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Long-term Morphological Changes of the Velum and the Nasopharynx in Patients With Cleft Palate

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Abstract

Objective: To investigate long-term morphological changes in the soft palate length and nasopharynx in patients with cleft palate. We hypothesized that there would be differences in the morphological development of the soft palate and nasopharynx between patients with and without cleft palate and that these developmental changes would negatively affect the soft palate length to pharyngeal depth ratio involved in velopharyngeal closure for patients with cleft palate.

Design: Retrospective, case-control study.

Setting: Institutional practice.

Patients: Ninety-two patients (Group F) with unilateral cleft lip, alveolus, and palate and 67 patients (Group CLA) with unilateral cleft lip and alveolus not requiring palatoplasty were included.

Main Outcome Measures: The soft palate length, nasopharyngeal size, and soft palate length to pharyngeal depth ratio were measured via lateral cephalograms obtained at three different periods.

Results: Group F showed a shorter soft palate length and smaller nasopharyngeal size than Group CLA at all periods. Both these parameters increased with age, but the increase in amount was significantly less in Group F compared with that in Group CLA. The soft palate length to pharyngeal depth ratio in Group F decreased with age.

Conclusions: In patients with cleft palate, the soft palate length to pharyngeal depth ratio, which is involved in velopharyngeal closure, can change with age. Less soft palate length growth and unfavorable relationship between the soft palate and nasopharynx may be masked in early childhood but can manifest later on with age.

Keywords
cleft lip and palate, velopharyngeal closure, palatoplasty, nasopharynx

Introduction

Velopharyngeal closure is a mechanism that enables closing of an opening of the nasopharynx by coordination between elevation of the soft palate and contraction of the pharyngeal circumferential wall (Perry, 2011; Glades and Deal, 2016; Perry et al., 2018). Velopharyngeal closure increases the intraoral pressure that is necessary to blow air effectively and for consonant pronunciation (Glades and Deal, 2016). It also prevents intrusion of food or liquid into the nasal cavity during swallowing (Perry, 2011; Perry et al., 2018).

The soft palate is elevated mainly by the contraction of the palatine levator muscle, and the pharyngeal circumferential wall is contracted mainly by the nasopharyngeal contractile muscle (Perry, 2011; Glades and Deal, 2016; Perry et al., 2018). Therefore, muscle reconstruction and replacement are necessary for children with cleft palate to achieve adequate

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velopharyngeal closure (Perry et al., 2018). Moreover, a soft palate elongated backwards by surgery is beneficial for adequate velopharyngeal function (Iwasaki et al., 2012). However, even if the palatoplasty is conducted appropriately, velopharyngeal insufficiency persists in 15–30% of children with cleft palate (Schuster et al., 2013; Woo, 2017). Many reports have stated that approximately 10–20% of children with cleft palate need further surgical treatments (Pigott et al., 2002; Lohmander and Persson, 2008; Lohmander et al., 2012). Congenital short palate and levator muscle hypoplasia may cause velopharyngeal closure dysfunction in such patients (Hassan and Askar, 2007; Mahoney et al., 2013). Moreover, the scar formation following palatoplasty is plausibly considered to have a negative impact on velopharyngeal function (Oosterwijk et al., 2017; Yannas et al., 2017) as well as maxillary growth (Woo, 2017).

It is also known that the function of velopharyngeal closure changes with age due to nasopharyngeal anatomical growth in patients with and without cleft palate (Fletcher, 1966; Siegel-Sadewitz and Shprintzen, 1986; Perry et al., 2019). In 2015, Kitano et al., reported that among patients with cleft palate who underwent palatoplasty, complete velopharyngeal closure at the age of 4 years was seen in approximately 90% of the patients, but complete velopharyngeal closure until the age of 16 years was maintained in less than 30% of them. This exacerbation has been attributed to age-dependent changes in anatomy, such as shrinkage of the adenoid tissue and a downward shift of the palatal plane (Subtelny, 1957).

In addition, balanced growth of the soft palate and the nasopharynx plays an important role in normal velopharyngeal function (Satoh et al., 2004). Patients with lip and alveolus cleft who did not require palatoplasty were found to maintain normal velopharyngeal function throughout their life. Thus, we hypothesized that there are developmental changes in the morphology of the nasopharynx between patients with and without cleft palate. Identifying these differences is important for understanding the effect of palatoplasty on the growth of the soft palate and the nasopharynx. In this retrospective, case-control study, we analyzed nasopharyngeal soft tissue growth using lateral cephalograms and compared the results between the patients with and without cleft palate.

Methods

Of the series of patients who underwent palatoplasty between 1998 and 2003, patients with cephalograms that were obtained properly at specified time points were identified. Ninety-two patients with non-syndromic complete unilateral cleft lip, alveolus, and palate (Group F) were compared with 67 patients with

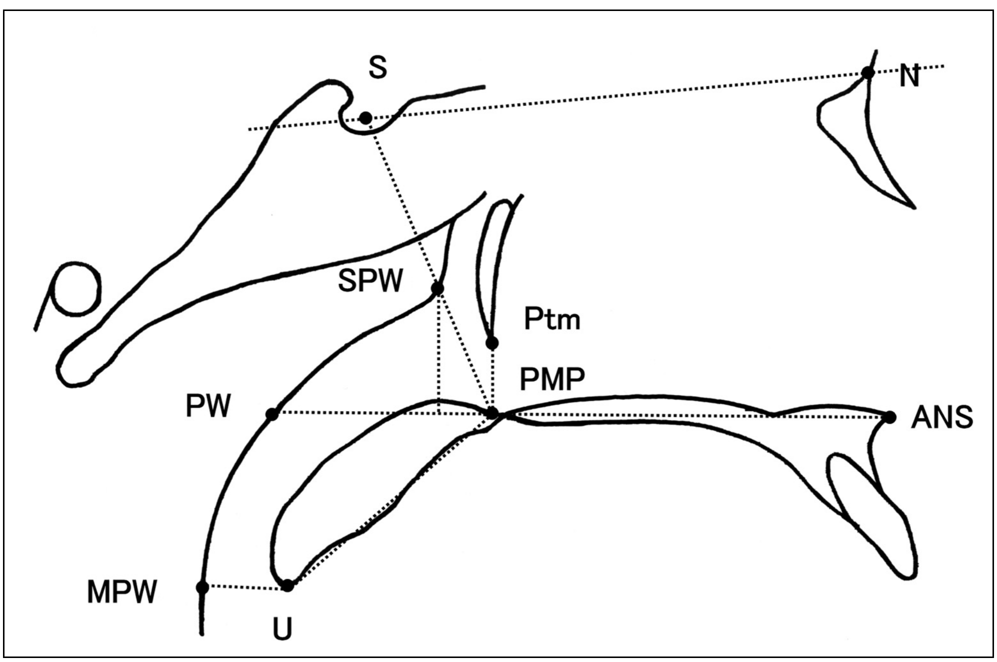

Figure 1. The cephalometric landmark points: S, center of the sella turcica; N, nasion; Ptm, pterygomaxillary fissure; ANS, anterior nasal spine (the most anterior point of the bony palate); PNS, posterior nasal spine (most posterior point of the bony palate); PMP, posterior maxillary point. If the PNS is absent or unclear because of the cleft, the PNS would be approximated as the intersection between the palatal plane and the perpendicular line from the Ptm to the palatal plane; SPW, superior pharyngeal wall (intersection of a line passing through S and PNS/PMP with the posterior upper wall of the nasopharynx); PPW, posterior pharyngeal wall (intersection of the line extending posteriorly from the palatal plane and the posterior wall of the nasopharynx); U, tip of the velum; MPW, mesopharyngeal wall (intersection of a line parallel to the palatal plane, passing through U and the posterior wall of the nasopharynx). Reference lines: *Palatal plane*, the line passing through the ANS and PNS/PMP; *SN plane*, the line passing through sella and nasion. Measured soft tissue variables: *Soft palate length*, PMP-U length; *Upper pharyngeal height*, the length of the perpendicular from SPW to the palatal plane; *Pharyngeal depth*, PNS/PMP-PPW length; *Nasopharyngeal depth*, U-MPW length; *Soft palate inclination angle*, ANS-PMP-U angle; *Palatal plane inclination angle*, angle between the SN and Palatal plane.

Table 1. Distribution of the subjects.

Stage (males / females)	Group	Subject Number	Age, mean (SD)
Childhood period	F	21 (12/9)	4 years 10 months (10 months)
	CLA	17 (8/9)	5 years 6 months (5 months)
School period	F	38 (23/15)	8 years 8 months (6 months)
	CLA	29 (13/16)	8 years 6 months (8 months)
Adolescent period	F	33 (18/15)	12 years 8 months (10 months)
	CLA	21 (10/11)	12 years 6 months (6 months)

non-syndromic unilateral cleft lip and alveolus (Group CLA). All patients received continued care and management at our Department from birth into adulthood. At approximately 3 months of age, the patients underwent cheiloplasty using the modified Millard technique. Additionally, all the patients in Group F were treated with our early two-stage palatoplasty protocol (Yamanishi et al., 2011), in which soft palate closure was performed using the Furlow double-opposing Z-plasty technique at approximately 12 months of age, and the residual cleft in the hard palate was closed at approximately 18 months of age.

We analyzed nasopharyngeal morphologic changes using lateral cephalograms obtained in three distinct periods: the childhood period (4–5 years old), school period (approximately 8 years old), and adolescent period (14 years old). Lateral cephalograms were obtained with the patient in a standing position and with the lip relaxed at rest. The head position was standardized with the Frankfurt plane parallel to the horizontal plane, and the infraorbital plane was positioned parallel to the horizontal plane. Although cephalograms were obtained for all patients, some cephalograms were not focused due to an unconscious head position and the patient shifting their posture. Therefore, we could not assess all cephalograms properly, and there may be a selection bias on target patients.

For this study, lateral cephalograms were reformatted using WinCeph® software (Rise Co. Ltd., Japan). Scaled calibration was performed before identifying cephalometric landmarks in this program. The first analysis step involved determining 10 landmark points on each cephalogram. These landmark points were used to determine seven reference lines, allowing for measurements of four soft tissue lengths, two soft tissue angles, and one ratio variable (Figure 1). The increases in soft palate lengths between the childhood and school periods were obtained by subtracting the average values at childhood from the corresponding values from the school period. The adequate ratio was defined as the ratio of the soft palate length to the pharyngeal depth.

To minimize error in this study, measurements were carried out twice at 1-week intervals by the same examiner. Intra-examiner reliability was assessed by calculating Spearman's correlation coefficient using the rank test, and the calibration showed a high correlation of 0.93. The standard error was less than 0.6 mm and 0.7° for each measurement. There was also no remarkable difference between the first and second measurements, and the first measurements were used for statistical analysis. Results are expressed as the mean, standard deviation (SD), mean difference, and 95% confidence interval of the mean difference (95% CI). The Student's *t*-test was used for comparisons between groups. The threshold for statistical significance was set at $P < 0.05$.

Results

The demographic characteristics of all patients are listed in Table 1, and the measurement results are presented in Table 2–5. The soft palate length and the upper pharyngeal height showed remarkable increases throughout the study period in both groups. However, these values were lower in Group F than in Group CLA at each time point. Further, the

Table 2. Cephalometric measurements (length).

	Period	mean (SD)		mean difference	(95% CI)	*P-value*
		Group F	Group CLA			
Soft palate length (mm)	Childhood	21.5 (2.3)	22.9 (2.3)	1.36	(−0.18, 2.90)	$p = 1.36$
	School	23.2 (2.4)	25.6 (1.9)	2.46	(1.42, 3.51)	$p < 0.01$
	Adolescent	24.9 (2.3)	28.7 (2.7)	3.77	(2.31, 5.24)	$p < 0.01$
Pharyngeal height (mm)	Childhood	11.9 (2.8)	14.8 (2.1)	2.91	(1.31, 4.50)	$p < 0.01$
	School	13.9 (2.7)	17.3 (2.8)	3.37	(2.01, 4.73)	$p < 0.01$
	Adolescent	16.4 (2.2)	20.7 (1.8)	4.27	(3.16, 5.37)	$p < 0.01$
Pharyngeal depth (mm)	Childhood	14.9 (4.1)	20.8 (3.2)	5.88	(3.50, 8.26)	$p < 0.01$
	School	17.9 (4.7)	23.2 (3.0)	5.23	(3.35, 7.11)	$p < 0.01$
	Adolescent	20.1 (3.7)	26.3 (2.9)	6.24	(4.44, 8.04)	$p < 0.01$
Nasopharyngeal depth (mm)	Childhood	12.5 (3.0)	12.0 (3.1)	-0.57	(-2.59, 1.45)	$p = 0.57$
	School	13.4 (3.5)	12.8 (2.9)	-0.60	(-2.17, 0.98)	$p = 0.46$
	Adolescent	13.5 (2.9)	13.2 (3.2)	-0.29	(-2.04, 1.47)	$p = 0.74$

Table 3. Cephalometric measurements (angle).

	Period	mean (SD) Group F	Group CLA	mean difference	(95% CI)	*P-value*
Soft palate inclination angle (°)	Childhood	132.0 (9.0)	138.8 (4.3)	6.84	(2.30, 11.38)	$p < 0.01$
	School	127.3 (7.5)	137.2 (6.6)	9.95	(6.50, 13.40)	$p < 0.01$
	Adolescent	126.2 (8.1)	135.8 (6.8)	9.53	(5.44, 13.63)	$p < 0.01$
Palatal plane inclination angle (°)	Childhood	8.9 (1.8)	6.6 (3.9)	2.26	(-1.45, 5.97)	$p = 0.20$
	School	10.3 (2.5)	7.2 (3.6)	3.17	(0.78, 5.56)	$p = 0.01$
	Adolescent	10.4 (3.9)	7.7 (3.9)	2.68	(-0.47, 5.82)	$p = 0.09$

Table 4. Adequate ratio.

	Period	mean (SD) Group F	Group CLA	mean difference	(95% CI)	*P-value*
Adequate ratio	Childhood	1.55 (0.48)	1.12 (0.18)	−0.43	(−0.66, −0.20)	$p < 0.01$
	School	1.42 (0.60)	1.12 (0.16)	−0.29	(−0.50, −0.09)	$p < 0.01$
	Adolescent	1.28 (0.19)	1.10 (0.13)	−0.18	(−0.30, −0.07)	$p < 0.01$

Table 5. The increase amount (length).

P-value	Period	mean (SD) Group F	Group CLA	mean difference	(95% CI)	P-value
Soft palate length (mm)	School - Childhood	1.61 (2.42)	2.71 (1.87)	1.10	(0.06, 2.15)	$p = 0.04$
	Adolescent - School	1.76 (2.33)	3.14 (2.85)	1.31	(−0.16, 2.77)	$p = 0.08$
Pharyngeal height (mm)	School - Childhood	2.04 (2.69)	2.51 (2.80)	0.465	(−0.89, 1.82)	$p = 0.50$
	Adolescent - School	2.49 (2.21)	3.38 (1.80)	0.896	(−0.21, 2.00)	$p = 0.11$
Pharyngeal depth (mm)	School - Childhood	2.99 (4.69)	2.34 (2.97)	−0.65	(−2.53, 1.23)	$p = 0.49$
	Adolescent - School	2.13 (3.70)	3.14 (2.85)	1.01	(−0.79, 2.81)	$p = 0.27$

increase in these values was smaller in Group F than in Group CLA. The pharyngeal depth also showed an increase throughout the study period in both groups, and the values in Group F were consistently lower than those in Group CLA. From the childhood to school period, the increase in the pharyngeal depth was greater in Group F than in Group CLA, but from the school period to adolescence, it was greater in Group CLA than in Group F. The nasopharyngeal depth showed a consistent increase throughout the study period and was greater in Group F than in Group CLA at each time point; however, there was no statistically significant difference between the groups.

The soft palate inclination angle showed a consistent decrease throughout the study period. The soft palate inclination angle in Group F was significantly lower than that in Group CLA at each time point. The palatal plane inclination angle showed a consistent increase throughout the study period and was greater in Group F than in Group CLA; however, there was only a significant difference between the groups in the school period.

The adequate ratio in Group CLA remained stable from childhood to adolescence. Moreover, the adequate ratio was significantly higher in Group F than in Group CLA at each time point, but it consistently decreased throughout the study period, resulting in a significant difference between the values in childhood and adolescence.

Conclusion

Obtaining appropriate velopharyngeal function after palatoplasty is essential for patients to achieve correct speech. There are various examinations to evaluate velopharyngeal function; however, there are no examinations to examine the entire function spectrum, including three-dimensional morphology and movement. Lateral cephalometric analysis is one of the most commonly performed examinations to evaluate the velopharyngeal function based on the morphology of the soft palate and the surrounding maxillofacial structures in the sagittal plane (Mazaheri et al., 1994). Although three-dimensional evaluations with the endoscope are recommended (Siegel-Sadewitz and Shprintzen, 1986), two-dimensional cephalometric evaluation has a lower burden and can therefore be easily conducted with children at an early age.

Therefore, we analyzed data obtained from lateral cephalograms taken at rest and compared morphological changes in the nasopharyngeal elements from early childhood to adolescence between patients with a repaired cleft palate and patients in the control group with lip and alveolus cleft who did not require palatoplasty. However, we excluded some unclear cephalograms of patients who underwent X-ray examination with consent. It was ethically unacceptable to re-take cephalograms for our study because of the irreversible risk of X-ray exposure. Therefore, it was possible that all patients were not evaluated similarly or objectively by the restriction on additional examinations. The possibility of the selection bias on target patients is limitation of our study and suffer from the inherent problem of distort our results.

Morphologically, it is known that the soft palate length and the pharyngeal depth are important elements for velopharyngeal closure (Satoh et al., 2005). This is because the pharyngeal depth represents the distance between the posterior maxillary bony point and the posterior pharyngeal wall at the level of the velopharyngeal closure. Sagittal cephalometric analyses have shown that the level of the velopharyngeal closure almost matched that of the extension of the palatal plane (Yoshida et al., 1992; Satoh et al., 2004). The palatal plane has also been considered a useful indicator to estimate the level of velopharyngeal closure regardless of the presence or absence of cleft palate (Satoh et al., 2005). Moreover, the posterior nasal spine is an important landmark in relation to velopharyngeal closure because it is one end of the palatal plane and the attachment site of the soft palate (Satoh et al., 2005). Owing to these features, we selected parameters such as the soft palate length, pharyngeal depth, upper pharyngeal height, and the palatal plane inclination angle as cephalometric variables in the present study to evaluate the nasopharyngeal morphology of significance to velopharyngeal closure.

The present study showed that Group F had a shorter soft palate length than Group CLA in childhood. Although the soft palate length increased continuously throughout the study period in both groups, the overall increase between each time point was less in Group F than in Group CLA. Consequently, differences in the soft palate length between both groups increased with age. This was consistent with the results of a study that showed that the soft palate length of patients with cleft palate was shorter than that of patients without cleft palate, even though the soft palate had been extended by palatoplasty in the patients with cleft palate (Satoh et al., 2005). Our results suggest that the growth of the soft palate was inhibited in Group F, resulting in velopharyngeal incompetence (Satoh et al., 2005).

In our study, the nasopharyngeal depth, measured as the distance between the apex of the soft palate and the posterior wall of the nasopharynx, showed no remarkable difference between both groups at all time points. The posterior nasal spine in the patients with cleft palate tends to deviate more posterosuperior (Satoh et al., 2004). Therefore, it is possible that there is no remarkable difference in nasopharyngeal depth between both groups, despite Group F having a shorter soft palate length than Group CLA. In contrast, the pharyngeal depth and the upper pharyngeal height were significantly less in Group F compared with those in Group CLA at each time point. Since the curve of the posterior pharyngeal wall downwards and ventrally is almost perpendicular, the larger the palatal plane inclination angle deviates, the more upward and forward is the intersection between the posterior pharyngeal wall and the palatal plane (Satoh et al., 2004; Satoh et al., 2005). The palatal plane inclination angle was larger in Group F than in Group CLA, and the nasopharyngeal size was smaller in Group F than in Group CLA. Certainly, some reports demonstrated that the posterior nasal spine in the patients with cleft palate tended to present more superiorly, resulting in a small nasopharyngeal space (Cronin and Hunter, 1980; Satoh et al., 2004; Satoh et al., 2005). Since the muscles of the soft palate in patients with cleft palate are hypoplastic, the muscle sling junction repaired by overlapping both sides of the short palatine levator muscle in palatoplasty may deviate toward the head of the muscle. This may consequently induce upward deviation of the posterior nasal spine, narrowing the nasopharyngeal size.

The adequate ratio used in our study was defined as the relative length of the soft palate to the pharyngeal depth and was calculated by Hoopes et al. (1970) to be 1.35 in adults without a history of cleft palate. The adequate ratio has been reported to be a stable indicator of how adequately the soft palate closes the pharyngeal depth and is estimated to range from 1.2 to 1.4 regardless of age in healthy people without cleft palate [Subtelny, 1957; Hoopes et al., 1970]. In the present study, the adequate ratio in Group CLA was stable and ranged from 1.10 to 1.12 throughout the study period; these values were slightly different from those seen in people without cleft palate [Hoopes et al., 1970].

In contrast, Hoopes et al. (1970) estimated the adequate ratio to be 1.05 in the patients with a repaired cleft palate having velopharyngeal insufficiency. The adequate ratio in Group F decreased with age but ranged from 1.55 to 1.28, which was significantly larger than that in Group CLA. At childhood, the soft palate length was similar between both groups, but the pharyngeal depth in Group F was significantly less than that in Group CLA. Consequently, the adequate ratio in Group F was significantly larger than that in Group CLA. In the school and adolescence periods, the increase in the soft palate length in Group F was smaller than that in the pharyngeal depth, and the adequate ratio in Group F significantly decreased in an age-dependent manner between childhood and adolescence.

The smaller nasopharyngeal size observed in Group F in childhood might have kept the soft palate close to the upper pharyngeal wall of the nasopharynx and compensated for the shorter soft palate length to obtain the velopharyngeal closure. However, the velopharyngeal closure has been reported to change with age due to the downward movement of the palatal plane, the expansion of the nasopharyngeal size, and the disappearance of the adenoids (Subtelny, 1957). The soft palate length, pharyngeal depth, and upper pharyngeal height in both groups increased with age, but the increase in Group F was less compared with that in Group CLA throughout almost the entire study period. The developmental differences in the anatomy of the nasopharynx between patients with and without cleft palate were shown in the present study.

Moreover, the age-dependent decrease in the adequate ratio in Group F suggests that the growth and extension of the soft palate could not catch up with the morphologic expansion of the nasopharyngeal size. These age-dependent changes, unfavorable for velopharyngeal closure in patients with cleft palate, could worsen the velopharyngeal competence with age. This is consistent with the findings of Kitano et al. (2015), who reported a decrease in the number of patients [with a history of cleft palate] with complete velopharyngeal function with increasing age, on speech evaluation. Changes in the velopharyngeal closure pattern have been reported to occur in 60% of children without cleft palate compared to only 30% of children with cleft palate [Siegel-Sadewitz and Shprintzen, 1986]. It is important to guide patients with cleft palate to adjust and adapt to the velopharyngeal closure pattern resulting from age-dependent changes in the nasopharyngeal morphology. Although we could not directly evaluate velopharyngeal function in this morphological study, our results suggest that patients with cleft palate should receive support from speech and language therapists based on the patient's age and growth.

Another limitation of our study is that the size of the adenoids was not evaluated. The adenoids located along the superior portion of the nasopharynx are important elements for velopharyngeal closure (Sørensen et al., 1980); they grow and increase in size between early and late childhood and then involute with age during adulthood (Ishida et al., 2018). Therefore, additional research is necessary to examine the effect of adenoids on velopharyngeal closure in patients with cleft palate.

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Supplemental Material

Supplemental material for this article is available online.

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