Maraabeh et al. BMC Oral Health (2025) 25:456
https://doi.org/10.1186/s12903-025-05835-4

BMC Oral Health

RESEARCH

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Three-dimensional volume changes of the palatal vault and pharyngeal airway following facemask therapy and maxillary expansion: a prospective comparative study

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Abstract

Background This study evaluated three-dimensional volumetric changes in the palatal vault and pharyngeal airway following facemask therapy (FM) with or without slow maxillary expansion (SME) in late mixed and early permanent dentition. Additionally, it compared dimensional changes in the palatal vault, including its length, height, and width.

Materials and methods The sample included 26 patients (16 females, 10 males), aged 10 to 14 years (mean age: 11.88 ± 1.18 years) with Class III malocclusion who had completed facemask therapy, either with or without slow maxillary expansion. Patients were divided into two groups: FM/SME ($n = 13$) and FM ($n = 13$). The palatal vault was subdivided into anterior and posterior sections, and the upper airway was divided into the nasopharynx, velopharynx, and glossopharynx. Changes were assessed using CBCT before (T0) and after (T1) treatment with standardized methods. Statistical analysis included the Shapiro-Wilk test for normality, paired t-test and Wilcoxon signed-rank tests for within-group comparisons, and independent samples t-test and Mann-Whitney tests for between-group comparisons.

Results Both groups exhibited significant increases in total palatal vault volume and posterior palatal vault volume. Nasopharyngeal volume also increased significantly in both groups from T0 to T1, while no significant changes were observed in the lower pharynx (velopharynx and glossopharynx).

Conclusion Both treatment groups demonstrated distinct effects on the palatal vault and nasopharyngeal volume. The FM/SME group yielded a greater increase in the palatal vault volume (16%) compared to the FM group (11.4%); however, this difference was not statistically significant. Combining FM with SME did not yield significant additional effect on the pharyngeal airway volume compared to FM alone, suggesting limited clinical advantage.

Keywords Palatal vault volume, Pharyngeal airway, Facemask therapy, Maxillary expansion, CBCT

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Background

Treating Class III malocclusion poses significant challenges for clinicians. The long-term outcomes of Class III treatment are highly unpredictable [1, 2]. Class III malocclusion can result from a variety of etiological factors. In the Chinese population, the incidence of Class III malocclusion was reported to range between 9.65% and 14.98% in individuals prior to adolescence. Over 70% of skeletal Class III patients exhibit retrognathic maxilla, either with or without a prognathic mandible [3], leading to functional and aesthetic issues. A typical Class III individual exhibits backward and upward rotation of the middle cranial fossa, resulting in a retrusive nasomaxillary complex. Early intervention is crucial to prevent further complications [4]. Facemask therapy (FM) has been used with various appliances and techniques, combination with maxillary expansion has become a routine and effective orthopaedic treatment for correcting both transverse and sagittal maxillary deficiencies in Class III malocclusion patients [5].

Maxillary protraction induces changes in the size and positioning of skeletal and adjacent soft tissues. These changes can enhance airway dimensions through forward maxillary displacement, clockwise mandibular rotation, and counterclockwise palatal plane rotation, leading to soft palate growth and increased velopharyngeal space [6]. Maxillary expansion, often combined with FM, is a widely used and effective treatment for Class III malocclusions. Some authors suggest that loosening the sutural connections of the maxilla with the other nine craniofacial bones during expansion may enhance the efficacy of the FM [7]. Furthermore, the opening of spheno-occipital synchondrosis during maxillary expansion may facilitate the forward and downward movement of the maxilla [8]. While Rapid Palatal Expander (RPE) is well documented for improving nasal airway patency and reducing nasal obstruction [9], its effects on the anteroposterior (AP), height, and volumetric dimensions of the palatal area remain inconclusive [10]. Brunetto et al. compared the effects of slow and rapid maxillary expansion using Hass-type expanders in mixed dentition; they reported that both protocols yielded similar transverse results [11].

The width and the volume of the hard palate are closely correlated with the nasal cavity. Approximately 50% of the structures within the nasal cavity are formed by the maxillary bones, and the nasal cavity alone constitutes half of the total resistance in the upper airway [12]. A high-arched, narrow palatal vault or reduced pharyngeal airway is associated with airway obstruction, which increases the risk of breathing difficulty and exacerbates the likelihood of developing obstructive sleep apnea (OSA) [7, 13, 14]. To our knowledge, no study has yet assessed the impact of FM and Slow Maxillary Expansion (SME) on the palatal vault volume and pharyngeal airway, despite the potential clinical implications for improving palatal and airway dimensions. This study aimed to: (1) compare the effects of FM and FM/SME therapies on the three-dimensional volumes of the palatal vault and pharyngeal airway in the late mixed and early permanent dentition; (2) evaluate changes in skeletal and dental structures in the palatal vault area, including length (AP), palatal height (PH), tallest height (TH), and transverse dental width; and (3) investigate whether application of the SME influences the impact of FM.

Table 1 Comparison of the chronological age, sex distribution, and treatment time

Treatment	*n*	Sex(F/M)	Chronological age (year) Mean ± SD	Treatment time (month) Mean ± SD
FM/SME	13	8/5	12.15 ± 0.99	7.31 ± 1.75
FM	13	8/5	11.62 ± 1.33	9.08 ± 2.72
Total	26	16/10	11.88 ± 1.18	8.19 ± 2.42
p-value		1.000†	0.252‡	0.141‡

Values are presented as mean ± standard deviation

Abbreviations n, number of participants; SD, standard deviation; FM/SME, facemask with maxillary expansion; FM, facemask

†Chi-square test, ‡Independent samples t-tests

Materials and methods

Study design and participants

This prospective, two-group comparative study was conducted at the Department of Orthodontics, School of Stomatology, Affiliated Union Hospital of Tongji Medical College, Wuhan, China, from July 2022 to July 2024. The study was conducted in accordance with the Declaration of Helsinki and approved by the ethical committee of Wuhan Union Hospital (Reference No. 2024 – 0628).

A total of 75 subjects were considered as potentially eligible participants. Of these, 39 were excluded for not meeting the inclusion criteria, and 36 were found eligible. Informed consent forms were obtained from the parents for participation in this study. Based on clinical presentation and treatment needs, patients were allocated into two groups: (1) facemask with slow maxillary expansion (FM/SME, $n = 18$) and (2) facemask group (FM, $n = 18$). During the study, 5 participants were excluded from each group: 4 due to unclear or missing CBCT data, and 1 due to poor cooperation. A total of 26 patients were finally included in the analysis, with 13 patients in each group, as shown in Table 1. The potentially eligible participants were evaluated based on the following inclusion and exclusion criteria:

Inclusion criteria

1. Early permanent or mixed dentition patients aged 10–14 years;

2. Circumpubertal stage of development (CVMS3 + CVMS4 in cervical vertebral maturation) at the initial stage. The assessment was conducted using the methods of McNamara & Franchi [15];
3. Patients with a concave facial profile, skeletal Class III (ANB angle between – 5° and 1°, and Wits appraisal between – 9 mm and – 2 mm);
4. Patients with slow-banded maxillary expansion (Hass type, expansion protocol: twice a week);
5. The availability of pre-treatment (T0) CBCT scans with complete and clear imaging.

Exclusion criteria

1. Patients with poor cooperation;
2. Previous orthodontic treatment;
3. Patients with any craniofacial anomaly, such as cleft lip and palate;
4. Patients with incomplete or missing records;
5. Patients with unclear CBCT or incomplete imaging of the upper airway.

To ensure consistency and reliability in treatment outcomes, only patients with unilateral crossbite undergoing slow maxillary expansion were included. Patients with bilateral posterior crossbite were excluded to maintain sample homogeneity and avoid variability in treatment protocols. Such cases often involve severe transverse discrepancies that require alternative approaches, which could potentially confound the results.

Data collection

CBCT images were obtained at two time points: pre-treatment (T0) and immediately post-treatment (T1) using the CS 9300 C machine (Carestream Dental, USA) with the following scanning protocol: 60–90 kV, 2–15 mA, an exposure time of 6.4 s, a voxel size of 90–500 µm, and a field of view of 17 × 11 cm. The patient was positioned in an upright and natural head position.

CBCT landmark identification

CBCT DICOM data were imported into ITK-SNAP 4.0.2 (Pennsylvania, USA), a software tool for medical image segmentation and visualization, in DICOM image series format. The following methods were carried out in four steps. First, to standardize measurements and minimize errors, all DICOM images were manually reoriented using the Frankfort Horizontal Plane (FH) as a reference before segmentation. The FH plane was constructed from the right porion (the most latero-superior point of the external auditory meatus) and the right orbitale. In the lateral view, the FH plane was made parallel to the floor; in the frontal view, the head was oriented so that the floor of the orbits parallel was parallel to the floor; in the axial view, the plane passed through the Crista galli to the Basion.

Second, the area of interest for palatal vault volume (shown in Fig. 1) was defined using the patient's mid-sagittal plane, determined by the anterior midpoint of the maxillary central incisors and the posterior midpoint of the spine. The palatal volume borders were delineated as follows: (1) the superior border, determined as the most superior point of the palatal vault on the mid-sagittal image; (2) the inferior border, delineated as the inferior cemento-enamel junction (CEJ) of the right central incisors, minimizing the influence of buccal tipping on the measurement; (3) the anterior border, defined as the inferior CEJ of the central incisors; (4) the posterior border, identified as the most posterior point of the bony hard palate (PNS); and (5) the lateral borders, established on the axial section by the most mesial aspect of the first molars at the CEJ (Fig. 1G). Furthermore, to achieve comparable values between T0 and T1, the palatal vault volume was divided into anterior and posterior sections at the most distal aspect of the upper first molar crown, thus separating the anterior and posterior volumes. The AP length was measured as the length of the inferior margin of the palatal crude prism in the PA direction and divided into anterior and posterior palatal vault lengths (Fig. 1D). The molar-to-molar width was calculated as the distance between the CEJ of the upper first molars at the level of the palatal root orifice. The inter-premolar width and canine-to-canine width were measured from CEJ to CEJ of the premolars and canines, respectively. The height of the palatal vault was assessed from the superior border of the palate to the inferior border of the crude prism, which is a line parallel to the Frankfort plane passing through the CEJ of the right central incisor at two locations: (1) the palatal height (PH) measured at the coronal plane level of the palatal root orifice of the upper right first molar and (2) the tallest height (TH) measured at the absolute highest point in the palatal vault area. A study by Gohl et al. [10] used similar boundaries.

Third, the boundaries for the sub-regional pharyngeal airway were defined, including the nasopharynx, velopharynx, and glossopharynx (with the velopharyngeal and glossopharyngeal airways collectively referred to as the oropharyngeal airway). The airway margins were derived from previous studies [16, 17] and were defined as follows: superior: soft tissue contour of the pharyngeal wall, as a transverse plane parallel to FH intersecting the root of the clivus (the last slice before the fusion of the nasal septum with the posterior wall of the pharynx); inferior: a plane parallel to FH that intersecting the apex of the epiglottis; anterior: a frontal plane perpendicular to FH passing through PNS; posterior: the posterior wall of the pharynx; and lateral: the lateral pharyngeal walls (Fig. 2). Fourth, the various volumetric measures were

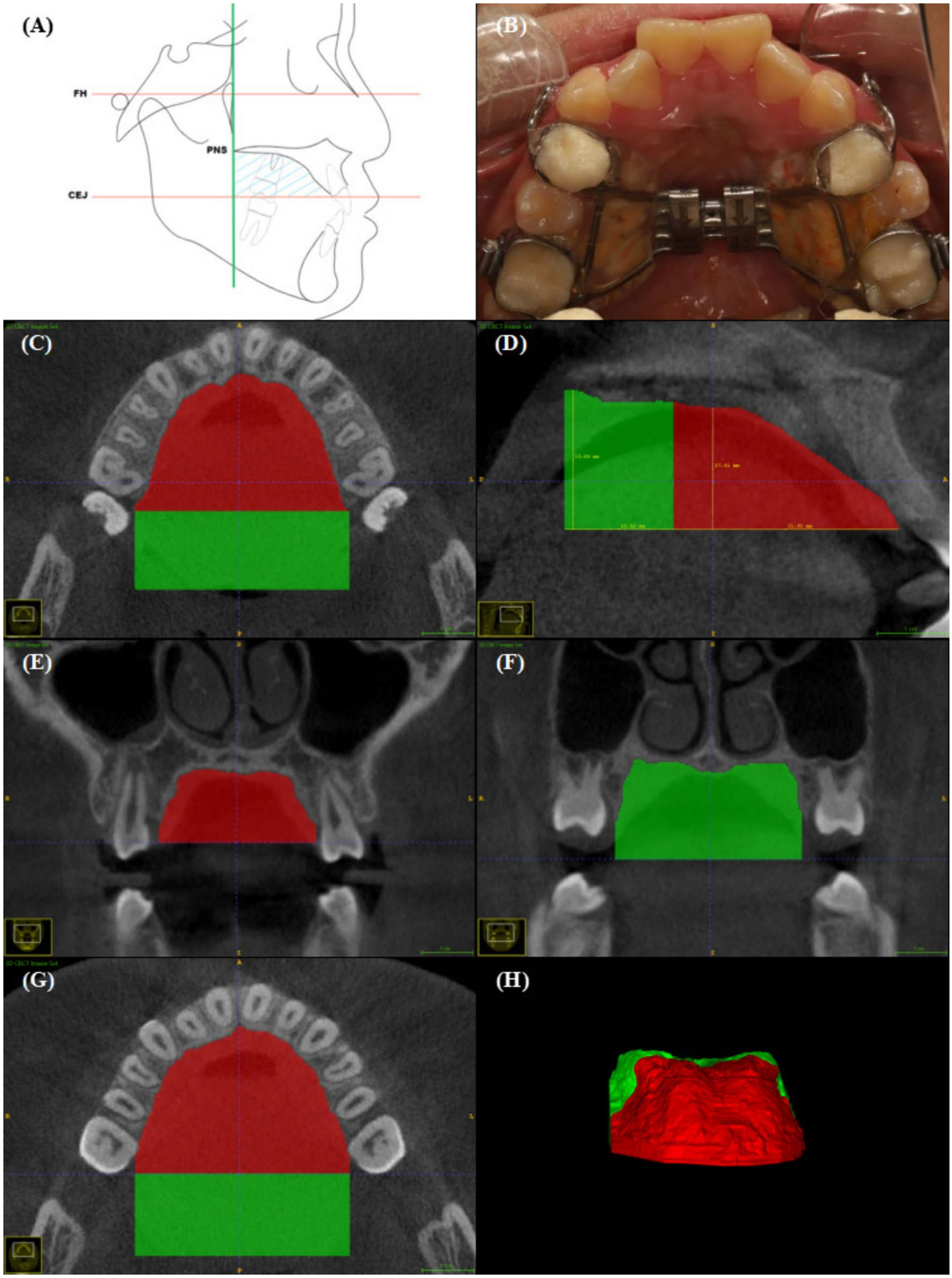

Fig. 1 Diagrammatic representation of the landmarks. **(A)** Showing the landmarks: FH, Frankfort horizontal plane; PNS, posterior nasal spine; CEJ, a line parallel to FH that goes through the cemento-enamel junction of the central incisor; **(B)** Intraoral photograph of the appliance; **(C)** Axial section at the level of the palatal orifice of the upper first molars, used to define the coronal view shown in (D); **(D)** Mid-sagittal section showing the anatomical palatal vault volume, including the inferior, anterior, and posterior borders. The total AP length, the height of the palatal vault at the fixed coronal plane (defined by the horizontal blue line in (C)), and the tallest palatal vault height; **(E)** Coronal section of the anterior palatal vault volume; **(F)** Coronal section of the posterior palatal vault volume; **(G)** The horizontal blue line defined as the most distal portion of the upper first molar crown, which separates the anterior (red) and posterior (green) palatal vault volumes. The lateral borders of the palatal volume defined by the most mesial portion of the first molars at the CEJ; **(H)** Anterior view of the 3D volume

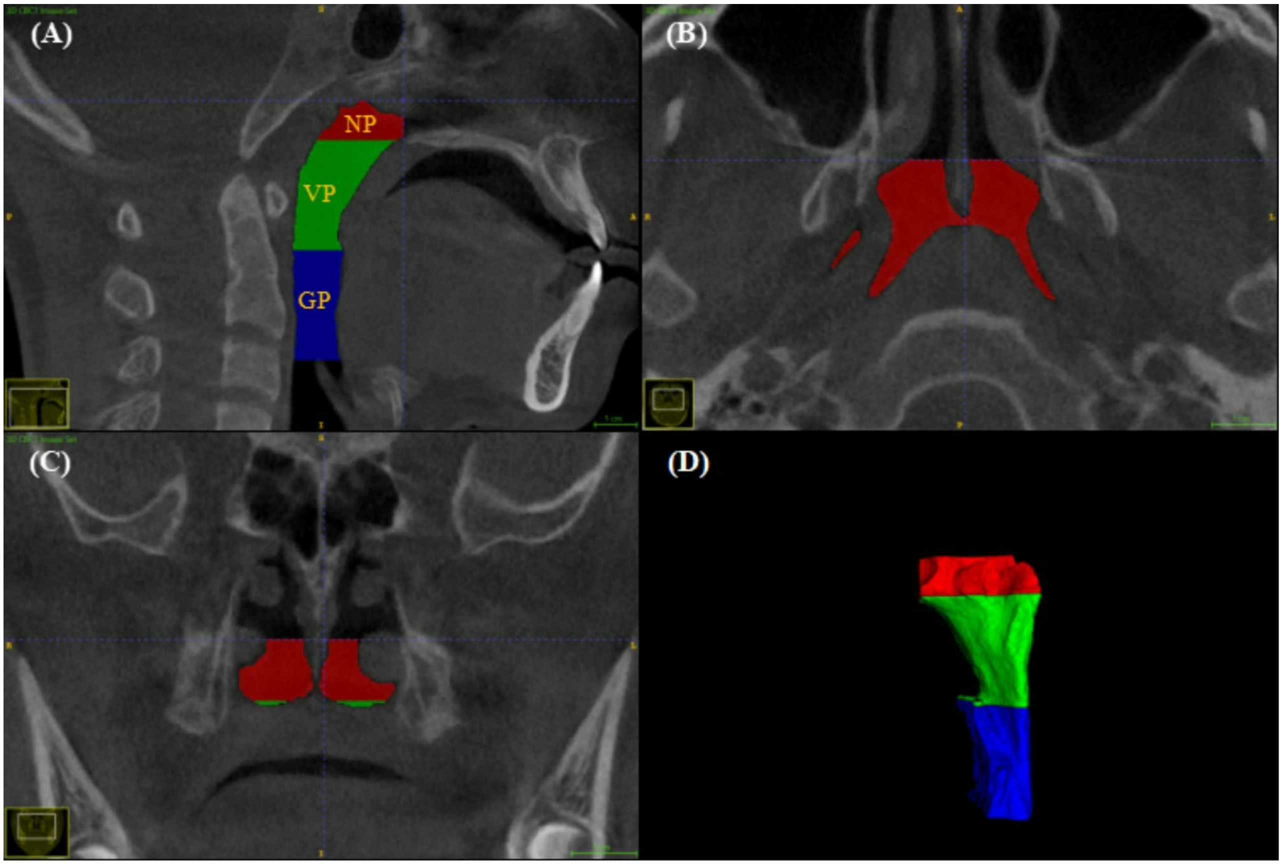

Fig. 2 Segmentation of the pharyngeal volume by ITK-SNAP. **(A)** Pharyngeal volume segmentation showing the nasopharynx in red (lower margin: plane parallel to the FH passing through the PNS and extending to the posterior wall of the pharynx), the velopharynx in green (lower margin: plane parallel to the FH passing through the lowermost part of the soft palate), and the glossopharynx in blue (lower margin: plane parallel to the FH passing through the apex of the epiglottis). The horizontal line in is parallel to the FH line, and the vertical line is perpendicular to the FH line passing through the PNS (anterior border). This view is used to define the axial and coronal views shown in (B) and (C), respectively; **(B)** The last slice before the fusion of the nasal septum with the posterior pharyngeal wall, marking the superior border; **(C)** The first slice posterior to PNS, marking the anterior border; **(D)** Lateral view of the 3D segmentation volume

calculated semi-automatically by segmenting the area of interest and locating "seed points" in sagittal, coronal, and axial views by visual inspection using threshold mode to identify and separate the area of interest from the surrounding tissue, followed by human re-evaluation. To improve accuracy, individual heights, lengths, and widths were measured twice, and the mean values were used for the analysis.

Treatment protocol

Patients were given facemask (tooth-borne, Petit type). The hooks were positioned in the canine region, and elastics were attached at a 15–30° downward angle to the occlusal plane. Elastic size was customized to provide 400–450 g of traction force per side. An illustration of the appliance is shown in Fig. 1B. Patients were instructed to wear the appliance for at least 12 h per day (after school and during sleep) and remove it for meals and sports. They were also advised to replace the elastics daily or whenever one was lost. All patients were treated until a positive dental overjet was achieved, after which treatment was discontinued, and the second phase of the orthodontic treatment was initiated. In the expansion group, maxillary expanders were banded to the first molars and first premolars. Patients were instructed to activate the expander once (0.25 mm) every 2–3 days until overexpansion was achieved.

Statistical analysis

The sample size was calculated using G*Power (version 3.1.9.7, Franz Faul, Universität Kiel, Germany), based on palatal volume changes observed in the treatment group in a previous study [18]. A total of 12 subjects were required to detect significant palatal volume changes with 95% power ($\alpha = 0.05$). The Shapiro-Wilk test was used to assess data normality. Descriptive statistics were calculated for all variables. Intragroup differences were analyzed using a paired t-test, while intergroup comparisons were performed using an independent samples t-test. For non-normally distributed data, the Wilcoxon

Table 2 Comparison of the initial cephalometric measurements at pre-treatment (T0)

Variable	FM/SME Group	FM Group	
	Mean ± SD	**Mean ± SD**	***p*-value‡**
SNA (°)	78.77 ± 2.92	80.83 ± 3.07	0.184
SNB (°)	80.16 ± 2.75	81.36 ± 2.99	0.298
ANB (°)	-1.39 ± 1.86	-0.96 ± 1.94	0.503¶
Co-A (mm)	75.76 ± 3.49	75.05 ± 3.05	0.583
Co-Gn (mm)	108.55 ± 4.28	104.04 ± 4.51	0.015*
Wits (mm)	-4.87 ± 2.15	-5.95 ± 2.08	0.204
U1/FH (°)	116.78 ± 4.64	114.69 ± 5.77	0.165¶
L1/MP (°)	86.99 ± 5.43	87.94 ± 9.95	0.766
MP-FH (°)	25.42 ± 3.57	25.44 ± 4.03	0.988

Values are presented as mean ± standard deviation

Abbreviations FM/SME, facemask with maxillary expansion; FM, facemask

‡Independent samples t-test; ¶Mann-Whitney test; SD, standard deviation; NS, non-significant, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

signed-rank test and Mann-Whitney test were applied. All statistical analyses were performed using GraphPad Prism (version 9.5.0, GraphPad Software, USA) and MedCalc (version 23.0.8, MedCalc Software Ltd, Belgium) for Windows. Results were considered statistically significant at $p < 0.05$. Additionally, the intraclass correlation coefficient (ICC) was used to assess intra-operator reliability for volume measurements. All measurements were carried out by a single calibrated operator, with repeated measurements performed at a two-week interval to evaluate consistency. The ICC values ranged from 0.95 to 0.98, with no statistically significant differences observed between the test-retest measurements.

Results

There were no statistically significant differences in chronological age, sex distribution, or treatment time between the groups (Table 1). The mean chronological age was slightly greater in the FM/SME group (12.15 ± 0.99 years) compared to the FM group (11.62 ± 1.33 years) ($p > 0.05$). Both groups had an equal sex distribution, with 8 females and 5 males each. The mean treatment time was slightly higher in the FM group (9.08 ± 2.72 months) compared to the FM/SME group (7.31 ± 1.75 months) ($p > 0.05$). Table 2 shows a comparison of the initial cephalometric measurements. No significant differences were observed between the groups at T0, except for Co-Gn.

Changes in the palatal vault volume and dimensions after treatment

Table 3 summarizes the palatal vault volume changes within and between the two groups. The increase in total PVV from T0 to T1 was statistically significant in both groups, with no significant differences between them. The mean percentage change was 16.02% ± 10.46 in the FM/SME group and 11.43% ± 4.81 in the FM group, with

Table 3 Evaluation of the palatal vault and pharyngeal airway volume changes

	FM/SME (mm^3)	FM (mm^3)	*p*-value†
Total PVV			
T0	14826.08 ± 2142.97	14679.31 ± 2028.79	0.859
T1	17250.15 ± 3295.37	16369.00 ± 2564.95	0.511¶
(ΔT1-T0)	2424 ± 1679	1690 ± 843.3	0.172
p-value‡	< 0.001***§	< 0.001***	
Anterior PVV			
T0	9034.69 ± 1216.41	8950.62 ± 1260.80	0.864
T1	9513.62 ± 1469.01	8602.31 ± 1556.82	0.138
(ΔT1-T0)	478.9 ± 983.9	-348.3 ± 865.1	0.032*
p-value‡	0.105	0.172	
Posterior PVV			
T0	5791.38 ± 1726.62	5728.69 ± 1340.12	0.762¶
T1	7736.54 ± 2222.65	7766.69 ± 1866.86	0.970
(ΔT1-T0)	1945 ± 1093	2038 ± 752.2	0.803
p-value‡	< 0.001***§	< 0.001***	
Total pharyngeal volume			
T0	18376.92 ± 4591.64	14361.46 ± 5657.35	0.058
T1	20350.54 ± 4512.63	16008.85 ± 4535.38	0.022*
(ΔT1-T0)	1974 ± 3628	1647 ± 2370	0.788
p-value‡	0.073	0.028*	
Oropharyngeal volume			
T0	13484.77 ± 3558.96	10231.31 ± 4370.43	0.048*
T1	14379.69 ± 3922.55	11224.77 ± 3477.85	0.040*
(ΔT1-T0)	894.9 ± 2757	993.5 ± 2432	0.924
p-value‡	0.265	0.167	
Nasopharyngeal volume			
T0	4892.15 ± 1799.60	4130.15 ± 1577.93	0.262
T1	5970.85 ± 1627.54	4784.08 ± 1716.86	0.083
(ΔT1-T0)	1079 ± 1695	653.9 ± 506	0.395
p-value‡	0.041*	< 0.001***	
Velopharyngeal volume			
T0	8703.77 ± 2055.38	6395.15 ± 2466.38	0.016*
T1	9241.85 ± 2236.23	7199.08 ± 2203.03	0.028*
(ΔT1-T0)	538.1 ± 1658	803.9 ± 1405	0.663
p-value‡	0.265	0.061	
Glossopharyngeal volume			
T0	4781.00 ± 2272.66	3836.15 ± 2314.53	0.091¶
T1	5137.85 ± 2342.79	4025.69 ± 1541.81	0.166
(ΔT1-T0)	356.8 ± 1483	189.5 ± 1365	0.767
p-value‡	0.414§	0.414§	

Values are presented as mean ± standard deviation

Abbreviations FM/SME, facemask with maxillary expansion; FM, facemask; PVV, palatal vault volume; AP, anterio-posterior

†Independent samples t-test; ‡Paired t-test; §Wilcoxon test; ¶Mann-Whitney test

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

no significant differences between them. The anterior palatal vault volume increased in the FM/SME group but decreased in the FM group. While within-group changes were not statistically significant, the between-group difference was significant. The posterior vault volume increased significantly from T0 to T1 in both groups, with no significant differences between them.

Table 4 presents the changes in the palatal vault height, length, and width. Both palatal height and tallest height showed no significant changes from T0 to T1, except for the tallest height in the FM group. No statistically significant differences were observed between the two groups. The total AP length increased significantly in both groups after treatment, with a significant between-group difference ($p < 0.01$). The anterior part length showed a statistically significant decrease in the FM/SME group, whereas the decrease in the FM group was not statistically significant. However, no statistically significant differences were observed between them. In contrast, the posterior part length showed a statistically significant increase between T0 and T1 in both groups (Table 4). At T0, no significant differences were observed between the two groups for any of these variables.

Table 4 Evaluation of the palatal vault height, length, and width changes

	FM/SME (mm)	FM (mm)	*p*-value†
Palatal height			
T0	15.38 ± 1.33	15.23 ± 1.67	0.798
T1	15.75 ± 1.85	15.58 ± 2.12	0.830
(ΔT1-T0)	0.37 ± 1.63	0.36 ± 0.81	0.410¶
p-value‡	0.426	0.139	
Tallest height			
T0	16.33 ± 1.29	16.31 ± 1.63	0.974
T1	17.02 ± 1.99	16.83 ± 2.08	0.815
(ΔT1-T0)	0.69 ± 1.49	0.52 ± 0.83	0.830¶
p-value‡	0.121	0.043*	
AP length			
T0	39.57 ± 2.96	37.96 ± 3.77	0.236
T1	40.62 ± 2.78	40.12 ± 3.68	0.695
(ΔT1-T0)	1.05 ± 0.89	2.16 ± 0.82	0.003**
p-value‡	0.001**	< 0.001***	
Anterior part length			
T0	28.95 ± 2.26	27.87 ± 2.53	0.266
T1	28.01 ± 2.54	27.35 ± 3.07	0.552
(ΔT1-T0)	-0.93 ± 1.50	-0.53 ± 1.35	0.474
p-value‡	0.044*	0.184	
Posterior part length			
T0	10.63 ± 2.56	10.08 ± 2.21	0.569
T1	12.61 ± 2.30	12.77 ± 2.47	0.868
(ΔT1-T0)	1.99 ± 1.28	2.69 ± 1.06	0.142
p-value‡	< 0.001***	< 0.001***	
Inter-molar width			
T0	35.48 ± 3.16	36.75 ± 2.01	0.231
T1	38.38 ± 2.62	37.35 ± 2.15	0.284
(ΔT1-T0)	2.91 ± 1.98	0.60 ± 0.99	< 0.001***¶
p-value‡	< 0.001***	0.049*	
Inter-premolar width			
T0	27.03 ± 1.97	28.96 ± 3.25	0.081
T1	29.70 ± 1.62	28.82 ± 3.27	0.397
(ΔT1-T0)	2.66 ± 1.59	-0.13 ± 1.19	< 0.001***
p-value‡	< 0.001***	0.690	
Inter-canine width			
T0	23.28 ± 2.71	24.43 ± 2.36	0.292
T1	24.55 ± 2.23	24.75 ± 2.10	0.831
(ΔT1-T0)	1.27 ± 1.01	0.33 ± 0.87	0.025*
p-value‡	0.002**	0.221	

Values are presented as mean ± standard deviation

Abbreviations: FM/SME, facemask with maxillary expansion; FM, facemask; AP, anterio-posterior

†Independent samples t-test; ‡Paired t-test; ¶Mann-Whitney test

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Changes in the pharyngeal airway volume after treatment

The total pharyngeal volume increased significantly from T0 to T1 in the FM group ($p < 0.05$), but this increase was not statistically significant in the FM/SME group. The nasopharyngeal volume increased significantly from T0 to T1 in both groups, with no significant differences between the groups. However, oropharyngeal, velopharyngeal, and glossopharyngeal volumes did not show significant changes from T0 to T1 (Table 3). The total oropharyngeal and velopharyngeal volumes were significantly larger in the FM/SME group than in the FM group at both T0 and T1. Although the FM group showed a greater mean volume increase in both oropharyngeal and velopharyngeal volumes, the difference between the groups was not statistically significant.

Discussion

The findings revealed volumetric and dimensional changes in the palatal vault and airway following late FM and SME (Haas-type appliance), with significant differences between the groups. Notably, patients who underwent FM/SME therapy exhibited a greater increase in the total palatal vault volume compared to those who received FM therapy alone. Moreover, the nasopharyngeal volume increased significantly in both groups. In addition, a significant increase in the total pharyngeal volume was observed only in the FM group ($p < 0.05$).

Numerous studies have used laser-scanned records or digital modalities to evaluate changes in the palatal area by creating 3D reconstructions from scanned models. However, the reliability of these methods for obtaining accurate 3D data remains unclear [19]. Furthermore, dental casts may contain minor inaccuracies associated with impression and model pouring [20]. A 3D CBCT assessment has the potential to accurately describe the palatal morphology, as well as skeletal and dental changes.

Few studies have examined the effect of FM, SME, or their combination on the palatal vault volume, which poses challenges for direct comparison. At the beginning of the treatment, the FM/SME group presented slightly greater palatal vault volumes than the FM group, although the FM group had greater transverse widths. However, the FM/SME group had a greater AP length, which might have partly accounted for the slightly greater volume.

The increase in total palatal vault volume (PVV) from T0 to T1 was statistically significant in both groups: 2424 ± 1679 mm^3 (FM/SME, $p < 0.001$) and 1690 ± 843.3 mm^3 (FM group, $p < 0.001$). However, no significant differences were observed between the two groups. The mean percentage of change in PVV was 16.02% for the FM/SME group and 11.43% for the FM group ($p > 0.05$). In a previous study using similar methods [10], the mean percentage of change in palatal volume (total palatal volume in our study) was 10.8% in the control group and 21.7% in the RPE group. While these results suggest that RPE may achieve a greater increase in palatal volume compared to a control group, our study evaluated FM/SME. Therefore, differences in treatment conditions should be considered, and direct comparisons should be made with caution, as the addition of FM may influence the results.

The anterior palatal vault volume showed a non-significant mean increase in the FM/SME group (478.9 ± 983.9 mm^3), while the FM group showed a non-significant mean decrease (-348.3 ± 865.1 mm^3). This may be attributed to the mesial tipping of the first molar. The difference between the two groups was statistically significant ($p < 0.05$), highlighting the potential additional impact of maxillary expansion. Similar results were observed in a study using digital models after slow maxillary expansion (Hass) in early mixed dentition [18]. In that study, palatal volume (specifically anterior palatal volume, as in our study) was significantly greater compared to controls after expansion ($p < 0.001$), while the effect in the control group was minimal. Another study showed that nonsurgical maxillary expansion is still able to affect the palatal morphology in adults and significantly increase the palatal volume (anterior palatal volume in our study) [21].

The increase in the posterior vault volume from T0 to T1 was statistically significant in both groups, although no significant differences were found between the two groups. No previous studies have compared findings related to posterior vault volume. Existing studies have utilized different methodologies to calculate the palatal vault volume, with many of them focusing on the anterior region, likely due to the difficulty in identifying the posterior nasal spine (PNS) in the methods applied. Previous studies have emphasized the clinical relevance of palatal volume changes, suggesting that maxillary expansion may lead to nasal wall divergence, which in turn may widen the anterior part of the oropharynx [22, 23]. In addition, it can modify the shape of the palate for better tongue support and positioning, which may reduce the airway resistance, as lower and posterior tongue displacement has been linked to airway obstruction and pharyngeal collapse. Previous studies showed that Class III patients exhibit significantly lower tongue posture as compared to Class I [20, 24, 25]. Furthermore, there is a negative correlation between the palatal volume and soft palate area, which is a strong etiological factor in patients with OSA [13]. The significant increase in the palatal vault volume, particularly in the posterior region, suggests a positive impact on maxillary morphology and arch dimensions, which may enhance oral function by optimizing tongue posture and reducing airway resistance.

In addition to the volumetric changes in the palate vault, we also observed alterations in its height, length, and width, which are critical factors in evaluating overall palatal morphology. Both the palatal height and the tallest height showed no significant changes from T0 to T1, except for the tallest height in the FM group ($p < 0.05$). Similar results were obtained by Gohl et al. [10], they found no significant differences in palatal vault height at the first molar level on CBCT. Additionally, dental casts may impact the height measurements due to thinning of the palatal soft tissues due to growth or stretching the tissue during expansion.

The AP length increased significantly in both groups after treatment (1.05 ± 0.89 mm ($p < 0.01$) and 2.16 ± 0.82 mm ($p < 0.001$) for the FM/SME and FM groups, respectively), with a significant difference between the two groups ($p < 0.01$). However, clinically, this difference may not be significant. The anterior part length showed a decrease in the mean difference between T0 and T1 in both groups (-0.93 ± 1.50 mm ($p < 0.05$) and -0.53 ± 1.35 mm ($p > 0.05$) for the FM/SME and FM groups, respectively). This can probably be attributed to the mesial tipping of the upper first molar due to the protraction force applied by the FM. The posterior part length significantly increased from T0 to T1 in both groups, with a mean difference of (1.99 ± 1.28 mm ($p < 0.001$) and 2.69 ± 1.06 mm ($p < 0.001$) for the FM/SME and the FM groups, respectively), with no significant differences between the two groups. No previous studies are available for comparison.

Many studies have examined the effects of maxillary protraction on the pharyngeal airway. However, results have been inconsistent due to the use of 2D imaging, which lacks accuracy in assessing this complex region. Additionally, the lack of an untreated matched control group presents a challenge, as it is considered unethical to deny patients access to intervention in such critical conditions. Our results revealed a significant increase in the total pharyngeal airway volume in the FM group. In agreement with our findings, some studies have reported significant changes only in the nasopharynx [26, 27]. According to a systematic review by Ming et al. [28], post-palatal and nasopharyngeal airway dimensions significantly increased after maxillary protraction in growing Class III patients, and protraction appliances might have the potential to diminish the risk of OSAS in children with maxillary retrusion by broadening the airway space. In contrast, other studies found no significant correlation between FM and airway changes [29, 30].

Our 3D analysis revealed a significant increase in the nasopharyngeal volume in both groups. However, the difference between them was not statistically significant. This increase may result from the combined effect of increased space for the tongue, clockwise rotation of the mandible, and the soft palate, which are influenced by positional changes of the maxilla and its interaction with the tongue [31]. In agreement with a systematic review by Martin et al. [32], no significant changes were observed in the lower pharynx (velopharynx and glossopharynx) in either group. Similar results were obtained by Pamporakis et al. [33] and Husson et al. [29], which concluded that FM/RME therapy and FM exert no additional effects on the oropharyngeal airway beyond those caused by growth. However, we observed a non-significant increase, which may be influenced by growth-related factors, differences in segmentation protocols, or inconsistencies in head and tongue positioning.

The increase in the oropharyngeal volume from T0 to T1 was not statistically significant in either group, and no significant differences were found between the groups. In agreement with our study, previous studies found that maxillary expansion induces a significant increase in nasal passage volume, but no significant changes were noted in the oropharyngeal airway region compared with controls [34, 35], while other studies reported a significant increase in nasal cavity volume and nasopharynx volume and a non-significant decrease in the volume of the oropharynx following maxillary expansion [36]. These findings suggest that airway improvement may result from nasal cavity widening and reduced airflow resistance, as several studies have reported significant increases in nasal floor width and the nasal cavity volume after treatment. However, the impact of expansion on the pharyngeal airway remains controversial. Recent studies have indicated that these changes may also be influenced by natural growth and the regression of the adenotonsillar tissues. As a result, clinicians should interpret airway improvements cautiously [22, 37], and FM/SME should be guided by its orthopedic benefits rather than expectations of airway improvement.

Limitations

First, the study did not evaluate long-term post-treatment outcomes. While significant short-term improvements were observed, it remains uncertain whether these changes are sustained over time. Additionally, the limited research on the impact of FM/SME on the palatal vault complicates direct comparisons with previous studies. Furthermore, the absence of a control group limits the ability to differentiate treatment effects from natural growth. Future studies should focus on the long-term outcomes, stability of changes, and larger sample sizes to ensure more generalizable conclusions. Comparisons between FM/SME and FM/RME at different skeletal maturation stages would further clarify the relative effectiveness of these techniques.

Conclusion

Both treatments demonstrated distinct effects on the palatal vault volume, with the FM/SME group yielding a greater effect (16%) compared to the FM group (11.4%), although this difference was not statistically significant. Both groups showed a significant increase in nasopharyngeal volume, with no significant effect on the lower pharynx (velopharynx and glossopharynx). In late treatment, the combination of FM and SME did not result in any additional significant effects on pharyngeal airway volume and remained comparable to FM alone. Additionally, the increase in transverse dental measurements after expansion was greater posteriorly, while FM was more effective than FM/SME at increasing the anteroposterior (AP) length.

Abbreviations

FM	Facemask Appliance
SME	Slow Maxillary Expansion
RPE	Rapid Palatal Expander
RME	Rapid Maxillary Expansion
OSA	Obstructive Sleep Apnea
3D	Three Dimensional
FH	Frankfort Horizontal Plane
AP	Anterio-posterior
PH	Palatal Height
TH	Tallest Height
PVV	Palatal Vault Volume

Acknowledgements

Not applicable.

Author contributions

Fakhr Maraabeh (F.M.); Ramy Shihabi (R.S.); Xianzhe He (X.H.); Jiaqi Zhan (J.Z.); Jiaqi Zhang (J.Z.G.); Li Hu (L.H.); Li-li CHEN (L.L.C.).F.M. conducted the methodology, collected the data, prepared the figures and tables, and drafted the original manuscript. F.M. and R.S. performed the statistical analysis. L.H. and L.L.C. provided supervision. F.M., R.S., X.H., J.Z., J.Z.G., L.H., and L.L.C. reviewed and edited the manuscript. All authors read and approved the final manuscript.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: funded by China Oral

Health Foundation (No. A2023-009 to Li Hu) and by Hubei Provincial Natural Science Foundation of China (2022CFB236 to Li Hu).

Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethics approval was obtained from the ethical committee of Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. (Reference No. 2024 – 0628). An informed consent form was obtained from the participants' parents for participation in this trial. The study was performed in accordance with the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 22 December 2024 / Accepted: 18 March 2025
Published online: 29 March 2025

References

1. Tripathi T, Rai P, Singh N, Kalra S. A comparative evaluation of skeletal, dental, and soft tissue changes with skeletal anchored and conventional facemask Protraction therapy. J Orthod Sci. 2016;5(3):92–9.
2. Lucchi P, Rosa M, Bruno G, De Stefani A, Zalunardo F, Gracco A. Difference in using protrusion face mask before or after rapid palatal expansion in skeletal class III children: A preliminary study. Child (Basel). 2022;9(10).
3. Chen L, Chen R, Yang Y, Ji G, Shen G. The effects of maxillary Protraction and its long-term stability–a clinical trial in Chinese adolescents. Eur J Orthod. 2012;34(1):88–95.
4. Aboulfotouh M, Attia k, ElFeky H. Three-dimensional effects of maxillary Protraction on pharyngeal airway. Egypt Dent J. 2021;67(1):71–8.
5. Kale B, Buyukcavus MH. Determining the short-term effects of different maxillary Protraction methods on pharyngeal airway dimensions. Orthod Craniofac Res. 2021;24(4):543–52.
6. Mirhashemi SAGH, Bahrami R. Evaluation the effect of maxillary Protraction on the airway dimensions: A review. J Craniomaxillofac Res. 2022;8(4):164–71.
7. Cifter M, Ekmen O, Gumru Celikel AD, Tagrikulu B, Erbay E. Does the face mask increase the impact of rapid maxillary expansion on sagittal airway dimensions? Eur Oral Res. 2023;57(1):28–35.
8. Leonardi R, Ronsivalle V, Lagravere MO, Barbato E, Isola G, Lo Giudice A. Three-dimensional assessment of the spheno-occipital synchondrosis and clivus after tooth-borne and bone-borne rapid maxillary expansion. Angle Orthod. 2021;91(6):822–9.
9. Williams R, Patel V, Chen YF, Tangbumrungtham N, Thamboo A, Most SP, et al. The upper airway nasal complex: structural contribution to persistent nasal obstruction. Otolaryngology–Head Neck Surg. 2019;161(1):171–7.
10. Gohl E, Nguyen M, Enciso R. Three-dimensional computed tomography comparison of the maxillary palatal vault between patients with rapid palatal expansion and orthodontically treated controls. Am J Orthod Dentofac Orthop. 2010;138(4):477–85.
11. Ayub PV, Garib DG, Ebrahim H, Polido J, Blasca W, Yen S. Intercenter comparison of slow and rapid maxillary expansion in unilateral complete cleft lip and palate. Dent Press J Orthod. 2022;27(3).
12. de Julian-Lopez C, Veres J, Marques-Martinez L, Garcia-Miralles E, Arias S, Guinot-Barona C. Upper airway changes after rapid maxillary expansion: three-dimensional analyses. BMC Oral Health. 2023;23(1):618.
13. Kecik D. Three-dimensional analyses of palatal morphology and its relation to upper airway area in obstructive sleep apnea. Angle Orthod. 2017;87(2):300–6.
14. Ashraf A, Menon I, Gupta R, Arora V, Ahsan I, Das D. Oral findings as predictors of obstructive sleep apnea- A case-control study. J Family Med Prim Care. 2022;11(9):5263–7.
15. Franchi L, McNamara JA. The cervical vertebral maturation method: A user's guide. Angle Orthod. 2018;88(2):133–43.
16. Guijarro-Martinez R, Swennen GR. Three-dimensional cone beam computed tomography definition of the anatomical subregions of the upper airway: a validation study. Int J Oral Maxillofac Surg. 2013;42(9):1140–9.
17. Jessadapornchai T, Samruajbenjakun B, Chanmanee P, Chalidapongse P. 3D analysis of upper airway morphology related to obstructive sleep apnea severity. J World Federation Orthodontists. 2024;13(4):175–80.
18. Yen E, Aleksejūnienė J, Hannam A, Kennedy D, Bukhari A. Dimensional changes in the palate associated with slow maxillary expansion for early treatment of posterior crossbite. Angle Orthod. 2018;88(4):390–6.
19. Abdelsalam R, Nucci L, Carrino R, Shahen S, Abdelaziz F, Fahim F, et al. Comparison of palatal volume and surface changes between bone-borne and tooth-tissue-borne maxillary expansion on cone beam computed tomography digital cast models. Angle Orthod. 2023;93(3):282–8.
20. Saadeh ME, Ghafari JG. Uniformity of palatal volume and surface area in various malocclusions. Orthod Craniofac Res. 2022;26(1):72–80.
21. Türker G, Çoban G, Bayraktar AÜ, Kurt G, Kılıç E, Alkan A. Three-dimensional palatal morphology and upper arch changes following nonsurgical and surgical maxillary expansion in adults. Oral Surg Oral Med Oral Pathol Oral Radiol. 2022;134(4):425–31.
22. Ronsivalle V, Leonardi R, Lagravere M, Flores-Mir C, Grippaudo C, Alessandri Bonetti G, et al. Medium-term effects of rapid maxillary expansion on nasal cavity and pharyngeal airway volumes considering age as a factor: A retrospective study. J Dent. 2024;144:104934.
23. Galeotti A, Gatto R, Caruso S, Piga S, Maldonato W, Sitzia E et al. Effects of rapid palatal expansion on the upper airway space in children with obstructive sleep apnea (OSA): A Case-Control study. Child (Basel). 2023;10(2).
24. Vinha PP, Thuler ER, de Mello-Filho FV. Effects of surgically assisted rapid maxillary expansion on the modification of the pharynx and hard palate and on obstructive sleep apnea, and their correlations. J Craniomaxillofac Surg. 2020;48(4):339–48.
25. Primozic J, Farcnik F, Perinetti G, Richmond S, Ovsenik M. The association of tongue posture with the Dentoalveolar maxillary and mandibular morphology in class III malocclusion: a controlled study. Eur J Orthod. 2012;35(3):388–93.
26. Sayinsu K, Isik F, Arun T. Sagittal airway dimensions following maxillary Protraction: a pilot study. Eur J Orthod. 2006;28(2):184–9.
27. Kaygisiz E, Tuncer BB, Yuksel S, Tuncer C, Yildiz C. Effects of maxillary Protraction and fixed appliance therapy on the pharyngeal airway. Angle Orthod. 2009;79(4):660–7.
28. Ming Y, Hu Y, Li Y, Yu J, He H, Zheng L. Effects of maxillary Protraction appliances on airway dimensions in growing class III maxillary retrognathic patients: A systematic review and meta-analysis. Int J Pediatr Otorhinolaryngol. 2018;105:138–45.
29. Husson AH, Burhan AS, Hajeer MY, Nawaya FR. Three-dimensional oropharyngeal airway changes after facemask therapy using low-dose computed tomography: a clinical trial with a retrospectively collected control group. Prog Orthod. 2021;22(1):50.
30. Baccetti T, Franchi L, Mucedero M, Cozza P. Treatment and post-treatment effects of facemask therapy on the sagittal pharyngeal dimensions in class III subjects. Eur J Orthod. 2010;32(3):346–50.
31. Lee JW, Park KH, Kim SH, Park YG, Kim SJ. Correlation between skeletal changes by maxillary Protraction and upper airway dimensions. Angle Orthod. 2011;81(3):426–32.
32. Adobes Martin M, Lipani E, Alvarado Lorenzo A, Bernes Martinez L, Aiuto R, Dioguardi M, et al. The effect of maxillary Protraction, with or without rapid palatal expansion, on airway dimensions: A systematic review and meta-analysis. Eur J Paediatr Dent. 2020;21(4):262–70.
33. Pamporakis P, Nevzatoglu S, Kucukkeles N. Three-dimensional alterations in pharyngeal airway and maxillary sinus volumes in class III maxillary deficiency subjects undergoing orthopedic facemask treatment. Angle Orthod. 2014;84(4):701–7.
34. El H, Palomo JM. Three-dimensional evaluation of upper airway following rapid maxillary expansion: a CBCT study. Angle Orthod. 2014;84(2):265–73.
35. Abdalla Y, Brown L, Sonnesen L. Effects of rapid maxillary expansion on upper airway volume: A three-dimensional cone-beam computed tomography study. Angle Orthod. 2019;89(6):917–23.
36. Smith T, Ghoneima A, Stewart K, Liu S, Eckert G, Halum S, et al. Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion. Am J Orthod Dentofac Orthop. 2012;141(5):618–26.

37. Lo Giudice A, Polizzi A, Lagravere M, Flores-Mir C, Isola G, Ronsivalle V et al. Changes in upper airway airflow after rapid maxillary expansion considering normal craniofacial development as a factor: a retrospective study using computer fluid dynamics. Eur J Orthod. 2025;47(1).

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