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ORIGINAL RESEARCH

Nasopharyngeal lymphoid tissue, breathing pattern, and articulation disorders in children with unilateral posterior crossbite: controlled clinical trial

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Abstract

Background: Unilateral posterior crossbite (ULCB) in early mixed dentition is associated with hereditary factors, sucking habits, and impaired nasal breathing. This study aimed to assess ear, nose, and throat (ENT) structures, orofacial functions, and articulation disorders in children with ULCB, compared to healthy controls, and to evaluate the changes after rapid maxillary expansion (RME). **Methods**: Thirty-one children with ULCB (mean age 7.62 ± 1.3 years) and 31 age- and gender-matched control subjects without malocclusion (mean age 7.63 ± 0.67 years) were examined by an orthodontist, an ENT specialist, and speech therapist. Children with ULCB were treated with a Haas-type maxillary expander. ENT and orofacial assessments were repeated four years after treatment. Data were analysed using chi-square, Mann-Whitney, and Wilcoxon tests. **Results**: At baseline, children with ULCB were significantly more likely to have impaired nasal breathing ($p < 0.001$), enlarged adenoids ($p = 0.005$), low tongue posture ($p = 0.001$), lip incompetence ($p = 0.026$), and articulation disorders ($p < 0.001$) compared with controls. Post-treatment evaluations revealed significant improvements in nasal breathing ($p = 0.001$), tongue posture ($p < 0.001$), adenoid size and nasopharyngeal patency ($p < 0.001$), mentalis muscle activity ($p = 0.025$), lip competence ($p = 0.014$), and swallowing pattern ($p = 0.031$). **Conclusions**: A unilateral posterior crossbite was associated with articulation disorders, impaired nasal breathing, tongue posture at the floor of the mouth, and enlarged adenoids in the early mixed dentition. The widening of the maxilla had a significant effect, as it improved nasopharyngeal patency as well as the breathing pattern and tongue posture. **Clinical Trial Registration**: ISRCTN15126033 (Retrospectively registered).

Keywords

Unilateral posterior crossbite; Adenoids; Palatine tonsils; Tongue habits; Orofacial function; Mouth breathing; Articulation disorders

1. Introduction

A unilateral posterior crossbite (ULCB) is a common malocclusion and jaw irregularity, it is characterized by crossbite of one side of posterior dentition, lower midline deviation, and facial asymmetry. It occurs very frequently in the primary dentition and early mixed dentition. Morphologically, it can be of skeletal, dental, or functional origin and develops due to a transversal discrepancy. Very frequently (60%–97%), it is also associated with a functional lateral mandibular functional shift [1–4].

The prevalence of posterior crossbite in mixed dentition in Caucasian children varies between 6.49 and 16.2% [5]. Some studies indicate a higher prevalence in girls, especially those with bad oral habits [6]. However, self-correction may occur during the transition from primary to mixed dentition [7].

Posterior crossbite with a narrow upper dental arch can be attributed etiologically to deviated orofacial functions, such as sucking habits, mouth breathing, tongue posture, or open mouth posture, as well as to hereditary factors [7–10]. In addition, Melink *et al.* [11] have shown that the duration of breastfeeding is inversely related to the duration of the dummy habit, and that children with a dummy habit duration of more than 18 months are 3.6 times more prone to develop ULCB than children without dummy sucking habit. All these factors can affect the transversal growth of the maxilla. Patients try to avoid these unstable occlusions and deviate the mandible to the side, causing a functional shift [12, 13]. Studies also show a positive correlation between masticatory function and tooth wear in the primary dentition, with a lower degree of tooth wear on the crossbite side, especially in the maxillary canines, leading to the development of occlusal interference [14]. If left untreated, mandibular displacement can lead to deviated facial growth: Asymmetry of the lower and midface [15].

The application of the cervical vertebral maturation method (CVM) shows that rapid maxillary expansion (RME) before the peak of skeletal growth (Cervical stage (CS)1–CS3) is able to induce more pronounced transverse craniofacial changes at the skeletal level [16, 17] in both the maxillary and circumaxillary structures [18]. Rapid maxillary expansion (RME) is an effective orthopaedic procedure for the treatment of structural and functional problems in the midface [19]. Treatment of a ULCB creates normal conditions for normal occlusal development and skeletal growth and can improve facial symmetry [20]. The widening of the nasal base observed after opening the midface suture in growing patients allows a reduction in nasal airway resistance and an improvement in breathing pattern [19], regardless of previous adenotonsillectomy [21].

These findings are not only related to the increase in the transverse diameter and volume of nasal cavity, but also to mouth breathing, which supports nasal filtration and potentially reduces the incidence of respiratory infections [21].

Multiple studies have suggested that RME could be beneficial in addressing maxillary constriction linked to more severe breathing issues, such as obstructive sleep apnea (OSA) in adolescents. This benefit may result from an increase in pharyngeal dimensions, a change in tongue posture, and a reduction in nasal breathing difficulties [19, 21].

The palatine tonsils, adenoids, tubal tonsils, and lingual tonsils are lymphoepithelial tissues that form part of the Waldeyer's ring. Together, these components form the mucosal immune system, which plays a key role in the adaptive immune response by sampling antigens. The immunological function of the palatine and pharyngeal tonsils leads to their rapid growth in early childhood. Although the exact mechanism of this growth is still unclear, it is thought that exposure to exogenous antigens triggers the formation of germinal centers that results in lymphoid hyperplasia of the tonsils [22]. The thickness of the soft lymphoid tissue on the posterior nasopharyngeal wall peaks at the age of 5 years and decreases until about 10 years of age. A slight increase is observed between the ages of 10 and 11 years, followed by a further decrease [23].

Some patients may develop an abnormal immune response, which in turn leads to chronic inflammation of the adenoids, which can then spread to neighbouring areas of the mucosa, *e.g.*, the nose, sinuses, and middle ear [24]. When the nasal airways are blocked, airflow is diverted via the oral route [25]. However, the causes of adenoid and tonsil hypertrophy in children are not fully understood. They are most likely associated with immune responses, hormonal factors, or genetic factors [24], with an estimated prevalence of 34% in the paediatric population [26]. Upper airway obstruction in the form of hypertrophied adenoids or tonsils and allergic rhinitis can lead to mouth breathing, and is associated with narrow jaws, the development of a posterior crossbite [27, 28], a larger overbite and inappropriate dental arch form [29, 30]. The tongue posture is changed to an anterior position to ensure a clear oropharyngeal airway. Volk *et al.* [31] found that 81.5% of children with unilateral posterior crossbite had an incorrect, low tongue posture, while Melink *et al.* [11] found that children with posterior crossbite and a dummy sucking habit developed a low tongue posture due to a short frenula linguae.

The production of certain phonemes during speech requires coordinated effort of the teeth, lips, and tongue. Associations between malocclusion and articulation disorders (AD) have been reported in the literature [32, 33]. An estimated 2%–24% of school-age children have some type of articulation disorder [34]. Warren *et al.* [35] suggested that when speech is distorted by a defect in the oral cavity other than an open bite, an additional morphological or psychological factor is usually involved. Previous studies have shown possible etiological links between anatomical conditions, such as ULCB, and abnormal orofacial function. However, it is unclear what the condition of the pharyngeal lymphoid tissue is in children with ULCB and whether morphological and functional changes in the ULCB lead to articulation disorders [10, 11, 36, 37]. To our knowledge, no studies have investigated and followed up ENT structures, articulation disorders, and orofacial functions in ULCB.

The aim of our study was twofold. First, to investigate the ENT structures, irregular orofacial functions, and articulation disorders in children with ULCB in early mixed dentition and compare them with a healthy control group, with the first null hypothesis that the prevalence of irregularities in ENT structures and deviant orofacial functions is the same in children with ULCB compared with the control group. Secondly, to investigate the ENT structures and orofacial functions in ULCB children after treatment with RME compared to baseline, with the second hypothesis that the prevalence of irregularities in ENT structures and deviated orofacial functions would not change before and after treatment of ULCB.

2. Materials and methods

Ethical approval for this study was initially obtained from the local institutional review board (IRB) (80-81/04/06) and was later approved by the National Ethics Committee of the Ministry of Health in Ljubljana, Slovenia (approval number: 0120-452/2024-2711-3). Informed consent was obtained from each of the participating children and their parents.

A group of 62 Caucasian subjects, 31 with ULCB (15 boys, 16 girls) and 31 without malocclusion (control, 15 boys, 16 girls), were enrolled in a prospective controlled clinical study. The mean age of the ULCB group was 7.62 $\pm$ 1.3 years, while the mean age of the control group was 7.63 $\pm$ 0.67 years. There were no significant differences in age or gender distribution between the groups ($p > 0.05$) (Table 1).

TABLE 1. Table of the number of participants in ULCB and control group: their age, gender.

	ULCB	Control Group	*p*
Frequency (N)	31	31	
Age (yr)	7.62 $\pm$ 1.30	7.63 $\pm$ 0.67	0.970
Gender	15 m 16 f	15 m 16 f	0.799

There were no statistically significant differences between the groups.
ULCB: Unilateral posterior crossbite; m: male; f: female.

The subjects in the ULCB group with and without deviated oral functions or poor oral habits were randomly selected from the pool of prepubertal patients referred to the Orthos Institute in Ljubljana, Slovenia. Only patients with all posterior teeth in crossbite (canines, primary molars, and first permanent molars) that had deviated at least 2 mm unilaterally from the lower midline or had a lateral displacement of the mandible were included. The study started in 2020 and patients were followed up after 4 years. Control subjects were randomly selected (stratified randomization, controlled for malocclusion) from a local school and only subjects without malocclusion were included.

2.1 Anamnestic information

Prior to the clinical ENT examination, the parents or guardians of the participating children were interviewed verbally. Information was collected on daily or nocturnal breathing patterns, snoring, allergies, the occurrence of frequent sneezing, frequent colds, the frequency and type of nasal discharge, the occurrence of middle ear infections, and the occurrence of nasal or throat infections. The questionnaire on which the survey is based can be found in the **Supplementary material**.

2.2 Otorhinolaryngological assessment

The routine clinical examination by the otolaryngologist (IHB) was performed while the child was sitting in a relaxed position on a chair. The ENT specialist was unaware of patient's orthodontic status. The ENT specialist visually examined the eardrum (normal or retracted), the state of nasal mucosa (normal or oedematous), a possible deviation of the nasal septum, the mobility of the tongue, and performed objective nasal breathing evaluation (possible, obstructed). The size of the tonsils was assessed using Brodsky's standardised system for assessing tonsil size [38] (0: Tonsils in the tonsillar fossa, without obstruction of the oropharyngeal airway; +1: Tonsils outside the tonsillar fossa with obstruction of less than 25% of the airway; +2: Tonsils occupy 25%–50% of the oropharyngeal width; +3: Tonsils occupy 50%–75% of the oropharyngeal width; +4: Tonsils occupy >75% of the oropharyngeal width). The size of the adenoids was assessed with regard to the patency of the nasopharyngeal cavity for nasal breathing ((1) small or (2) medium—no significant obstruction of the nasopharyngeal cavity, (3) large—significant obstruction of the nasopharyngeal cavity, (4) very large—complete obstruction of the nasopharyngeal cavity). If the gag reflex was strong, the child was invited to undergo an additional flexible nasal endoscopy to correctly assess the size of the adenoids. Lip competence (closed, slightly open/pursed or incompetent lips) was determined with the child in a relaxed position. In the case of incompetent lip closure, the child's breathing was determined using the instrument that registers the temperature difference of the airflow through the mouth or nose to distinguish mouth breathing from incompetent lip closure. Tongue position (normal or on the floor of the mouth), mentalis muscle activity (in relaxed, closed mouth position: normal, no muscle activity; incompetent, mentalis muscle contraction observed) and upper lip length (normal, short) were also assessed.

The clinical examination was performed in the ULCB group and the controls at the beginning of the study and repeated four years after treatment and the retention period at the follow-up examination of the ULCB group.

2.3 Assessment of the articulation disorder

The articulation disorders were assessed in both groups (ULCB and controls) by an experienced speech therapist (NP) at the beginning of the study. A three-position articulation test for the Slovenian language, without transcription, was used to assess whether an articulation disorder was present or not. The subjects had to describe 72 pictures according to the test, both with a single word and with a coherent speech sample. The single word test and the connected speech test included the assessment of the correct production of phonemes, phoneme combinations, and syllable forms [39].

2.4 Orthodontic assessment and treatment

Clinical examinations were performed by an experienced orthodontist (MO) who documented the orofacial functions and intraoral condition of the children. Each child was observed in a relaxed position and any cases of incompetent lip closure were noted. If this was not the case, the child's breathing pattern was recorded using a special airflow measuring device (Breathing Detector, MKS Elektronski sistemi, Ljubljana, Slovenia). This device measures the temperature of the airflow through the mouth or nose in people with insufficient lip closure, and thus makes it possible to distinguish between mouth breathing and incomplete lip closure. If the child had incomplete lip closure (pursed lips), the breath detector was positioned in front of the mouth. The light sign or signal on the device confirmed that the airflow was coming through the mouth, thereby detecting improper mouth breathing.

To assess the swallowing pattern, we used the method proposed by Melsen *et al.* [40]. First, mandibular movements and contractions of the perioral muscles were observed during swallowing. Then the examiners palpated the temporalis and masseter muscles while the child performed an unconscious swallow, as this may be different from a swallow on command. The normal (somatic) swallowing pattern was characterised by tooth contact and the activity of the masticatory muscles. If no muscle contraction was registered, an atypical (visceral) swallowing pattern was recorded. Each child swallowed three times and the consensus opinion on the swallowing pattern was accepted.

During the intraoral examination, posterior crossbite, midline deviation, and transverse buccal relationships were recorded in the ULCB group. The dental arches were digitally scanned with the 3Shape TRIOS 3 scanner (intraoral scanner, 3Shape A/S, Copenhagen K, Denmark) and analysed with the Dolphin programme (Dolphin Imaging & Management Solutions, 2009, Chatsworth, CA, USA). In the ULCB group, an alginate impression of the upper dental arch was taken and cast in hard blue plaster. A rapid maxillary expander appliance (Haas type) was fabricated in the dental laboratory (Orthos Institute, Ljubljana).

All patients were treated according to the same clinical procedure with the same appliance (Fig. 1): a Haas-type RME

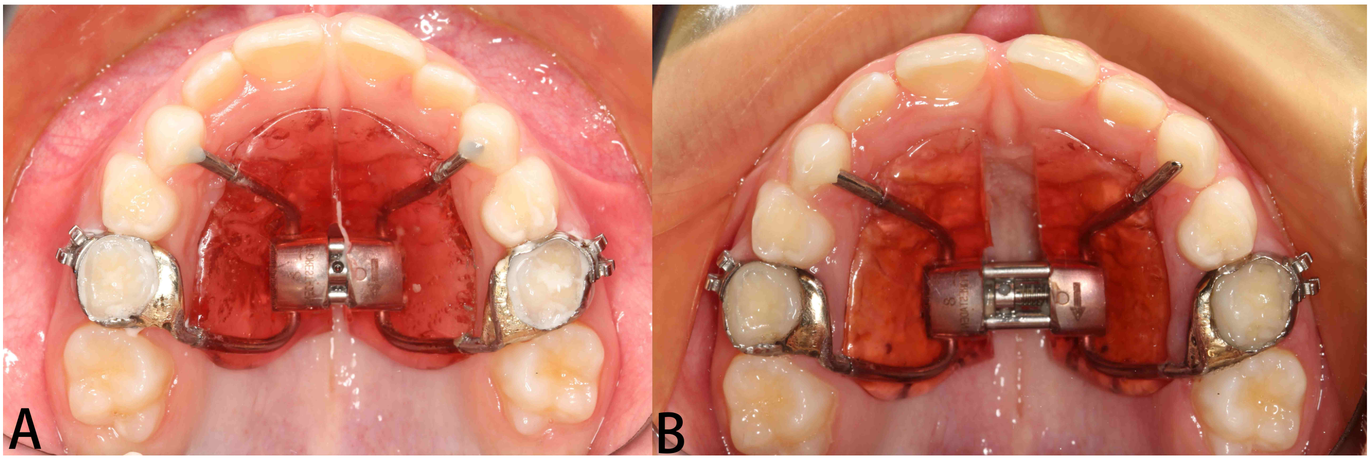

FIGURE 1. Rapid maxillary expander. (A) prior and (B) after the maxillary expansion.

appliance with a size 8 expansion screw. Palatal expander [41] was made with bands on the second deciduous molars to avoid potential negative side effects of the appliance to the upper first permanent molars [42]. Glass-ionomer cement (FujiCem, GC) was used for bonding bands and bonded flowable composite resin (Tetric EvoFlow, Ivoclar) was used to bond the extensions to the deciduous canines. In the patients with posterior crossbite, all appliances were activated twice a day (0.25 mm twice a day) for the first 2 weeks and once a day (0.25 mm once a day) thereafter according to protocol described by Bishara *et al.* [43, 44]. Patients were monitored weekly by the clinician during the active expansion phase. The expansion was continued until the posterior crossbite on the permanent molars was self-corrected and a transversal hypercorrection of 1.5 mm was achieved. After 6–9 months, retention appliances were used to maintain the transversal dimension. The expansion screw was secured with a ligature wire. After 6–9 months, passive fixed retention appliances (palatal arch) were used to maintain the transversal dimension. Patients were monitored clinically during the follow-up period.

2.5 Statistical analysis

Data were collected using Microsoft Excel (Excel 16.0, Microsoft, Redmond, WA, USA) and analyzed with SigmaPlot (v14.0, Systat Software, Inc., San Jose, CA, USA). Statistical significance was set at $p \leq 0.05$ (95% confidence). Sample size was calculated to detect differences between groups in articulation disorders and pharyngeal lymphoid tissue size (power = 0.80, $\alpha = 0.05$). This required at least 24 participants for articulation disorders (assessed by chi-square test) and 61 for lymphoid tissue size. The initial participant number was increased to account for potential attrition during the follow-up period.

Descriptive statistics and one-way frequency tables were used to describe the ULCB and control groups. Group differences in gender were assessed using the chi-square test, and age differences with the Student *t*-test. Data are presented as mean ± standard deviation (SD) or median (25th–75th percentile) unless stated otherwise.

Chi-square and Fisher's exact tests were used to compare nominal variables between the ULCB and control groups. These variables included tongue posture, motor function of the tongue, mentalis muscle hyperactivity, swallowing pattern, articulation disorders, and patient-reported presence of allergies or frequent throat infections. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for variables that differed significantly. The Mann-Whitney rank sum test was employed to compare ordinal variables between groups, such as eardrum condition, nasal mucosa condition, adenoid size, palatine tonsil size, lip posture, objective assessment of nasal breathing, and patient-reported snoring or daily (diurnal) breathing pattern.

Within the ULCB group, changes between baseline (before orthodontic treatment) and follow-up (after orthodontic treatment) were assessed using the non-parametric Wilcoxon Signed Rank test for dependent samples. Relationships for selected parameters are presented graphically using bar charts and boxplots. In boxplots, the center box represents the 25th–75th percentile range, the dashed line indicates the sample mean, the solid line shows the median, and whiskers denote the 5th and 95th percentiles. An asterisk (*) signifies a *p*-value ≤ 0.05. The ● symbolizes an outlier.

3. Results

3.1 Comparison between ULCB and control group at the baseline

There were no differences between the ULCB group and the control group before treatment in terms of the frequency of pharyngeal infection, allergies or snoring reported by the patients. However, patients with ULCB had significantly more often diurnal mouth breathing pattern compared with the control group (Mann-Whitney test, $p < 0.001$). Patients in the control group did not report a significantly higher incidence of allergies or a lower incidence of pharyngitis. The results are shown in Table 2 and Fig. 2.

ENT and orthodontic specialist evaluation of anatomical structures in ULCB and control group at the baseline showed that there were no differences in appearance of the eardrum, state of nasal mucosa, mentalis muscle contraction, or size of palatine tonsils (Fig. 3) between the experimental and control groups (Table 3). Medium size of palatine tonsils and swollen

TABLE 2. Patient reported functions and conditions: comparison between ULCB and control group.

Variable	ULCB Group (n = 31)	Control Group (n = 31)	*p*-value
Snoring	No (No–Sometimes)	No (No–No)	0.212[a]
Frequent pharyngeal infections			
Present	27 (87.1%)	26 (83.9%)	1.000[b]
Not present	4 (12.9%)	5 (16.1%)	
Diurnal breathing pattern	Sometimes mouth (Nasal–Sometimes mouth)	Nasal (Nasal–Nasal)	**<0.001**[a]

Ordinal Scale Definitions:
Snoring: No, Sometimes, Often. Diurnal breathing pattern: Nasal, Sometimes mouth, Always mouth.
Statistical Notation:
Bold p-values indicate statistical significance ($p \leq 0.05$).
Data presented as Median (Interquartile Range) for ordinal variables.
Data presented as n (%) for categorical variables.
[a]Mann-Whitney U test.
[b]Chi-square test.
ULCB: Unilateral posterior crossbite.

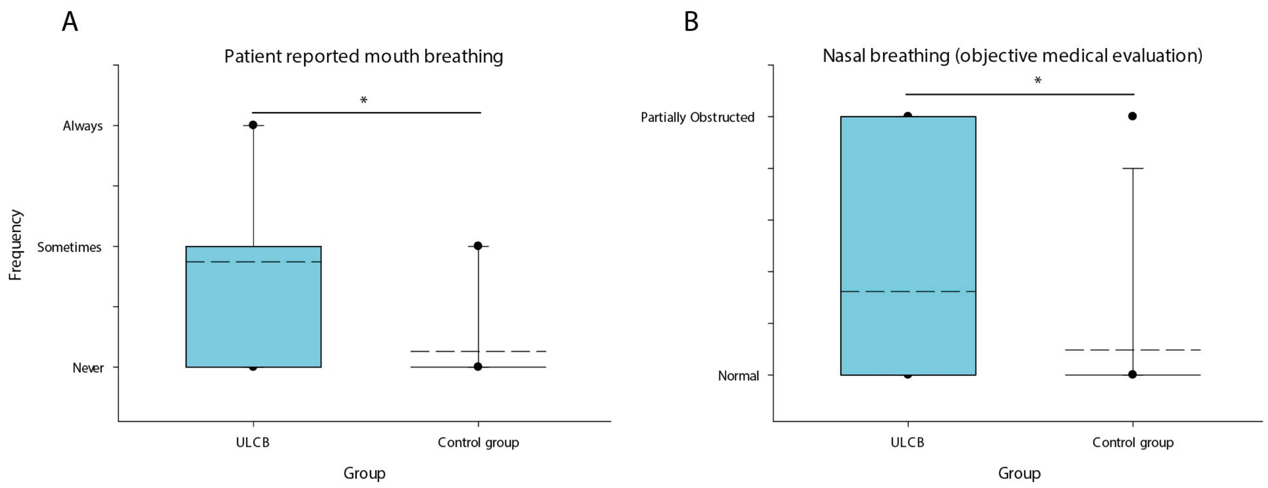

FIGURE 2. Patient reported diurnal breathing pattern (A) and ENT specialist evaluation of nasal breathing (B). *signifies a statistically significant difference ($p < 0.05$). ULCB: Unilateral posterior crossbite.

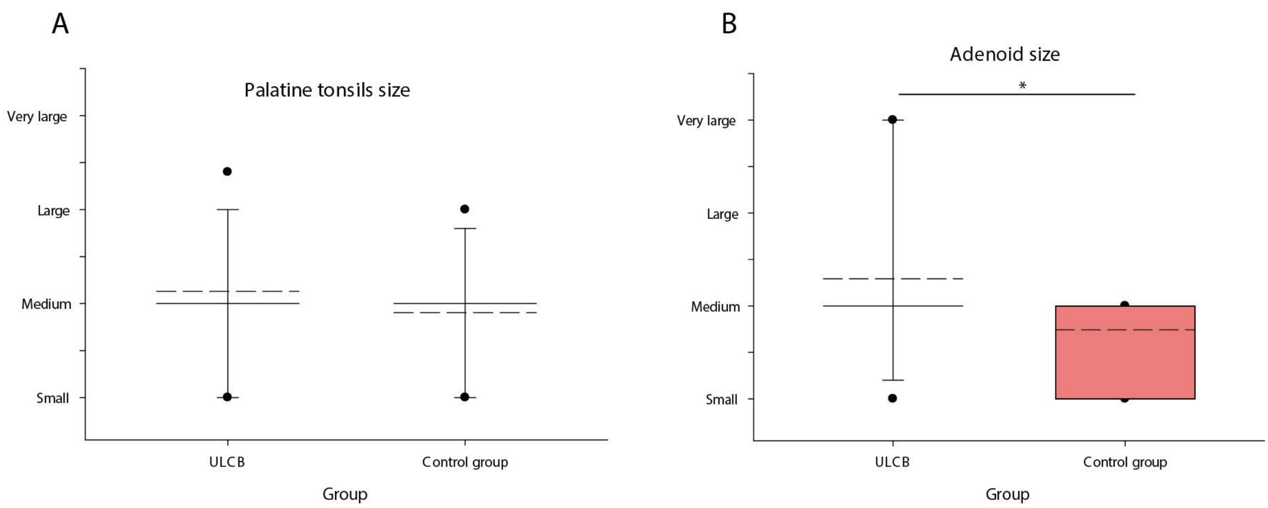

FIGURE 3. Palatine tonsil (A) and adenoid size (B) in experimental and control group at the baseline. ULCB: Unilateral posterior crossbite. An asterisk (*) signifies a *p*-value ≤ 0.05.

TABLE 3. Comparison of anatomical structures between ULCB and control group.

Variable	ULCB Group (n = 31)	Control Group (n = 31)	p-value	OR (95% CI)
State of eardrum	Normal (Normal–Retracted)	Retracted (Normal–Retracted)	0.067[a]	-
Adenoid size	Medium (Medium–Medium)	Medium (Small–Medium)	**0.005**[a]	-
State of nasal mucosa	Swollen (Normal–Swollen)	Swollen (Normal–Swollen)	0.596[a]	-
Palatine tonsils size	Medium (Medium–Medium)	Medium (Medium–Medium)	0.178[a]	-
Tongue posture				
Mouth floor	27 (87.1%)	14 (45.2%)	**0.001**[b]	8.20 (2.31–29.07)
Palate	4 (12.9%)	17 (54.8%)		
Lip posture	Pursed (Closed–Pursed)	Closed (Closed–Pursed)	**0.026**[a]	-

Ordinal Scale Definitions:
State of eardrum: Normal, Retracted, Exudative otitis, Acute otitis, Chronic otitis.
Adenoid size: Small, Medium, Large.
State of nasal mucosa: Normal, Swollen, Very swollen.
Palatine tonsils size: Small, Medium, Large.
Tongue posture: Palate, Mouth floor.
Lip posture: Closed, Pursed, Open.
Statistical Notation:
Bold p-values indicate statistical significance ($p \leq 0.05$).
Data presented as Median (Interquartile Range) for ordinal variables.
Data presented as n (%) for categorical variables.
[a] *Mann-Whitney U test.*
[b] *Chi-square test.*
ULCB: Unilateral posterior crossbite; OR: Odds ratios; CI: confidence interval.

state of nasal mucosa appeared in both groups at the baseline. However, examination revealed also some significant differences between the groups at the baseline. Patients with ULCB had significantly larger size of their adenoids (Mann-Whitney test, p = 0.005) (Fig. 3), more often tongue posture on the mouth floor (Chi square test, $p < 0.001$), and incompetent lip seal (Mann-Whitney test, $p = 0.026$) more often compared with the control group (Fig. 4).

The examination of patient status of orofacial functions carried out by orthodontists, ENT specialists, and speech therapists showed that patients with ULCB had significantly more frequent speech articulation disorders (chi-square test, $p <$ 0.001) and their nasal breathing was significantly more frequently impaired (Mann-Whitney test, p = 0.031) (Fig. 2). No statistically significant differences were found in the contraction of the mentalis muscle at rest, the motor function of the tongue, and the swallowing pattern (Table 4). However, the contraction of the mentalis muscle at rest, the clumsy motor function of the tongue, and the visceral swallowing type occurred more frequently in the ULCB group than in the control group at baseline.

3.2 ULCB post treatment follow-up

Patients with ULCB were followed up after treatment and retention for 4 years after baseline.

After treatment and retention, patients with ULCB reported no difference in snoring and incidence of throat infections; however, they reported a change in their breathing pattern (Fig. 5), with patients observing significantly more nasal breathing during the day after treatment (Wilcoxon test, $p <$ 0.001) compared with baseline (Table 5).

No changes in the condition of the eardrums, the nasal mucosa, the size of the palatine tonsils, or the lip posture were found in the ULCB patients at the follow-up examination by the ENT specialist and the orthodontist. At the follow-up examination 4 years after treatment, we observed a significant reduction in the size of the adenoids, the tongue posture of the patients had shifted more towards the palate and the upper lip had lengthened (Table 6, Figs. 6,7).

Compared with pre-treatment baseline, children with ULCB had significantly less mentalis muscle tension and more frequently somatic swallowing pattern at follow-up. There were no differences in their professionally evaluated nasal breathing or motoric function of the tongue (Table 7).

4. Discussion

In the present study, the ENT structures, irregular orofacial functions and articulation disorders in children with unilateral posterior crossbite (ULCB) in early mixed dentition were investigated and compared with a control group without malocclusion. In addition, the ENT structures and orofacial functions of ULCB children were analysed before and after treatment and retention time with a rapid maxillary expander. The results of the study showed that children with ULCB in the early mixed dentition were statistically significantly more likely to have articulation disorders, impaired nasal breathing, tongue posture at the floor of the mouth, and enlarged adenoids, which refuted the first null hypothesis. At the follow-up examination

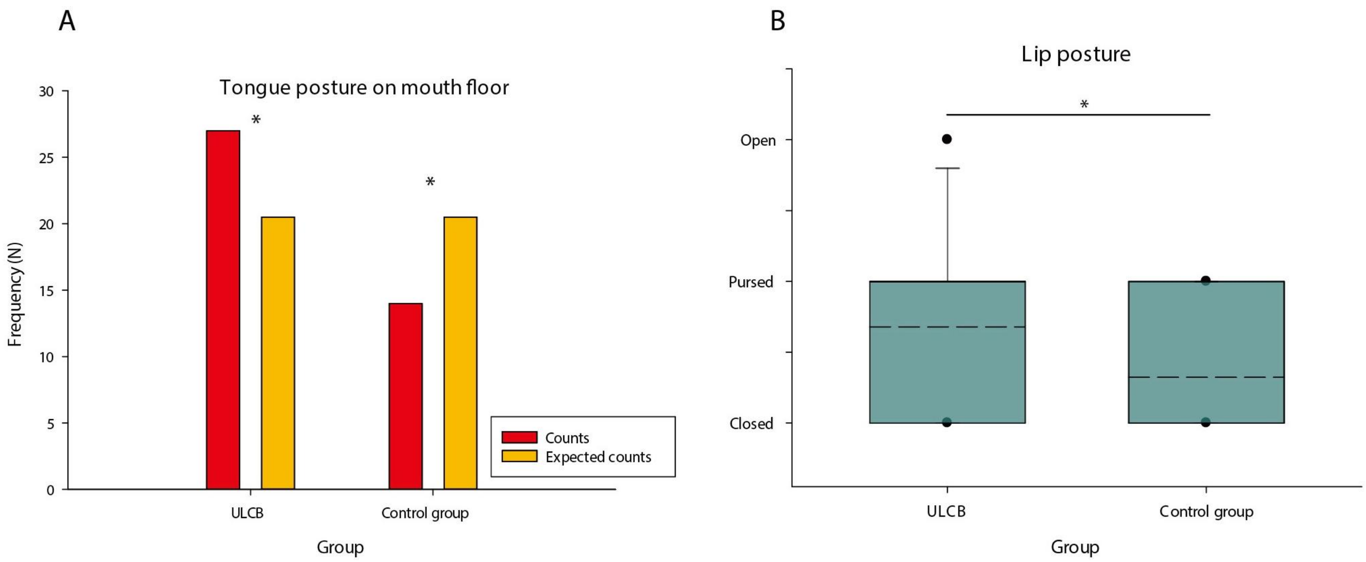

FIGURE 4. Tongue posture (A) and lip posture (B) in experimental and control group. ULCB: Unilateral posterior crossbite. An asterisk (*) signifies a *p*-value ≤ 0.05.

TABLE 4. Comparison of orofacial functions between ULCB and control groups.

Variable	ULCB Group (n = 31)	Control Group (n = 31)	*p*-value	OR (95% CI)
Objective nasal breathing evaluation	Normal (Normal–Partially obstructed)	Normal (Normal–Normal)	**0.031**[a]	-
Speech articulation disorders				
Present	19 (61.3%)	5 (16.1%)	<**0.001**[b]	8.26 (2.48–27.32)
Not present	12 (38.7%)	26 (83.9%)		
Mentalis muscle contraction at rest				
Present	22 (71.0%)	21 (67.7%)	1.000[b]	-
Not present	9 (29.0%)	10 (32.3%)		
Tongue motoric function				
Clumsy	4 (12.9%)	1 (3.2%)	0.354[c]	-
Normal	27 (87.1%)	30 (96.8%)		
Swallowing pattern				
Somatic	25 (80.6%)	30 (96.8%)	0.104[c]	-
Visceral	6 (19.4%)	1 (3.2%)		

Ordinal Scale Definitions:
Objective nasal breathing: Normal, Partially obstructed, Obstructed.
Tongue motoric function: Normal, Clumsy.
Swallowing pattern: Somatic, Visceral.
Statistical Notation:
Bold p-values indicate statistical significance (p ≤ 0.05).
Data presented as Median (Interquartile Range) for ordinal variables.
Data presented as n (%) for categorical variables.
[a]*Mann-Whitney U test.*
[b]*Chi-square test.*
[c]*Fisher's exact test.*
ULCB: Unilateral posterior crossbite; OR: Odds ratios; CI: confidence interval.

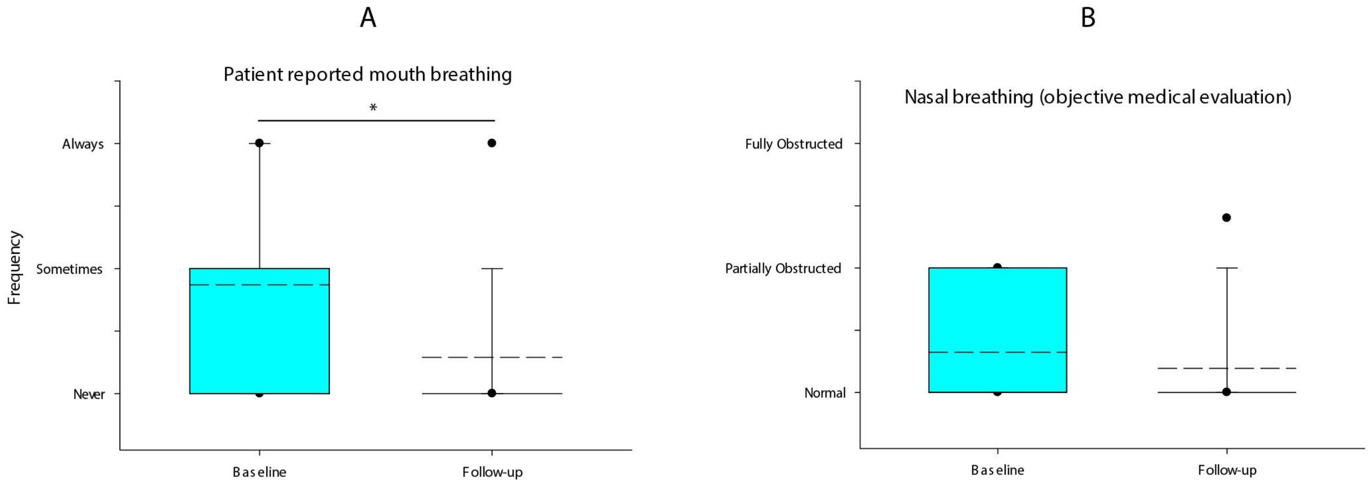

FIGURE 5. ULCB patient reported diurnal breathing pattern at baseline and follow-up (A) and objective evaluation of nasal breathing (B). An asterisk (*) signifies a p-value ≤ 0.05.

TABLE 5. Patient reported functions: ULCB group at baseline and follow-up.

Variable	Baseline (n = 31)	Follow-up (n = 31)	p-value
Snoring	No (No–Sometimes)	No (No–Sometimes)	0.212[d]
Frequent pharyngeal infections	No (No–No)	No (No–No)	0.250[d]
Diurnal breathing pattern	Sometimes mouth (Nasal–Sometimes mouth)	Nasal (Nasal–Nasal)	**0.001**[d]

Ordinal Scale Definitions:
Snoring: No, Sometimes, Often.
Diurnal breathing pattern: Nasal, Sometimes mouth, Always mouth.
Statistical Notation:
Bold p-values indicate statistical significance ($p \leq 0.05$).
Data presented as Median (Interquartile Range) for ordinal variables.
[d] *Wilcoxon signed-rank test.*

TABLE 6. State of anatomical structures: ULCB group at baseline and follow-up.

Variable	Baseline (n = 31)	Follow-up (n = 31)	p-value
State of eardrum	Normal (Normal–Retracted)	Retracted (Normal–Retracted)	0.542[d]
Adenoid size	Medium (Medium–Medium)	Small (Small–Small)	**<0.001**[d]
State of nasal mucosa	Swollen (Normal–Swollen)	Swollen (Normal–Swollen)	0.813[d]
Palatine tonsils size	Medium (Medium–Medium)	Medium (Medium–Medium)	1.000[d]
Tongue posture	Mouth floor (Mouth floor–Mouth floor)	Palate (Palate–Palate)	**<0.001**[d]
Lip posture	Pursed (Closed–Pursed)	Closed (Closed–Pursed)	0.305[d]
Upper lip length	Short (Short–Short)	Short (Normal–Short)	**0.014**[d]

Ordinal Scale Definitions:
State of eardrum: Normal, Retracted, Exudative otitis, Acute otitis, Chronic otitis.
Adenoid size: Small, Medium, Large.
State of nasal mucosa: Normal, Swollen, Very swollen.
Palatine tonsils size: Small, Medium, Large.
Tongue posture: Palate, Mouth floor.
Lip posture: Closed, Pursed, Open.
Statistical Notation:
Bold p-values indicate statistical significance ($p \leq 0.05$).
Data presented as Median (Interquartile Range) for ordinal variables.
[d] *Wilcoxon signed-rank test.*

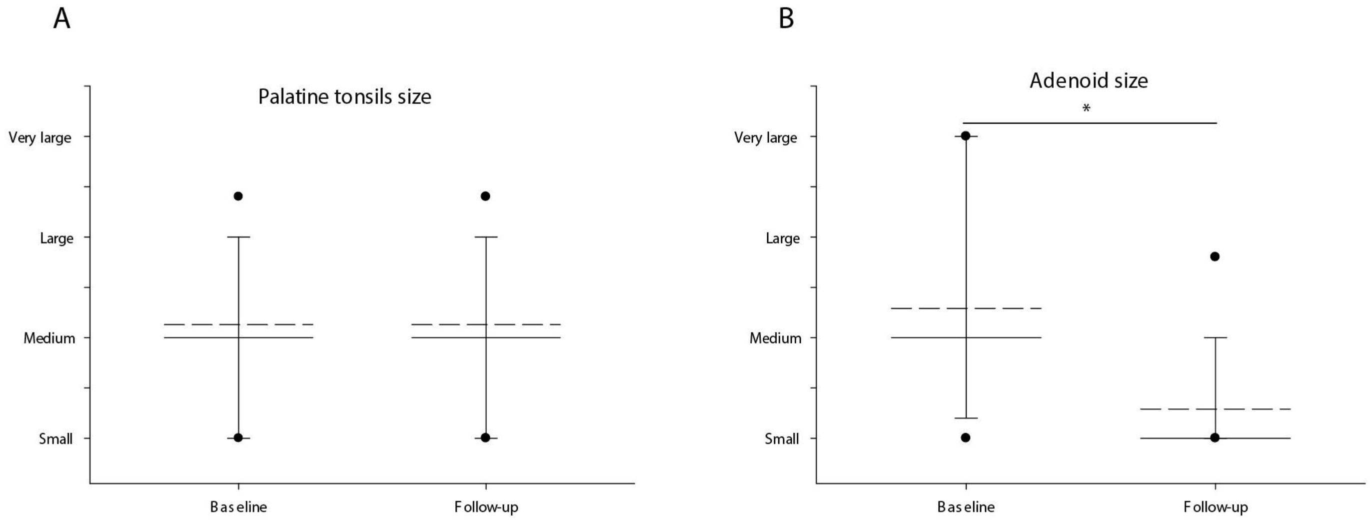

FIGURE 6. ULCB group palatine tonsil (A) and adenoid size (B) at baseline and follow-up. An asterisk (*) signifies a p-value ≤ 0.05.

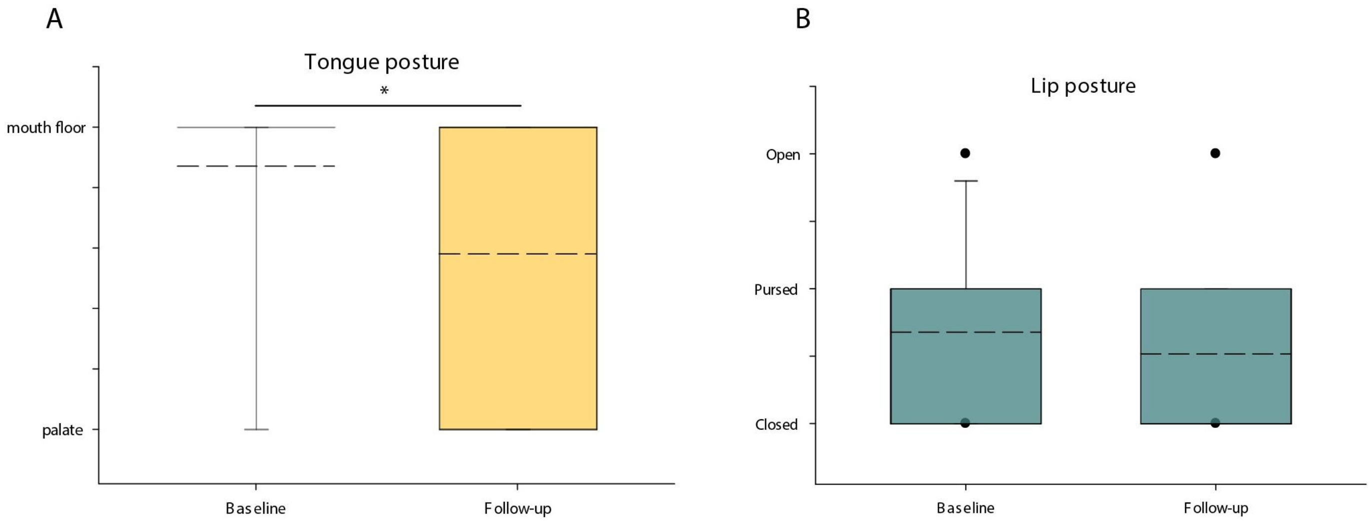

FIGURE 7. ULCB group tongue (A) and lip posture (B) at baseline and follow-up. An asterisk (*) signifies a p-value $\leq$ 0.05.

TABLE 7. Orofacial functions: ULCB group at baseline and follow-up.

Variable	Baseline (n = 31)	Follow-up (n = 31)	*p*-value
Objective nasal breathing evaluation	Normal (Normal–partially obstructed)	Normal (Normal–Normal)	0.275[d]
Mentalis muscle contraction at rest	Contracted (Relaxed–Contracted)	Relaxed (Relaxed–Contracted)	**0.025**[d]
Tongue motoric function	Normal (Normal–Normal)	Normal (Normal–Normal)	0.125[d]
Swallowing pattern	Somatic (Somatic–Somatic)	Somatic (Somatic–Somatic)	0.031[d]

Ordinal Scale Definitions:
Objective nasal breathing: Normal, Partially obstructed, Obstructed.
Mentalis muscle contraction at rest: Relaxed, Contracted.
Tongue motoric function: Normal, Clumsy.
Swallowing pattern: Somatic, Visceral.
Statistical Notation:
Bold p-values indicate statistical significance ($p \leq 0.05$).
Data presented as Median (Interquartile Range) for ordinal variables.
[d] *Wilcoxon signed-rank test.*

after jaw expansion, the patency of the nasopharyngeal cavity, the length of the upper lip, the breathing pattern, and the tongue posture improved, thus refuting the second null hypothesis.

In the study, the participants or their parents/guardians reported on the frequency of their snoring, throat infections, the occurrence of allergies, and described the child's breathing pattern. Compared with the healthy control group, we did not find a higher prevalence of throat infections, allergies, or snoring in the ULCB group. This could explain long-term nasal obstruction and, as a consequence, incorrect breathing with incorrect tongue position in the oral cavity. Snoring depends on several factors: the position of the overgrown lymphatic tissue, the muscle tone of the pharynx, and the posture during sleep [29, 45]. Due to the lateral position of the palatine tonsils under the narrow passage of the pharynx, the child can breathe through the nose during the day, while during sleep the palatine tonsils fall backwards and meet in the midline and may cause partial obstruction of the oropharyngeal passage [29]. This observation could be explained by the fact that ENT assessment of tonsil size showed no statistically significant difference between the groups, as did sleep-disordered breathing due to their mouth bypass.

However, our ULCB patients reported a significantly more frequent mouth breathing pattern during the day. Objective assessment of breathing patterns by an ENT specialist also showed significantly more frequent obstructed nasal breathing in the ULCB group compared with controls. The more frequent mouth breathing in ULCB could be due to a narrower nasal passage and pharyngeal obstructions, such as large adenoid. Several other studies also emphasized the role of breathing pattern in the development of malocclusion [10, 36, 46, 47]. The lip posture was closely related to the mouth breathing pattern, as ULCB patients were significantly more likely to have an open or pursed lip posture.

Examination of the ears, nose and throat revealed no difference in the appearance of the tympanic membrane, the condition of the nasal mucosa, or the size of the palatine tonsils between ULCB and the control groups. However, our results showed a statistically significant difference in the size of the adenoids at the beginning of treatment. The patency of the nasopharyngeal cavity was more obstructed in the ULCB group compared with the control group at baseline. Several previous studies have considered a possible role of enlarged adenoids in the development of ULCB or malocclusion [11, 46, 48]. The role of adenoids in malocclusion is probably associated with the breathing pattern as one of the causative factors of nasal obstruction [8, 48, 49].

Children with ULCB had 8.2 times (95% CI: 2.31–29.07) higher odds of tongue posture on the floor of the mouth. In the study published by Volk *et al.* [31], an objectively assessed incorrect tongue posture on the floor of the mouth was found in 81.5% of children with unilateral posterior crossbite, while in our study 87.1% of patients in the ULCB group were also found to have an incorrect tongue posture, while their tongue motor function was preserved.

The evaluation of the speech therapist examination showed that patients with ULCB had a significantly higher prevalence of articulation disorders. Laine *et al.* [50] concluded that risk factors for incorrect articulation appear to be occlusal abnormalities which affect the position of the tongue and hyoid bone, reduce the intermaxillary space in the posterior part of the oral cavity, or affect the size and shape of the resonance space in the anterior part of the oral cavity. Grabowski *et al.* [51] reported that in patients with posterior crossbite, the prevalence of articulation disorders was 56.5% in the primary dentition and 50.4% in the early mixed dentition.

While many authors acknowledge the close relationship between form and function, the extent of their interaction remains a subject of debate [40, 52]. The development of occlusion should be understood as the outcome of interactions between genetically determined developmental factors and various external and internal environmental influences, including orofacial function [40]. One explanation for the altered balance of form and function is the relationship between mouth breathing and/or open mouth posture due to the enlarged lymphoid tissue and the lowered position of the tongue [53]. In children with nasopharyngeal obstruction, the mandible is lowered to allow mouth breathing [54]. An improper tongue position on the floor of the mouth disrupts the dynamic balance between the muscle strength of tongue, cheeks, and lips. In the case of the maxilla, there is no developmental influence on the oral surfaces of the teeth and alveolar ridge, meaning that the actions of the lips and cheeks have a dominant effect on the buccal surfaces of the maxillary teeth and alveolar ridge [10]. The lack of normal functional balance leads to the development of a narrow and short maxilla [55]. The reduced space in the maxilla forces the tongue to lie on the floor of the oral cavity, and this has a detrimental effect on morphological craniofacial features and a higher prevalence of crossbite in children with enlarged tonsils and adenoids [30, 53]. However, some authors report that the development of maxillary narrowing in unilateral functional crossbite may not be influenced by the breathing pattern [36], and it is possible for an individual to breathe through the nose while the lips are incompetent [56].

The children in the ULCB group were followed up 4 years after the initial examination.The results of the follow-up showed a significant improvement in patient-reported breathing pattern, less contraction of the mentalis muscle, and elongation of the upper lip in patients after ULCB treatment. It should be noted that the changes observed at the 4-year follow-up could be due to both treatment effects and the natural maturation process during these four years. Improvements in breathing function have been frequently described in the literature as a positive effect of treatment with RME [57–59]. In the most recent study, Pirelli *et al.* [60] used cone beam computed tomography (CBCT) to demonstrate volumetric expansion of the nasomaxillary complex and all its structures, the nasal cavity, oropharynx, and nasopharynx after RME. The increased nasal width in the posterior nasal spine (PNS) plane contributed to the increase in the volume of the nasopharynx and oropharynx. In the study published by De Felippe *et al.* [61], 61.3% of the subjects responded positively to the subjective impression of an improvement in nasal breathing after treatment with a rapid maxillary expander. In addition, the volume of the nasal cavity increases due to the mid-palatal disjunction, whereby the expansion also includes the lateral nasal walls

[61]. Similar effects and an improvement in breathing have also been reported after maxillary expansion in young patients with obstructive sleep apnea. Nasopharyngeal cavity patency decreased significantly after maxillary expansion, which could be due to the enlargement of the total nasal lumen, which increases during maxillary expansion [62, 63]. It is also known that lymphoid tissue decreases during adolescence [23]. It is likely that maxillary expansion itself influenced the decrease in size of adenoids, as the size of the palatine tonsils, which remain largely unaffected by maxillary expansion, did not change significantly during the follow-up period. These results are similar to those of Yoon *et al.* [64]; they reported a reduction in the size of tonsils and adenoids after expansion. Their study showed that 90% of patients who underwent RME had a significant reduction in the volume of the adenoids. However, the effects of RME on the function of the adenoids and tonsils are not yet known. In the same study, Yoon *et al.* [64] explained the reduction in size of the adenoids and tonsils after RME by the increased nasal volume, which reduces air velocity and resistance in the nasal cavity, and reduces inflammation and irritation of the lymphatic tissue and collapsibility of the upper airways. Restoring nasal breathing allows the inhaled air to be filtered, warmed and humidified, and may therefore help to prevent infection and possibly alleviate adenoid hypertrophy. In our study, however, there was no difference between the ULCB group and the control group with regard to the parameters of frequent throat infections and allergies recorded in the questionnaires, either at the beginning of the study or at the follow-up examination.

There was a statistically significant improvement in tongue posture after maxillary expansion at the follow-up examination. Similarly, a study by Ozbek *et al.* [65] observed an improved tongue posture at the 6-month follow-up examination and Arhar *et al.* [66] at the 12-month follow-up examination after the maxillary expansion. Studies show that due to the narrowing of the maxilla, the space required by the tongue on the roof of the mouth is insufficient, which is why the tongue posture is lower than desirable [67, 68]. Maxillary expansion probably creates additional space for the tongue, and it is hypothesized that spontaneous repositioning of the tongue on the roof of the mouth may occur in patients without respiratory disorders [67]. This could improve the long-term stability and success of maxillary expansion by equalizing buccal pressure. Normalization of tongue posture could also break a cycle of low tongue posture and inharmonious growth and replace it with a cycle of high tongue posture and harmonious growth, leading to normalization of the maxillary growth pattern and thus stable expansion [65].

The role of swallowing pattern is probably more indicative of malocclusion than a causative factor in ULCB, even though visceral swallowing has previously been associated with several malocclusions, such as ULCB [10]. The study by Grabowski *et al.* [51] showed a high prevalence of visceral swallowing type in patients with lateral crossbite in both primary and early mixed dentition, while in our study, visceral swallowing was not statistically significant at pretreatment, but at follow-up, a significant improvement of the more frequent somatic swallowing pattern was found in ULCB. This is consistent with a study by Ovsenik *et al.* [69], in which the authors found a significant correlation between swallowing pattern and tongue posture in the primary and mixed dentition, and that the visceral swallowing pattern was inversely related to the age of the children.

Although this prospective, controlled clinical study provides long-term data after ULCB treatment, it has some limitations. The number of participants in each group is relatively modest, which may lead to an increased risk of type II error. It only reports on the long-term data of ULCB, as subjects in the control group were not followed up. Children with ULCB were not reassessed by a speech and language therapist at follow-up. To increase the objectivity of the speech assessment, an artificial intelligence (AI) based tool could be used to assess articulation disorders in a recording of a representative speech sample. Therefore, we cannot say whether the affected jaw expansion contributed to the alleviation of articulation disorders. As there is no data on whether articulation improves after RME, this is certainly a research question that should be pursued in the future. ENT structures were assessed by visual observation by an ENT specialist, their condition/size was qualitatively recorded using ordinal descriptors, *e.g.*, small/medium/large. The use of an imaging method that allows volumetric quantification of these structures could further reduce potential bias and allow a distinction between relative (adenoid is relatively smaller due to the larger nasopharyngeal lumen) and absolute reduction (there is less volume of adenoid tissue) in the size of the lymphoid tissue with greater certainty. In addition to expert assessment, which can be subjective, imaging techniques, such as ultrasonography, lateral nasopharyngeal films, lateral cranial localisation films, computed tomography (CT), magnetic resonance imaging (MRI), nasal acoustic reflex, electric nasopharyngoscopy, polysomnography (PSG), and nasal endoscopy, can be used to assess the ENT structures [48].

The results of the study have clinical implications as they confirm that children with ULCB are more likely to have abnormal orofacial functions (breathing, mouth or tongue posture, and articulation), many of which are influenced by ENT structures, such as enlarged adenoids.

After RME, patients show an improvement in breathing patterns, tongue posture, and a reduction in patency of nasopharyngeal cavity. The improved nasal breathing reduces the contraction of the mentalis muscle and lengthens the upper lip.

5. Conclusions

The assessment of ENT structures and orofacial functions in children with ULCB showed that:

Patients with ULCB have a significantly higher prevalence of mouth breathing patterns, improper tongue posture at the floor of the mouth, decreased patency of nasopharyngeal cavity, and their speech exhibits more articulation disorders.

After treatment with RME, patients with ULCB observed an increase in patency of nasopharyngeal cavity. The patients also showed a better tongue posture, a nasal breathing pattern, and a somatic swallowing pattern.

AVAILABILITY OF DATA AND MATERIALS

Data is incorporated into the article. Some of the data contains sensitive personal information and is therefore protected by national and EU laws (GDPR). However, data that does not jeopardise the privacy of study participants may be made available by the corresponding author (AG) upon reasonable request.

AUTHOR CONTRIBUTIONS

MGJ, MO, AG—conceptualization. MGJ, AG, MO, IHB—methodology. AG, MGJ—formal analysis; data curation; writing–original draft preparation. MGJ, IHB, NP—investigation. MO—resources. MO, IHB, NP—writing–review and editing. AG—visualization. MO, IHB—supervision. MO, AG—funding acquisition. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval for this study was obtained from the Slovenian Ethics Committee of the Ministry of Health in Ljubljana, Slovenia (approval number: 0120-452/2024-2711-3). Written informed consent was obtained from all the participating children and their parents or their legal guardians.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2006256429948649472/attachment/Supplementary%20material.docx.

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