Original Article

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Corresponding Author:
Associated Professor
Marasri Chaiworawitkul,
Department of Orthodontics and
Pediatric Dentistry, Faculty of Dentistry,
Chiang Mai University, Chiang Mai
50200 Thailand.
E-mail: dr.marasri@gmail.com

Comparison of the Upper Pharyngeal Airway in Thai Children With or Without Unilateral Cleft Lip and Palate in the Supine Position

Prang Wiwattanadittakul[1], Marasri Chaiworawitkul[2], Nuntigar Sonsuwan[3], Sangsom Prapayasatok[4]

[1]Postgraduate Student in Residency Training Program of Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University, Thailand
[2]Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University, Thailand
[3]Department of Otolaryngology, Faculty of Medicine, Chiang Mai University, Thailand
[4]Department of Oral Biology and Diagnostic Sciences, Faculty of Dentistry, Chiang Mai University, Thailand

Abstract

Objectives: This study aimed to evaluate differences in the upper pharyngeal airway morphology between Thai children with repaired unilateral cleft lip and palate (UCLP) and Thai non-cleft children.

Methods: This prospective study used cone beam computed tomography (CBCT) and polysomnography (PSG) studies. The subjects were 34 children with UCLP (21 males and 13 females; mean age 8.94±1.87); and 32 non-cleft children (20 males and 12 females; mean age 10.03±1.91). The Dolphin imaging software measured the volume and the most constricted cross-sectional airway (version 11.7 premium).

Results: An independent sample t-test showed that the differences between groups were significant. The means of oropharyngeal (p=0.003), hypopharyngeal (p=0.020), and total volume (p=0.013) in UCLP children were lower than those in non-cleft children. Furthermore, the most constricted axial area of the oropharyngeal airway in UCLP children was narrower than that in non-cleft children (p=0.004).

Conclusions: The volume and most constricted axial area of the upper pharyngeal airway in Thai UCLP children were significantly smaller than those in Thai non-cleft children.

Keywords: cleft lip and palate, cone-beam computed tomography, upper pharyngeal airway lumen, upper pharyngeal airway volume

Introduction

Orofacial clefts are the most common congenital defect in head and neck regions.[1] Studies in newborn infants in the northern Thai population have shown a prevalence of 1.6 per 1000 newborn children.[2] These defects can significantly impact facial growth, particularly in the midface, pharyngeal airway, and maxilla.[3,4] Moreover, medical conditions such as respiratory constriction, sleep problems, obstructive sleep apneas (OSAS), adenoid hypertrophy and velopharyngeal insufficiency[5-7] have been reported in children with cleft lip and palate (CLP), significantly affecting their quality of life.[8]

Sleep disorder breathing (SDB) encompasses various conditions characterized by snoring and resistance while breathing during sleep, the range of it was from just primary snoring (PS) to upper airway resistance syndrome and apnea (OSAS, Central Sleep Apnea, and Mixed Sleep Apnea).[9] According to the American Thoracic Society, OSAS in children is defined as a disorder of breathing during sleep characterized by prolonged partial upper airway obstruction and/or intermittent complete obstruction (obstructive apnea) that disrupt normal ventilation during sleep and normal sleep pattern.[10-12] OSAS is associated with various risk factors, including obesity (defined as a body mass index (BMI) greater than 22 kg/m^2), hypertrophy of the adenoid and enlargement of the tonsil glands.[11,13,14] Polysomnography (PSG) is a fundamental tool for diagnosis and treating sleep disorders. It is considered the gold standard for diagnosing sleep-related breathing disorders, including OSAS.[11] PSG data, including parameters such as apnea-hypopnea index (AHI), desaturation index (DI) and oxygen saturation levels, are utilized for diagnosing SDB.[15] In children, a normal AHI is one event per hour of total sleep time (hrTST), mild OSA is AHI one to five, moderate OSA is five to ten and severe OSA is more than ten.[11] Severe OSAS patients often use continuous positive air pressure machines (CPAP) to keep their airway open during sleep.[16]

The pharyngeal airway has been identified as a fundamental risk factor of OSAS in children. Previous studies have attempted to clarify the differences in the upper pharyngeal airway between CLP and non-cleft patients, using lateral cephalogram for calculation and estimation.[17] Nowadays, 3-dimensional (3D) cone-beam computed tomography (CBCT) images are considered more precise for evaluating the airway.[18,19] Software, such as the Dolphin imaging program, has been tested and proven accurate and reliable in evaluating both the volume and axial areas of the upper pharyngeal airway compared to other digital software programs.[20,21]

Muntz *et al*.,[1] Oosterkamp *et al*.,[22] and Celikoglu *et al*.[23] explained that cleft patients have a smaller pharyngeal airway size and volume compared to normal children. However, controversially, Ceilo *et al*.[24] and Rana *et al*.[25] found no difference in the upper pharyngeal airway between normal and abnormal children. Several studies have been conducted to evaluate the upper pharyngeal airway in an upright position[25,26], while sleep problems are typically identified during sleep or in the supine position.[5] To date, reports on the upper pharyngeal airway in growing unilateral CLP (UCLP) patients in the supine position using 3D radiographs are scarce, with none comparing cleft and non-cleft conditions.[27] Therefore, this prospective study focused on comparing the sizes of the most constricted axial area and volume of the upper pharyngeal airway using CBCT in the supine position between groups, controlling for demographics and PSG findings.

Materials and Methods

This study was conducted prospectively, enrolling subjects from patients who visited Chiang Mai University Hospital and the Faculty of Dentistry, Chiang Mai University, during the period from 2019 to 2021. The study received ethical approval from the Human Experimental Committee of the Faculty of Dentistry, Chiang Mai University, Thailand (No. 59/2019). Prior to participation, patients and their caregivers provided informed consent for the release of their CBCT scans, polysomnography reports, and medical information to the researchers.

Participants

The study included Thai children aged 5 to 12 years who visited the hospital and the Faculty of Dentistry during the period from 2019 to 2021. A total of 66 children who met the criteria for undergoing CBCT scans of their orofacial regions were divided into two groups.

The first group comprised of thirty-four children diagnosed with UCLP, without any additional orofacial cleft deformities. All participants in this group had undergone cheiloplasty and palatoplasty procedures at the appropriate times. The second group, consisting of thirty-two children, had no orofacial cleft conditions.

All participants with adenotonsillar hypertrophy were undergoing medication treatment for six weeks. However, those with a history of continuous positive airway pressure therapy, suspected or diagnosed with central sleep apnea or mixed sleep apnea, as well as participants and parents who did not agree to participate in the research project, were excluded from the study.

Measurements

Participants provided their personal information, including age, sex, weight and height. Body mass index (BMI) of each patient was calculated. A thorough medical evaluation of each child's tonsil glands and adenoid size was conducted by a physician. The physical examination of tonsil size used the Brodsky scale, which classifies tonsillar gland enlargement into five grades (0-4), with higher grades indicating more severe enlargement[28] (Figure 1). Adenoid hypertrophy was clinically evaluated using the adenoid-to-choanal opening ratio as a percentage, divided into three groups: groups 1-3 represented adenoid tissue occupying more than 50%, 50–75%, and more than 75%, respectively.[29] Overnight portable PSG type 4 (SOMNOlab-2, Hamburg, Germany) was conducted for all participants. A pediatric otolaryngologist with 12-year of expertise analyzed the PSG data to determine the AHI, DI, minimum oxygen saturation and average oxygen saturation.

CBCT scans of the samples were obtained using the MobiiScan scanner, following a standard protocol with specific settings (90 kV, 6 mA, 16 cm×16.8 cm FOV, 0.4 mm voxel size and 26 s scanning time).[30] The patients were positioned in the supine position on the machine bed, maintaining maximum intercuspation occlusion. The supine position was established using the machine's laser guide. During image acquisition, the subjects were instructed not to swallow or change positions.

Subsequently, CBCT DICOM raw files were exported and analyzed using the Dolphin imaging software (version 11.7 premium, Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). A clinician identified the boundaries of the upper pharyngeal airway prior to assessing airway volume using specific tools in the program. (Figure 2)

According to Rana *et al*.[25] assessment methods, we had calibrated the orientation of the images by using the manual option in the Dolphin imaging program. The midsagittal plane from Ricketts's analysis was adjusted in the frontal plane as illustrated in Figure 3. In cases of asymmetry, patients' conditions were assessed at the discretion of their attending physician. The sagittal planes were then adjusted using the Frankfort horizontal plane, a plane extending from left Orbitale to both Porion points. Using Dolphin 3D analysis, the clinician measured the volume and the most constricted axial area of the upper pharyngeal airway[25], employing the same anatomical landmarks as in 2D images as illustrated in Figure 4 and Figure 5. The definitions of all anatomical landmarks are described in Table 1. The linear axial slice 2D images of the pharyngeal airway were segmented into three planes for each part of the upper pharyngeal airway: the nasopharyngeal area, the oropharyngeal area and the hypopharyngeal area.

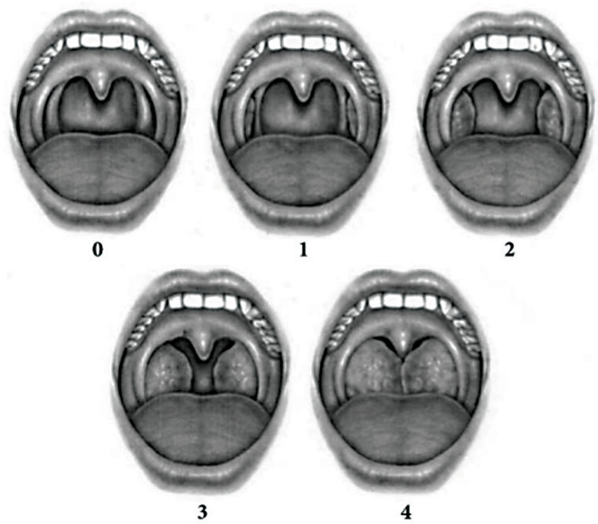

Figure 1: The tonsil grading scale from Brodsky grading scale as described in Cahali *et al*.[26]

Data Analysis

The Statistical Package for Social Sciences (SPSS) version 26.0 for Windows (IBM Corp., Armonk, New York, USA) was used for data analysis. Data normality was assessed using the Shapiro-Wilks test. Analysis of Variance (ANOVA) was employed to evaluate the differences in age, baseline characteristics and PSG findings between the groups.

To ensure accuracy and minimize errors in measurement and digital programming, each value was measured three times, and the mean was calculated. Intra-examiner

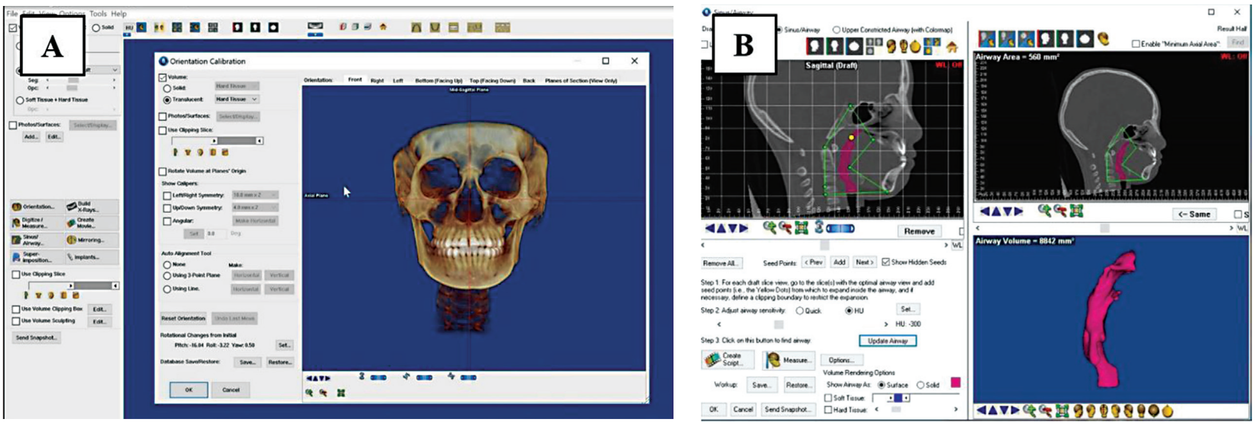

Figure 2: Screenshots of the Dolphin software, showing the manual option: (A) The orientation calibration (B) Airway measurement

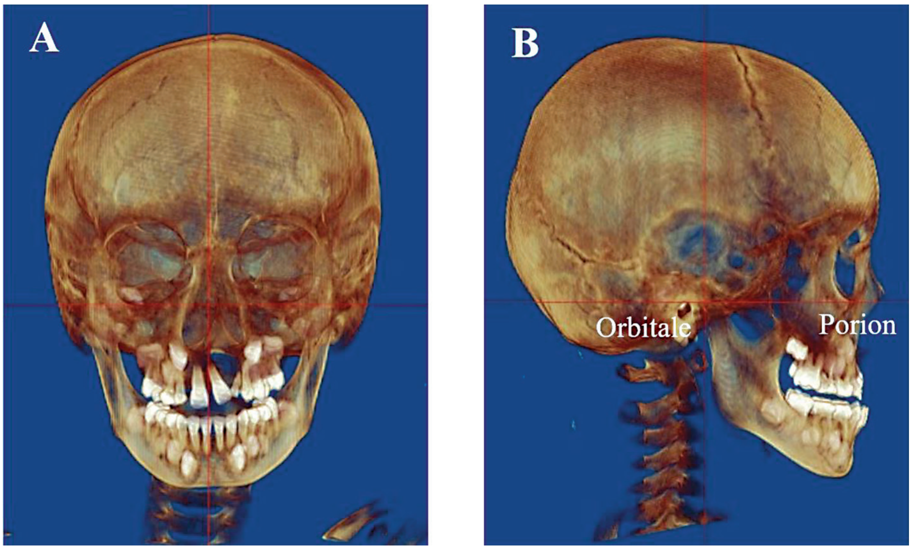

Figure 3: Adjusting the orientations of the images in two views prior to conducting measurements. (A) Frontal view was perpendicular to sagittal view and (B) Sagittal view with Frankfort horizantal plane (porion-orbitale).

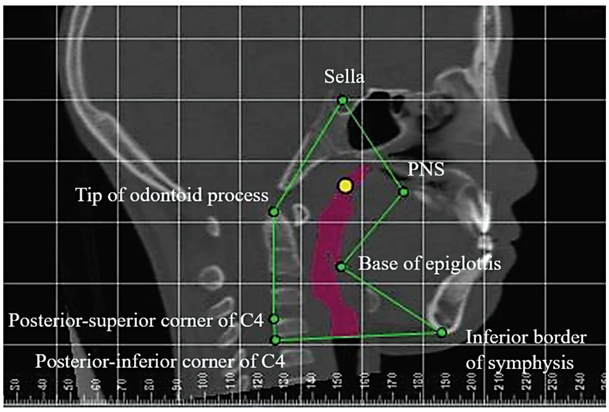

Figure 4: The anatomical landmarks identified in Dolphin 3D images. Labels in the form of green dots were strategically located to indicate the location of each major landmark. The images showed the upper pharyngeal airway spaces as the pink area.

assessment involved repeating the airway assessment on 10 radiographs, conducted three times within one week and then once more after one month from the initial assessment. For inter-examiner reliability, the assessments of 10 radiographs were compared with those of an expert. Additionally, an independent sample t-test was used to assess mean differences between the UCLP and non-cleft groups. *P*-value of less than 0.05 was considered as statistical significance.

Results

The demographic data for the study participants are presented in Table 2. The chronological ages of all patients ranged from 5.00 to 12.00 years, with a mean age of 9±2 years for the UCLP group and 10±2 years for the non-

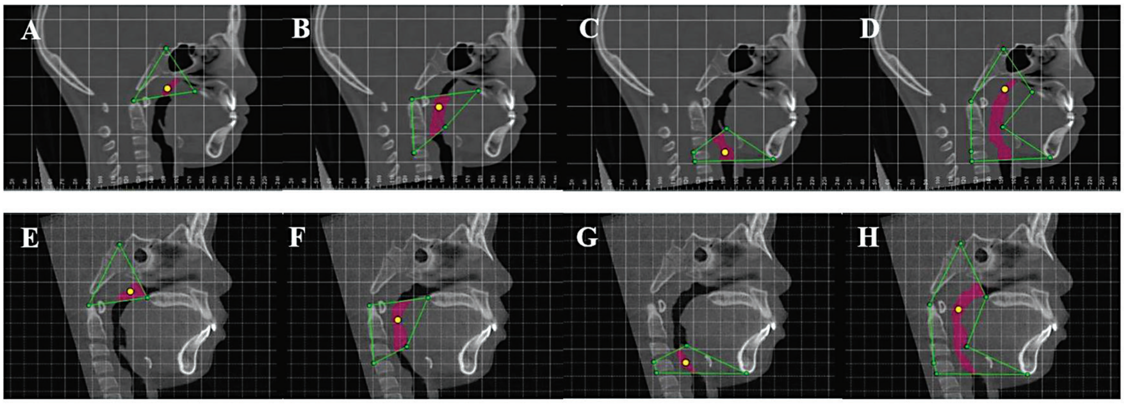

Figure 5: Assessment in sagittal view from CBCT in Dolphin software: (A) - (D) images were example images from UCLP subject, and (E) - (F) images were example images from non-cleft subject. (A) and (E); The image of nasopharyngeal airway (Sella-PNS-tip of odontoid process), (B) and (F); The images of oropharyngeal airway (tip of odontoid process - PNS - base of epiglottis - posterior-superior corner of C4), (C) and (G); The images of hypopharyngeal airway (posterior-superior corner of C4 - base of epiglottis - inferior border of symphysis - posterior-inferior corner of C4), and (D) and (H); The images of total upper pharyngeal airway spaces (all landmarks were used to construct the areas).

Table 1: The definition of CBCT anatomic landmarks as described in Rana S *et al.*[25]

Region	Anterior boundary	Posterior boundary	Superior boundary	Inferior boundary
Nasopharyngeal	Line extending from Sella (S) to the posterior nasal spine (PNS)	Line extending from Sella (S) to the tip of the odontoid process		Line extending from the PNS to tip of the odontoid process
Oropharyngeal	Line extending from the PNS to the base of the epiglottis	Line extending from the tip of the odontoid process to the posterior-superior border of cervical vertebra 4 (C4)	Line extending from the PNS to the tip of the odontoid process	Line extending from the base of the epiglottis to the posterior-superior border of C4
Hypopharyngeal	Line extending from the base of the epiglottis to the inferior border of the symphysis	Line extending from the posterior-superior corner of C4 to the posterior-inferior corner of C4	Line extending from the base of the epiglottis to the posterior-superior corner of the C4	Line extending from the posterior-inferior corner of C4 to the inferior border of the symphysis

cleft group. Within the UCLP group, there were 21 males and 13 females, while the non-cleft group consisted of 19 males and 13 females.

The average BMI of all subjects was below 22.9 kg/m^2, indicating that the sample was not considered obese. Both groups exhibited similar baseline demographics, adenotonsillar hypertrophy index, and polysomnographic findings.

Comparison between UCLP and non-cleft groups

The reliability tests conducted for intra- and inter-examiner measurements showed strong correlations (r=0.999, r=0.998), demonstrating a high level of reproducibility in the measurements. Analysis using the independent t-test revealed significant differences between the UCLP and non-cleft subjects in oropharyngeal volume (p=0.003), hypopharyngeal volume (p=0.020), total volume (p=0.013) and the most constricted axial area of the oropharyngeal airway (p=0.004). Furthermore, Figure 6 and 7 display the averages of the upper pharyngeal airway parts' volume and the corresponding most constricted cross-sectional areas.

Discussions

In this study, we aimed to compare the upper pharyngeal airway in Thai children with and without Unilateral Cleft Lip and Palate (UCLP) in the supine position. Orofacial clefts are common congenital defects that can

Table 2: The baseline demographics and polysomnographic findings

Variables		UCLP (n=34)	Non-cleft (n=32)	*p*-value
Demographic				
Sex	cases	male, 21; female, 13	male, 19; female, 13	0.020[a]
Age (years)	mean±SD	8.94±1.87	10.03±1.91	0.002[a]
Weight (kg)	mean±SD	30.01±9.57	40.90±17.21	0.003[a]
Height (cm)	mean±SD	130.38±12.08	141.02±15.52	0.032[a]
Body mass index (kg/m^2)	mean±SD	17.32±3.63	19.87±5.35	
Adenotonsillar hypertrophy index				
Tonsil size				
Brodsky scale 0	cases	8	7	
Brodsky scale 1	cases	11	3	
Brodsky scale 2	cases	8	14	0.102[b]
Brodsky scale 3	cases	7	7	
Brodsky scale 4	cases	0	1	
Adenoid-to-choanal opening ratio	percentage	55.85±22.83	45.16±22.41	0.059[a]
Polysomnographic findings				
Apnea-hypopnea index	per hour	2.23±3.05	2.53±3.93	0.733[a]
Desaturation index	per hour	3.78±3.27	4.63±5.80	0.463[a]
Minimum oxygen saturation	percentage	79.03±8.38	80.34±8.84	0.538[a]
Average oxygen saturation	percentage	97.52±0.87	96.93±1.12	0.019[a]

UCLP=unilateral cleft lip and palate; [a]One-way ANOVA; bFisher's Exact test; * indicates statistical significance: $p<0.01$

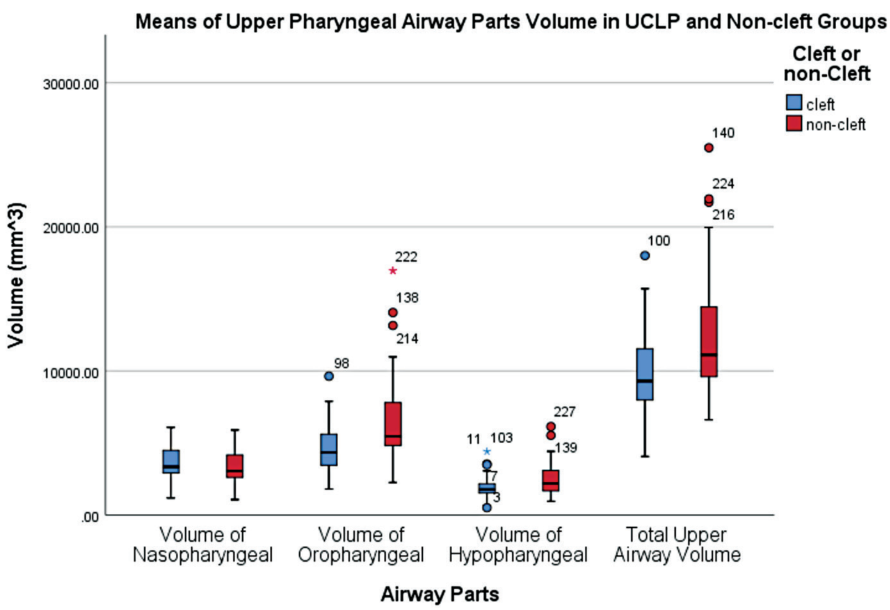

Figure 6: Box plots for the comparisons of the means volume of upper pharyngeal airway between UCLP and non-cleft groups.

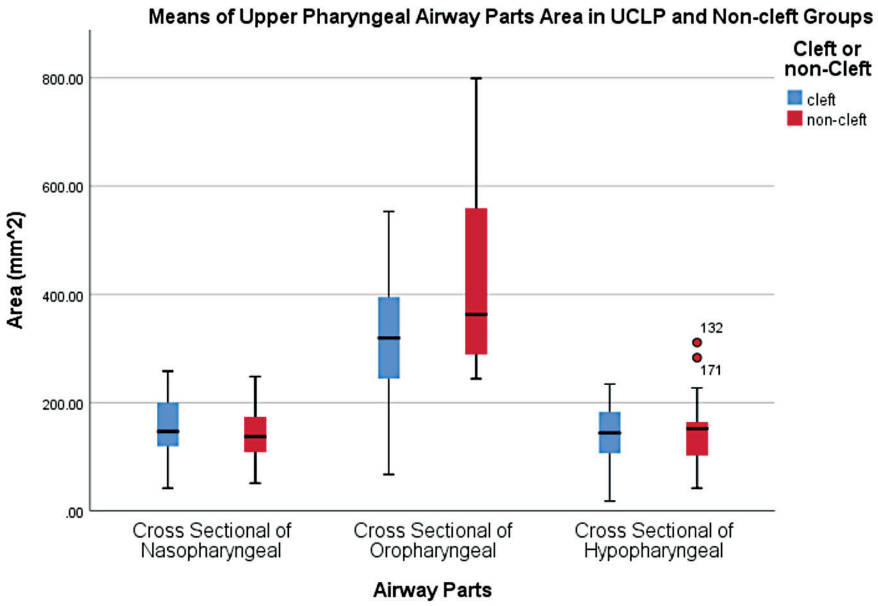

Figure 7: Box plots for the comparisons of the means of the most constricted cross-sectional area in each airway (mm^2) between two groups.

impact facial growth and lead to medical conditions such as obstructive sleep apneas. The upper pharyngeal airway has been identified as a crucial risk factor for sleep-related breathing disorders in these children. To achieve this comparison, we used 3D cone beam computed tomography (CBCT) and polysomnography data. The findings from this study contribute to a better understanding of the airway differences in children with UCLP, potentially aiding in the development of targeted interventions for better respiratory health and improved quality of life.

The results of this study revealed that the mean total volume of the upper pharyngeal airway in non-cleft patients was significantly larger compared to the UCLP groups. This finding is supported by Celikoglu *et al*.[23] and Karia *et al*.[31], who also reported decreased volumes and cross-sectional areas of the oropharyngeal and total upper airways in UCLP patients.

Regarding the nasopharyngeal airway, the mean volume and the most constricted cross-sectional area were larger in the UCLP group than in the non-cleft group, although the difference was not statistically significant, as supported by Rana *et al*.[25] Notably, despite palatoplasty surgery being performed in cleft patients, the percentage of adenoid glands in each group was quite similar to that in non-cleft patients. This could imply that the surgical deformities may have induced larger spaces in the nasopharyngeal airway. Additionally, it is important to consider that the use of PNS points as one of the landmarks for nasopharyngeal airway measurement could influence these values[3], as noted by Trindade *et al*.[32] who found anteriorly located nasal constriction in repaired cleft sides. In this study, we observed a significant difference in the mean volume of the hypopharyngeal airway between UCLP patients and non-cleft patients. Specifically, the hypopharyngeal airway volume in UCLP patients was found to be considerably smaller compared to the non-cleft group. This finding aligns with previous research by Yoshihara *et al*.[4] and Mattos *et al*.[33], who also reported a significantly larger mean volume of the oropharyngeal airway in the non-cleft group compared to the UCLP group. This reduction volume of the oropharyngeal airway in UCLP patients may be contributed to scar contraction resulting from the reparative procedures for the orofacial deformities.[34]

Moreover, our study found that the tongue positions in cleft patients were lower than those in non-cleft patients, primarily due to the smaller maxilla and the asymmetric anatomical shape of the dorsum of the tongue. Cleft patients also exhibited a higher number of muscle fibers in their tongues compared to normal children.[35] These unique characteristics of cleft patients might contribute to the observed differences in airway volume, particularly in the hypopharyngeal area, leading to a reduction in the hypopharyngeal airway volume in UCLP patients. However, our study found that the most constricted areas of the hypopharyngeal airway showed no significant difference between the two groups.

The mean total volume of the upper pharyngeal airway was significantly lower in children with UCLP children compared to non-cleft children, possibly due to the deformities resulting from the surgical procedures. Despite using CBCT images with a voxel size of 0.4 mm, previous research reported no significant differences in measurement accuracy between voxel sizes of 0.2 mm and 0.4 mm.[36] Taking a CBCT in the supine position, akin to sleeping, is relevant as gravity has been shown to influence airway shape and volume in different body positions.[27,37] However, it is worth noting that CBCT measurements of the minimum axial area and cross-sectional area at the level of vallecula in the pharyngeal airway may be subject to unreliability, as mentioned by Mattos *et al*.[33] Additionally, the study was limited in its inability to control for craniocervical inclination during CBCT scans, which could influence the alteration of the pharyngeal airway space[38] due to constraints with the MobiiScan system. On the other hand Rana *et al*.[25] suggested that using landmarks based on bony structures and soft tissue anatomy in the sagittal view of 2D cephalometric radiograph could minimize inaccuracies in measurements and allow reproducibility by other specialists. However, in UCLP patients with severe palate malformations, the shorter PNS points were more challenging to accurately mark.[3]

An additional limitation of the research is related to the postoperative deformities observed in UCLP children following cheiloplasty and palatoplasty procedures. These deformities have the potential to impact the anatomical structure and function of the participants. To mitigate of individual growth variations, subjects with dramatically different baseline demographics and measures were excluded.

Conclusions

In conclusion, this study provided comparison results of the upper pharyngeal airway in Thai children with and without UCLP in the supine position. We found that the volume and most constricted cross-sectional areas of the nasopharyngeal airway did not significantly differ between the UCLP and non-cleft groups. However, the oropharyngeal airway in the UCLP group exhibited significantly smaller volume compared to the non-cleft group, as did the hypopharyngeal airway. The total volume of the upper pharyngeal airway was also significantly less in the UCLP group. These findings highlight the importance of assessing the pharyngeal airway in children with UCLP, as it may have implications for their respiratory health and overall quality of life.

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Conflicts of Interest

The authors declare no conflicts of interest.

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