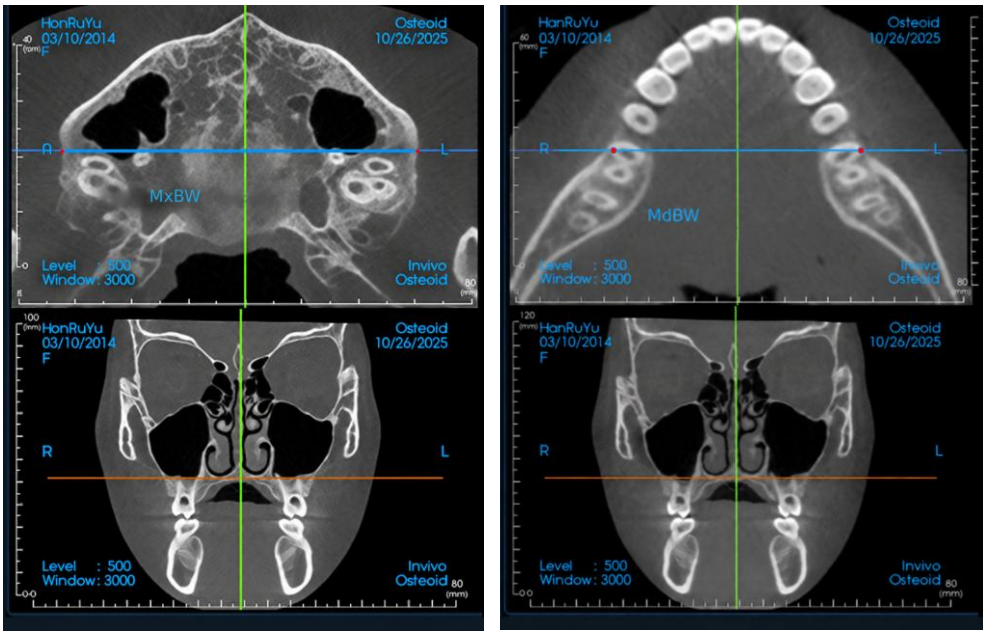


Fig. 3 Measurement of maxillary and mandibular basal widths. Left: maxilla; right: mandible.

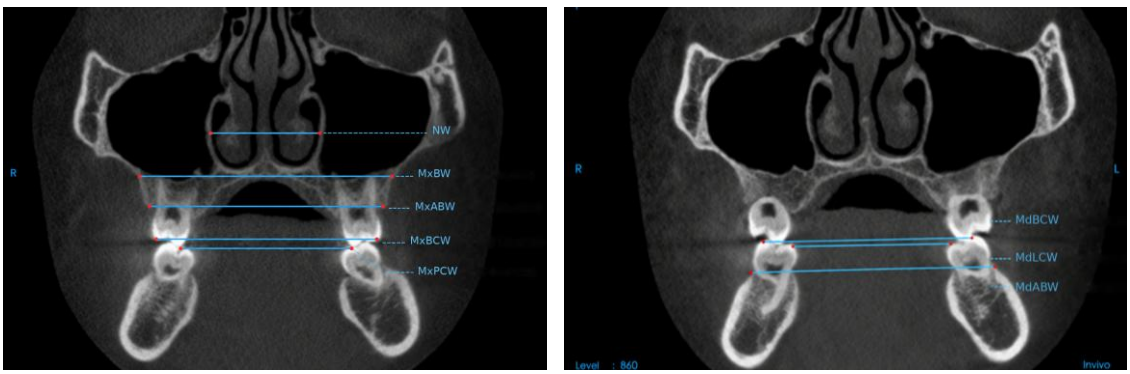


Fig. 4 Measurement of transverse skeletal and dental widths in the maxilla and mandible. Left: maxilla; right: mandible.

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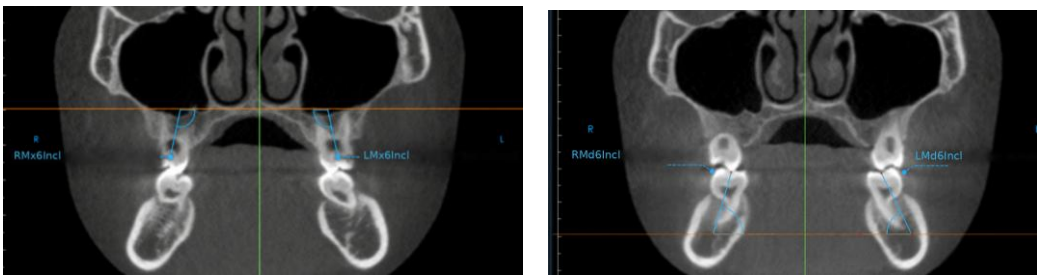


Fig. 5 Measurement of maxillary and mandibular first-molar inclination. Left: maxilla; right: mandible.

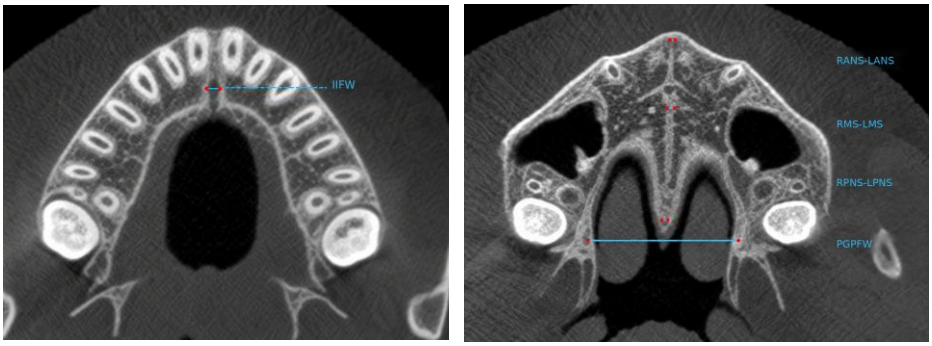


Fig. 6 Measurement of interincisive foramen width and midpalatal suture-related variables. Left: interincisive foramen width; right: midpalatal suture and greater palatine foramina.

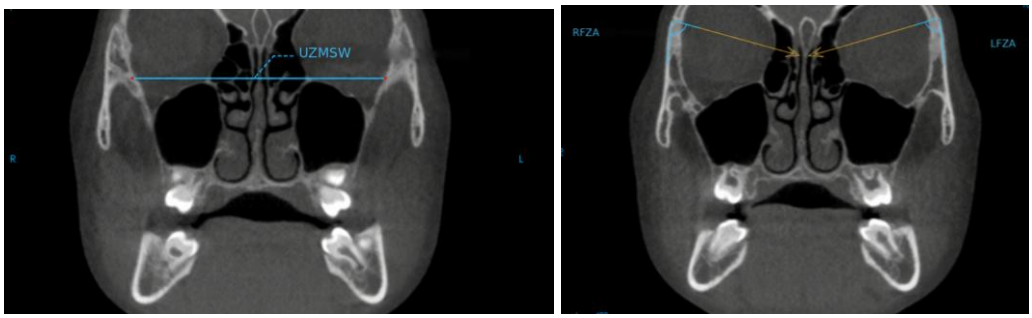


Fig. 7 Measurement of the zygomaticomaxillary suture and frontozygomatic angle. Left: zygomaticomaxillary suture; right: frontozygomatic angle.

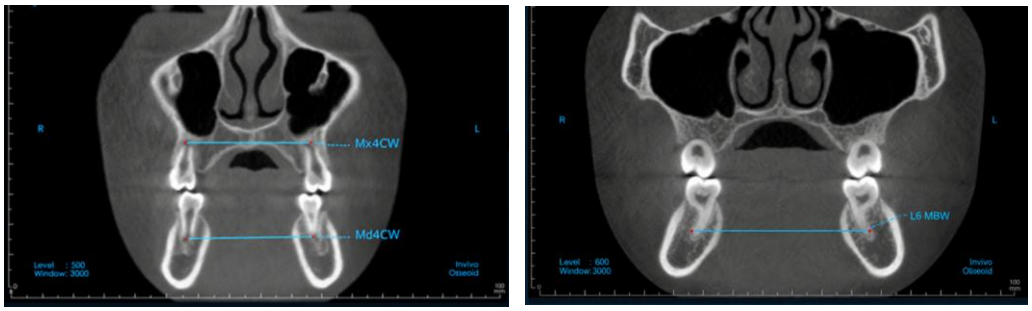


Fig. 8 Measurement of interapical widths at the first premolars and mandibular first molars.

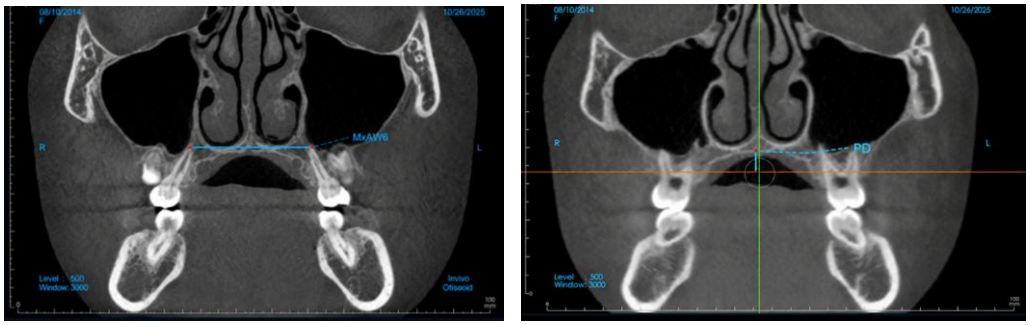


Fig. 9 Measurement of maxillary first-molar interapical width and palatal depth. Left: interapical width; right: palatal depth.

Upper airway measurements

Nasopharyngeal and oropharyngeal airways were segmented in InVivo 7. The nasopharyngeal region extended from the posterior nasal apertures to the level of the nasal floor/hard palate; the oropharyngeal region extended from the uvular to the epiglottic level. Axial slices were reviewed to identify the narrowest section within each region. Nasopharyngeal and oropharyngeal volumes (NPV and OPV, cm^3) and their minimum cross-sectional areas (NP-MCA and OP-MCA, mm^2) were recorded at T0 and T1.

Measurement repeatability and reliability

Twenty-two patients were selected at random. The same examiner independently repeated all measurements under identical conditions after a two-week interval. Intraexaminer reliability was assessed using intraclass correlation coefficients (ICCs). For all 74 measurements, ICCs ranged from 0.805 to 1.000. ICC ranges for skeletal, dental, periodontal, and airway variables were 0.821–0.996, 0.839–0.994, 0.947–0.996, and 0.805–1.000, respectively, indicating good to excellent agreement [14].

Statistical analysis

Analyses were performed using IBM SPSS Statistics 27.0. Normality of continuous variables was assessed with the Shapiro–Wilk test. Normally distributed variables are presented as mean ± standard deviation, and non-normally distributed variables as median (interquartile range). T0 and T1 values were compared within groups using paired-samples t-tests or Wilcoxon signed-rank tests, as appropriate. Between-group comparisons used change scores ($\Delta = T1 - T0$) and independent-samples t-tests or Mann–Whitney U tests according to the data distribution. Categorical variables were assessed using the chi-square test or an exact test. For exploratory association analyses, Pearson correlation or Spearman rank correlation was used according to the data distribution. Within each anchorage group, separate multivariable linear regression models assessed associations with change in maxillary basal width and with anterior midpalatal suture opening. Models for basal width included change in maxillary alveolar width at the first molars (MxABW6), anterior suture opening, maxillary first-molar buccal intercusp width, and maxillary first-molar interapical width; models for anterior suture opening included change in basal width, maxillary alveolar width, maxillary first-molar buccal intercusp width, and age. Standardized regression coefficients (β), R^2, and adjusted R^2 are reported. All tests were two-sided, with $P < 0.05$ considered statistically significant. The association analyses were exploratory and were not adjusted for multiple testing.

Results

Baseline characteristics

Age, sex distribution, the baseline difference between maxillary and mandibular basal widths, and cervical vertebral maturation stage did not differ significantly between groups (all $P > 0.05$; Table 1).

Table 1 Baseline characteristics of the two groups

Variable	Group 46 (n = 26)	Group 56 (n = 26)	P value
Age (years)	12.00 (12.00, 13.00)	12.50 (12.00, 13.00)	0.349
Sex (male/female)	6/20	10/16	0.229
MxBW−MdBW (mm)	4.16±4.14	5.07±3.89	0.414
CVM (CS3/CS4/CS5)	10/14/2	10/15/1	1.000

Note: CVM, cervical vertebral maturation; MxBW, maxillary basal width; MdBW, mandibular basal width. The overall distribution of CVM stages was compared with the Fisher–Freeman–Halton exact test. Age is shown as median (P25, P75); basal-width difference as mean ± standard deviation.

Skeletal changes

Maxillary basal width and alveolar bone widths in the maxillary first-premolar, second-premolar, and first-molar regions increased significantly in both groups after treatment ($P < 0.001$), as did anterior, middle, and posterior midpalatal suture opening. The increase in MxBW was greater in group 56 than in group 46 (2.01 vs 1.48 mm; $P = 0.007$). The increases in anterior, middle, and posterior suture opening were 0.89, 1.02, and 0.78 mm in group 56 versus 0.45, 0.47, and 0.54 mm in group 46 (all $P < 0.05$). Alveolar bone width in the maxillary second-premolar region also increased more in group 56 (3.12 vs 2.41 mm; $P = 0.04$; Table 2). Changes in key skeletal measures are shown in Fig. 10.

Table 2 Changes in selected skeletal measurements in the two groups (mm)

Variable	Group 46 Δ	Group 56 Δ	P value
Maxillary basal width	1.48	2.01	0.007
Maxillary alveolar width at first premolars	2.52	2.89	>0.05
Maxillary alveolar width at second premolars	2.41	3.12	0.040
Maxillary alveolar width at first molars	3.25	3.45	>0.05
Anterior midpalatal suture opening	0.45	0.89	<0.001
Middle midpalatal suture opening	0.47	1.02	<0.001
Posterior midpalatal suture opening	0.54	0.78	0.010

Note: Δ = T1 − T0; T0, before expansion; T1, end of the post-expansion retention period.

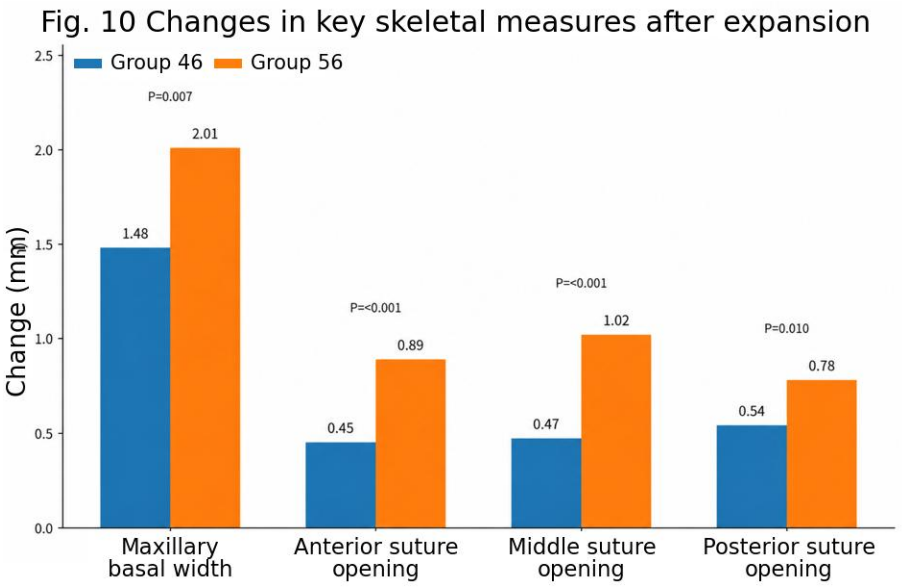


Fig. 10 Changes in key skeletal measurements after expansion in the two groups.

Dental changes

Buccal cusp, palatal cusp, and interapical widths of the maxillary first premolars, second premolars, and first molars increased significantly in both groups (all $P < 0.001$). Most between-group differences in changes in maxillary crown widths were not statistically significant. The increase in second-premolar interapical width was greater in group 56 than in group 46 (3.77 vs 2.29 mm; $P = 0.01$). Changes in tooth inclination were generally small and showed no consistent between-group pattern. Between-group comparisons of selected dental widths are shown in Table 3.

Table 3 Changes in maxillary premolar and first-molar dental widths in the two groups

Variable	Tooth	Group 46 Δ (mm)	Group 56 Δ (mm)	Δ difference	t	P
Maxillary buccal intercusp width (MxBCW)	4	+3.51 ± 2.12	+2.68 ± 1.85	-0.83	-1.56	0.12
	5	+3.27 ± 2.08	+3.89 ± 2.01	0.62	1.12	0.27
	6	+3.97 ± 2.15	+4.44 ± 2.08	0.47	0.78	0.44
Maxillary palatal intercusp width (MxPCW)	4	+3.46 ± 2.05	+3.33 ± 1.98	-0.13	-0.23	0.82
	5	+3.43 ± 2.10	+3.34 ± 2.02	-0.09	-0.15	0.88
	6	+3.91 ± 2.18	+3.89 ± 2.05	-0.02	-0.03	0.97
Maxillary interapical width (MxAW)	4	+3.27 ± 2.45	+3.22 ± 2.38	-0.05	-0.07	0.94
	5	+2.29 ± 2.12	+3.77 ± 2.01	1.48	2.56	0.01
	6	+3.25 ± 2.32	+3.88 ± 2.18	0.63	1.02	0.32

Note: Δ = T1 − T0; between-group difference = Δ in group 56 minus Δ in group 46. Teeth 4, 5, and 6 denote the maxillary first premolar, second premolar, and first molar, respectively. MxBCW,

maxillary buccal intercusp width; MxPCW, maxillary palatal intercusp width; MxAW, maxillary interapical width. Changes are mean ± standard deviation.

Periodontal changes

Both groups showed buccal bone plate thinning at some anchor teeth and changes in palatal bone thickness, with clear site-specific patterns. Changes in left and right second-premolar buccal bone thickness were +0.12 and −0.07 mm in group 46 versus −0.54 and −0.53 mm in group 56, respectively ($P < 0.001$ and $P = 0.01$ for between-group comparisons). Conversely, palatal bone thickness at the first premolars increased more at some sites in group 46, whereas that at the second premolars increased more in group 56 ($P < 0.05$). Buccal bone thickness at the first molars decreased in both groups, but most between-group differences at this region were not statistically significant. Between-group differences in selected outcomes are shown in Fig. 11, representative periodontal measures in Table 4, and the distribution of bone plate changes in Fig. 12.

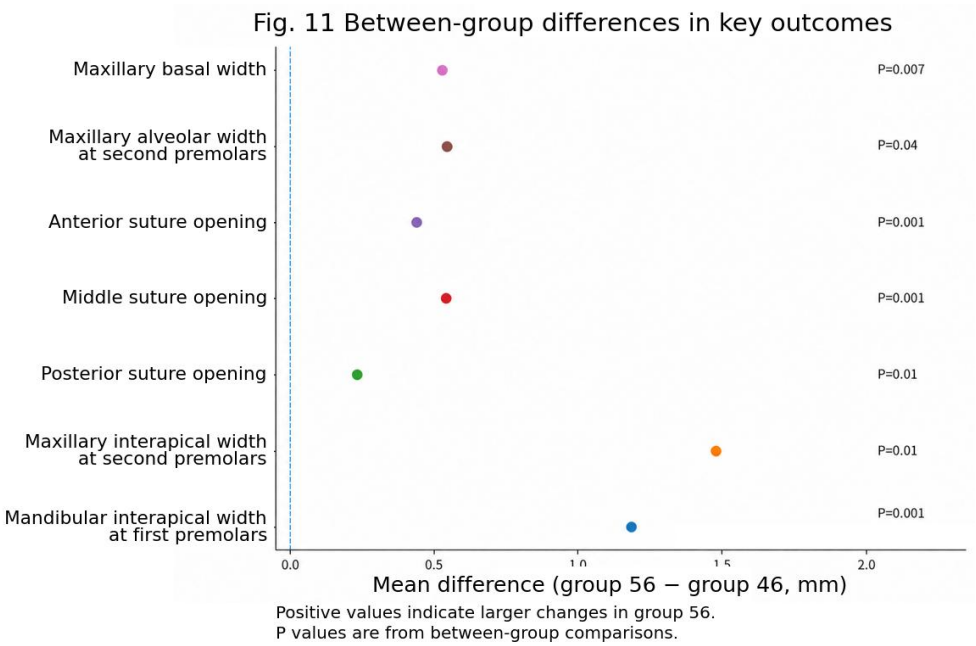


Fig. 11 Between-group differences in changes in selected variables. Positive values indicate a larger change in group 56.

Table 4 Changes in selected periodontal measurements in the two groups (mm)

Variable	Group 46 Δ	Group 56 Δ	P value
Left second-premolar buccal bone plate	+0.12	−0.54	<0.001
Right second-premolar buccal bone plate	−0.07	−0.53	0.010
Right first-premolar buccal bone plate	−0.52	−0.07	0.040
Left first-premolar palatal bone plate	+0.93	+0.27	0.050
Right first-premolar palatal bone plate	+0.74	+0.10	0.040
Left second-premolar palatal bone plate	+0.23	+1.05	0.001

Note: Δ = T1 − T0. Positive values indicate increased bone plate thickness and negative values indicate decreased thickness.

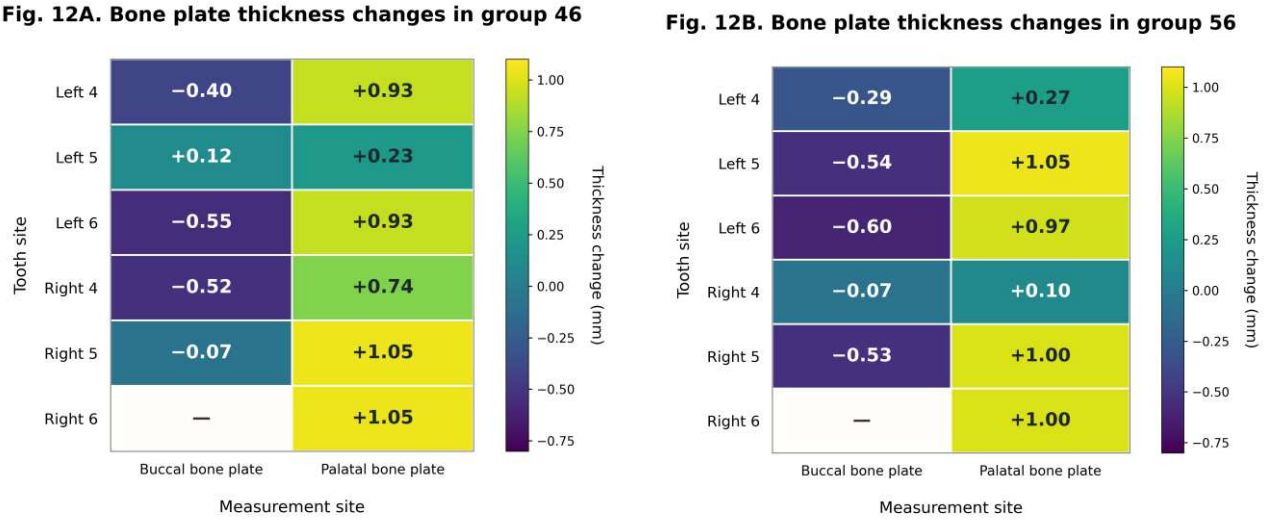


Fig. 12 Changes in periodontal bone plate thickness in the two groups. A (left), group 46; B (right), group 56.

Upper airway changes

In group 46, OPV increased from 7.97 ± 3.05 to 8.96 ± 3.30 cm³ (mean Δ = 0.99 cm³, within-group P = 0.02), and NPV increased from 3.53 ± 1.29 to 4.21 ± 1.31 cm³ (mean Δ = 0.68 cm³, P = 0.004). In group 56, the corresponding mean changes were 0.63 cm³ (P = 0.07) and 0.35 cm³ (P = 0.05). The median OP-MCA changes were 28.6 mm² in group 46 and 42.8 mm² in group 56 (within-group P = 0.07 and P = 0.37, respectively); median NP-MCA changes were 4.0 and 7.9 mm² (P = 0.65 and P = 0.22, respectively). Between-group differences in change were not significant for OPV (P = 0.48), NPV (P = 0.24), OP-MCA (P = 0.65), or NP-MCA (P = 0.58; Table 5).

Table 5 Upper airway changes after rapid maxillary expansion

Measure	Group 46 Δ	Group 56 Δ	P value
OPV (cm³)	+0.99 ± 1.95	+0.63 ± 1.72	0.48
NPV (cm³)	+0.68 ± 1.12	+0.35 ± 0.90	0.24
OP-MCA (mm²)	+28.6 (−38.2, +86.7)	+42.8 (−22.5, +95.3)	0.65
NP-MCA (mm²)	+4.0 (−44.2, +42.5)	+7.9 (−23.6, +59.4)	0.58

Note: Δ = T1 − T0. Volume changes are mean ± standard deviation and were compared between groups with independent-samples t-tests. Minimum cross-sectional area changes are median (25th, 75th percentile) and were compared with Mann–Whitney U tests. The P values refer to between-group comparisons; 1 cm³ = 1 cc.

Correlation analysis

In group 46, changes in maxillary basal width were positively correlated with anterior, middle, and posterior suture opening (correlation coefficients 0.52, 0.48, and 0.45; all $P < 0.05$); corresponding coefficients in group 56 were 0.68, 0.72, and 0.64 (all $P < 0.001$). Changes in maxillary alveolar width at the first molars (MxABW6) were also correlated with opening at the three suture sites (0.58, 0.54, and 0.49 in group 46; 0.74, 0.78, and 0.70 in group 56; all $P < 0.05$). Changes in maxillary first-molar buccal intercusp width correlated with basal-width change in both groups (0.62 and 0.78, respectively; both $P < 0.001$). The coefficients were numerically larger in group 56, but differences in correlation strength between groups were not formally tested.

Exploratory multivariable regression

For change in maxillary basal width, the group-46 model had $R^2 = 0.52$ (adjusted $R^2 = 0.43$), with change in MxABW6 associated with the outcome (standardized $\beta = 0.42$, $P = 0.01$). The group-56 model had $R^2 = 0.68$ (adjusted $R^2 = 0.62$); MxABW6 change ($\beta = 0.48$, $P = 0.001$) and anterior suture opening ($\beta = 0.32$, $P = 0.01$) were associated with basal-width change. For anterior suture opening, the group-46 model had $R^2 = 0.45$ (adjusted $R^2 = 0.35$), with basal-width change associated with the outcome ($\beta = 0.38$, $P = 0.02$). The group-56 model had $R^2 = 0.72$ (adjusted $R^2 = 0.67$), with both basal-width change ($\beta = 0.45$, $P = 0.002$) and MxABW6 change ($\beta = 0.38$, $P = 0.01$) associated with the outcome. The full set of model coefficients and reported P values is shown in Table 6.

Table 6 Exploratory multivariable models of transverse skeletal changes

Outcome	Predictor	Group 46 β	P	Group 56 β	P
ΔMxBW	ΔMxABW6	0.42	0.01	0.48	0.001
ΔMxBW	Δanterior suture opening	0.18	0.21	0.32	0.01
ΔMxBW	ΔMxBCW6	0.22	0.18	0.18	0.21
ΔMxBW	ΔMxAW6	0.12	0.40	0.10	0.44
Δanterior opening	ΔMxBW	0.38	0.02	0.45	0.002
Δanterior opening	ΔMxABW6	0.28	0.09	0.38	0.01
Δanterior opening	ΔMxBCW6	0.22	0.16	0.18	0.18
Δanterior opening	Age	−0.12	0.40	−0.08	0.51

Note: β, standardized regression coefficient; Δ, T1 − T0; MxBW, maxillary basal width; MxABW6, maxillary alveolar bone width at the first molars; MxBCW6, first-molar buccal intercusp width; MxAW6, first-molar interapical width. For ΔMxBW models, R^2/adjusted R^2 were 0.52/0.43 (group 46) and 0.68/0.62 (group 56). For Δanterior opening models, they were 0.45/0.35 and 0.72/0.67, respectively. Each model included the four predictors listed for that outcome.

Discussion

Within the same tooth-borne Hyrax RME system, we compared first-premolar/first-molar anchorage (group 46) with second-premolar/first-molar anchorage (group 56). The measured baseline characteristics showed no statistically significant between-group differences. Both groups showed transverse skeletal and dental increases, while skeletal, periodontal, and airway responses and associations among the measured changes were assessed separately. The findings are discussed in the order reported.

Skeletally, maxillary basal and alveolar bone widths at the first premolars, second premolars, and first molars increased, and the anterior, middle, and posterior midpalatal suture opened in both groups. These changes are consistent with previous three-dimensional imaging studies of RME [15,16]. Maxillary basal expansion and opening at all three suture sites were greater in group 56, whereas between-group differences in alveolar bone width changes at the first premolars and first molars were not statistically significant. A previous comparison of two-band and four-band expanders also found that anchorage design may be accompanied by differences in sutural and arch responses [13]. However, that study differed in the number of anchorage units and other appliance features; it cannot establish greater skeletal efficiency for second-premolar anchorage in the present setting.

The larger alveolar bone width increase at the second premolars in group 56 corresponds to their role as direct anchor teeth in that group. Finite element studies suggest that Hyrax screw position and anchorage configuration can affect the distribution of tooth displacement, periodontal stress, and maxillary displacement [17,18], suggesting a possible mechanical explanation for this local difference. Study [18], however, examined surgically assisted expansion. Moreover, the present study neither measured stress directly nor controlled the spatial position of the screw. Simulation findings should therefore not be treated as causal evidence for our between-group difference. Baseline alveolar bone conditions at the same tooth sites and individual differences in sutural maturation could also have contributed.

Dentally, buccal cusp, palatal cusp, and interapical widths of the maxillary premolars and first molars increased in both groups, whereas most crown-width changes listed in Table 3 were similar between groups. The only significant between-group difference in that table concerned second-premolar interapical width, which increased more in group 56. Previous research indicates that transverse gains with tooth-borne expansion include skeletal expansion, alveolar bending, and anchor-tooth movement [15,16]; similar increases in crown width therefore do not necessarily reflect identical dentoalveolar responses. Finite element work also suggests that the site of force application can alter crown and root-apex displacement [17].

Periodontally, the buccal bone plate at both second premolars decreased more in group 56 than in group 46, whereas palatal bone thickness increased more at some first-premolar sites in group 46. The first molars were anchor teeth in both groups; their buccal bone thickness decreased in both, with no significant between-group difference for most measures. Garib et al. reported buccal bone thinning and palatal bone thickening at anchor teeth after tooth-borne RME [7], and imaging studies by Brunetto et al. and Toklu et al. also observed post-expansion periodontal bone changes [19,20], broadly consistent with our findings. Akyalcin et al. observed an initial decrease followed by recovery in buccal bone thickness over 2–3 years after expansion, although the thickness changes did not reach statistical significance [21], underscoring the relevance of follow-up timing. In a study of group-46-type anchorage immediately after expansion, Rungcharassaeng et al. found less buccal bone reduction at the second premolars than at the first premolars and first molars [22], similar to the pattern of smaller second-premolar than first-premolar buccal bone reduction when the first premolars served as direct anchors in our study. The greater second-premolar buccal bone thinning when those teeth served as direct anchors suggests that anchorage position may be associated with local periodontal burden; this association does not establish causation.

The upper-airway findings should be interpreted separately from the skeletal expansion results. OPV and NPV increased within group 46, whereas changes in airway volumes and minimum cross-sectional areas did not differ significantly between the two anchorage groups. In a matched-control CBCT study, Abdalla et al. found increases in airway volume over time in both expanded and control children, without a significant between-group difference [23]. Ribeiro et al. observed an oropharyngeal

change but no significant nasopharyngeal volume change and emphasized the influence of head and tongue position during imaging [24]. Differences in airway boundaries, imaging posture, growth, and retention interval may contribute to variation across studies. Our static CBCT measures do not establish changes in breathing function or show that either anchorage configuration benefits the airway more than the other.

The exploratory analyses showed positive associations among basal-width, alveolar-width, molar-width, and sutural changes, with numerically larger coefficients and R^2 values in group 56. CBCT studies have documented that skeletal and dental responses coexist after tooth-borne expansion [15,25], although associations among specific measures have not been uniform across studies [25]. These correlations and regression coefficients describe shared variation within each group; they do not identify a causal force-transfer pathway, and neither the correlations nor model fit were formally compared between groups. With only 26 patients per group, related anatomical predictors, and multiple tested associations, the model estimates require confirmation in a larger prespecified analysis.

When selecting an anchorage configuration, clinicians should consider the required skeletal expansion, crown and root-apex responses, and baseline bone conditions at the first and second premolars and first molars. The present results do not support a universal preference for group-56-type anchorage. If both configurations are feasible and the second premolars have adequate buccal bone, second-premolar anchorage may be considered when greater skeletal expansion is desired. If the second-premolar buccal bone plate is thin, direct anchorage on these teeth warrants caution, and the ability of the first premolars to support the appliance should be assessed. Sperl et al. suggest that buccal alveolar bone near anchor teeth may continue to change during expansion and subsequent fixed-appliance treatment [26]. Ballanti et al. assessed dental and periodontal measures both immediately after active expansion and after retention, illustrating how observation time can affect interpretation of tissue changes [27]. Because this was a nonrandomized retrospective study with follow-up only until 3–6 months of retention, these considerations for anchorage selection require long-term validation.

This study has limitations. Its single-center retrospective design cannot exclude anchorage-selection bias or unmeasured confounding. With 26 patients per group and many measured variables, individual P values should be interpreted in light of effect sizes and clinical importance. Retention lasted 3–6 months, and images immediately after active expansion and at long-term follow-up were unavailable; therefore, immediate mechanical effects, early bone remodeling, and long-term stability could not be distinguished. CBCT morphologic changes cannot replace direct mechanical measurements, clinical periodontal assessment, or functional assessment of breathing. Airway segmentation based on static scans may be affected by head and tongue position, respiratory phase, and growth; there was no untreated airway control group. The exploratory correlations and regression models are also vulnerable

to unstable estimates, collinearity among anatomical measures, and multiple testing. Future prospective studies should prespecify primary outcomes, standardize imaging time points, increase sample size, and include long-term follow-up to examine the effects and risks of different premolar anchorage combinations.

Conclusions

Both first-premolar/first-molar and second-premolar/first-molar anchorage produced transverse maxillary expansion. In this sample, group 56 showed greater increases in maxillary basal width and anterior, middle, and posterior midpalatal suture opening, whereas overall dental expansion was similar between groups. Periodontal bone changes were concentrated around the respective anchor teeth. Airway changes did not differ significantly between groups. Exploratory associations among basal, alveolar, dental, and sutural changes may help describe the pattern of tissue response but do not establish causation. These findings require confirmation in prospective studies with longer follow-up.

List of abbreviations

ANS, anterior nasal spine; BACL, buccal alveolar crest level; BBPT, buccal bone plate thickness; CBCT, cone-beam computed tomography; CVM, cervical vertebral maturation; DICOM, Digital Imaging and Communications in Medicine; ICC, intraclass correlation coefficient; MdBW, mandibular basal width; MxBW, maxillary basal width; MTD, maxillary transverse deficiency; MxABW6, maxillary alveolar bone width at the first molars; NP-MCA, nasopharyngeal minimum cross-sectional area; NPV, nasopharyngeal volume; OP-MCA, oropharyngeal minimum cross-sectional area; OPV, oropharyngeal volume; PBPT, palatal bone plate thickness; PNS, posterior nasal spine; RME, rapid maxillary expansion; T0, pretreatment; T1, end of retention. Measurement-specific abbreviations are defined at first use and in the table notes.

Declarations

Ethics approval and consent to participate

The study was approved by the Clinical Scientific Research Ethics Committee of the School of Stomatology, Lanzhou University (LZUKQ-2025-111). Parental informed consent was obtained for all patients.

Consent for publication

Written consent for publication of the clinical images included in this manuscript was obtained from the parents or legal guardians of the patients shown.

Availability of data and materials

The de-identified numerical data used and/or analysed during the current study are available from the corresponding author on reasonable request, in accordance with institutional data protection requirements. The original CBCT images are not publicly available due to patient privacy.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XG: conceptualization, methodology, CBCT measurements, formal analysis, visualization, and writing – original draft. LL: data collection, CBCT measurements, data curation, and writing – review and editing. FP: methodology, formal analysis, preparation of figures and tables, and writing – review and editing. QZ: data collection, investigation, and writing – review and editing . QH and YG: data collection, CBCT measurements, and writing – review and editing. PC: data validation, interpretation of results, and writing – review and editing. BC: conceptualization, methodology, supervision, and writing – review and editing. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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