3-D Analysis of Palatal Morphology Associated with Palatalized Articulation in Patients with Unilateral Cleft Lip and Palate

Mai Nishikubo¹, Narihiro Hirahara¹, Akinori Gomi¹², Etsuro Nozoe¹ and Norifumi Nakamura¹

¹Department of Oral and Maxillofacial Surgery, Field of Oral and Maxillofacial Rehabilitation, Course of Advanced Therapeutics, Kagoshima University Graduate School of Medical and Dental Sciences
²Speech-Language-Hearing Therapist, Kagoshima University Hospital

Abstract: Palatalized articulation is one of the major articulation disorders which patients with cleft palate face after palatoplasty. Various causal factors have been suggested to date, but the main cause remains poorly understood. To clarify the possible causes of palatalized articulation in speakers with cleft palate, three-dimensional palatal morphology in patients with/without palatalized articulation in unilateral cleft lip and palate (UCLP) was analyzed.

Twelve UCLP patients with palatalized articulation (P group) and 20 UCLP patients with normal articulation (N group) participated in the present study. Speech was assessed in the two groups at the age of about four. Dental casts of the maxilla taken at the same time were analyzed three-dimensionally, and measurements in the horizontal, frontal, and sagittal planes were compared between patients with palatalized articulation and those with normal articulation. All dental casts were measured with a non-contact 3D laser scanner and the 3D data were analyzed with 3D-analyzing software.

Our study demonstrated three major findings of palatal morphology in UCLP patients with palatalized articulation when compared with their non-palatalized counterparts: 1) the posterior region of the palate was narrow in the horizontal plane, 2) asymmetry of the anterior palate was severe in the frontal plane, and 3) the palate was flat and shallow in the sagittal plane.

These findings suggested that palate deformities can affect the lingual-contact pattern, and may account for the backward movement of the articulation point.

Key words: cleft palate, articulation disorder, palatalized articulation, palatal form, 3D analysis

Introduction

Normal speech is the most important goal of cleft palate treatment. As surgical techniques and speech therapy have progressed, most patients with cleft lip and palate who underwent integrated treatment in our clinic achieved normal speech at the age of 4 years. However, some
patients remain troubled with speech problems.

Palatalized articulation, which is classified as consonant production errors in the universal parameters, is one of the major articulation disorders in postoperative cleft palate patients who acquired velopharyngeal closure. This pattern corresponds to abnormal backing of oral targets where the articulation point of the alveolar plosives /t, d/ backs to the mid-dorsum palate and/or velar place, while normal alveolar plosives are articulated with the tip of the tongue close to the superior alveolar ridge. Since palatalized articulation has less spontaneous improvement and poorer response to speech treatment than other abnormal articulations, it has continued to be a cause for concern. Several factors, such as a bad habit of tongue movement, palatal fistula, occlusal anomalies and abnormal morphology of the palate, have been suggested as being related to palatalized articulation, but the main factors are still not clear. For the prevention and treatment of palatalized articulation, it is necessary to examine the individual factors and the relationship among them.

Okazaki et al. reported that the incidence of palatalized articulation in patients with cleft lip and palate was significantly greater than in those with isolated cleft palate. This suggests that abnormal morphology of the palate is one of the causal factors in palatalized articulation, and the palatal form in palatalized articulation in speakers with cleft palate has been analyzed threedimensionally. Various methods have been developed for the three-dimensional (3D) analysis of morphology in patients with cleft lip and palate, with some studies analyzing the causes of palatalized articulation by focusing on palatal forms quantitatively. These investigations suggested that a small narrow anterior palate following palatoplasty could lead to abnormal contact of the tongue with the palate. Considering the articulatory movement of palatalized articulation, analyses of cross-sectional forms of the palate may give useful knowledge about the backward deviation of the contact point with the palate during the production of alveolar or dental articulation; however, there is little information about the cross-sectional form of the palate in the frontal and sagittal planes in patients with palatalized articulation.

To clarify the possible cause of palatalized articulation in cleft palate patients, we analyzed three-dimensional palatal morphology and occlusion in UCLP patients with palatalized articulation.

Materials and Methods

1. Subjects

In the Department of Oral and Maxillofacial Surgery of Kagoshima University Hospital, 354 patients with cleft palate have been treated comprehensively since 1981. Among them, 76 patients demonstrated articulation disorders, including 48 patients with palatalized articulation at 4 years of age. From these 48 patients, 12 patients with UCLP with palatalized articulation (P group) were selected for this study. Twenty patients, who also had UCLP with normal articulation (N group), were used as controls. To exclude other factors, case selection criteria were set as follows: (1) complete UCLP patients who underwent cheiloplasty and one-stage palatoplasty by the same surgical team in our clinic, (2) dental casts of maxilla taken at about 4 years, (3) adequate velopharyngeal function achieved, (4) not under other surgical or orthodontic treatments after palatoplasty until articulation assessment, (5) without systemic congenital abnormalities and mental retardation, or hearing loss, and (6) only palatalized articulation error detected. Consequently, patients with a small pinhole or fissured fistula at the anterior process were included because it was reported that the occurrence of palatalized articulation was scarcely correlated with fistula. Patients with mixed dentition were also excluded, because the landmarks identified on the palate between primary dentition and mixed dentition were inconsistent on the 3D analysis measurements.

Speech management of cleft palate in our department is as follows: (1) after palatoplasty, when wound healing has been achieved, blowing practice using toys, (2) periodical assessment of hearing ability, (3) activation of velopharyngeal function and (4) assessment of articulation are
performed. Audiological evaluation was made using an Audiometer AM-1 (Minato Medical Science Co., Japan) and all patients were followed up by an otologist to determine hearing loss during the years of speech acquisition. These therapies were continued monthly until four years old.

The mean age when taking dental impressions in the P and N groups was 59.1 months (range 48.0 to 78.0 months; standard deviation (SD) 9.4 months) and 58.4 months (range 50.4 to 69.6 months; SD 5.4 months), respectively, with no significant differences between the groups. Cheiloplasty was performed by the modified Tennison triangular flap method at about 3 months of age and pushback palatoplasty was carried out at 16–18 months. The mean age at palatoplasty in the P and N groups was 17.8 months (SD 1.4 months) and 18.4 months (SD 1.3 months), respectively, with no significant differences between the groups in terms of age at impression.

This investigation was approved by the institutional review board (IRB) of Kagoshima University Graduate School of Medical and Dental Sciences.

2. Speech assessment of articulation disorder

A speech-language-hearing therapist and two oral surgeons with experience of speech management for cleft palate patients assessed articulation independently when patients were about 4 years of age. Articulation was assessed as follows: (1) perceptual assessment (examination of monosyllables, words, and short sentences, and conversation listening), (2) visual examination (observation of articulation movement of tongue, lips and/or mandible), and (3) audiological examination (audiometry, examination by an otolaryngologist).

Patients who consistently showed palatalized articulation in monosyllables, words, sentences or conversations were rated as having palatalized articulation, and tongue-tip movements were assessed observationally. All examiners recognized palatalized articulation in all patients in the P group.

3. Analysis of dental casts

All dental casts were measured with a non-contact 3D laser scanner SURFLASER (Unisn Co., Osaka, Japan), with an accuracy of 0.05 mm. 3D data were analyzed with 3D-Rugle software (Medic Engineering Co., Kyoto, Japan).

A reference plane using the horizontal basic plane was set up with three landmarks: right and left maxillary tuberosity points (T, T’) and the deciduous canine point on the non-cleft side (C) (Fig. 1a). The straight line T T’ was designated the X axis, and the midpoint between T and T’ was termed the origin (O). The plane with the X-axis and point C was set as the XY plane (reference plane). The line perpendicular to the origin on the XY plane was termed the Y-axis and the line perpendicular to the XY plane through the origin was termed the Z-axis.

On the basis of the reference plane, landmarks were identified as shown in Figure 1b. To assess errors of landmark identification, one investigator positioned landmarks on 3D images five times, at one-month intervals, and measurement errors were calculated within 0.06 mm using the standard deviation of measurements.

For measurement consistency, right-sided cleft images were automatically converted to left-sided images with 3D-Rugle software. In addition, in the frontal (XZ plane) and sagittal (YZ plane) planes, we identified and marked characteristic points on the images. The means of 3D coordinates of these points were calculated and illustrated in three planes (XY, XZ, and YZ planes). The palatal form using projections and the following measurements between the P and N groups were then compared.

1) Measurements in the horizontal plane

The means of 3D coordinates of each landmark in the XY plane were calculated and the following measurements were carried out (Fig. 2a).

Palatal width
- C-C’: intercanine width (anterior palatal width)
- D-D’: interdeciduous first molar width
- T-T’: intertuberosity width (posterior palatal width)
Palatal length

- A-P₁: total palatal length
- A-P₂: anterior palatal length

Angle of anterior palatal curvature

- \( \angle \text{CAC'} \): angle between segment A-C and segment A-C'

Palatal surface area

- S₁: surface area of the palate bordered by the gingival margin and the perpendicular plane, including segment C-C' to the reference plane (anterior palatal surface area)
- S₂: surface area of the palate bordered by the

Fig. 1 Reference plane and landmarks. a: The reference plane was established using bilateral maxillary tuberosity points and the deciduous canine point on the non-cleft side. The midpoint of segment T-T' is the origin (O). The X, Y, and Z axes are mutually perpendicular. The positive direction of the x-axis points to the right of the origin, the positive direction of the y-axis points out from the viewer, and the positive direction of the z-axis points upward from the origin. b: Landmarks used in cast analysis. A: incisal point; C, C': deciduous canine points; D, D': interdental papillae between the first and second deciduous molars; T, T': maxillary tuberosity points; P₁: intersection of perpendicular line from point A to segment T-T'; P₂: intersection of segment A-P₁ and the plane containing segment C-C' and perpendicular to the reference plane; T₁, T₂: midpoints of segment T-O and segment T'-O, respectively.

Fig. 2 Points and measurements in three planes. a: Landmarks and measurements in the horizontal plane. Palatal width (C-C', D-D', T-T'), length (A-P₁, A-P₂), and angle of anterior palatal curvature (CAC') are shown. The dark gray area shows the anterior palatal surface area (S₁) and the light gray area shows the posterior palatal surface area (S₂). b: Points and measurements in the frontal plane. Area T was shown as a representative. The dashed line shows the reference plane. To: deepest points in Area T (Co in Area C, Do in Area D). Palatal depth was the distance between the deepest point and the reference plane. The angle of palatal shelves on the non-cleft side was termed \( \alpha \) and that on the cleft side was termed \( \beta \). The ratio of \( \alpha \) to \( \beta \) was calculated as the index of palatal symmetry. c: Points and measurements in the sagittal plane. Area O was shown as a representative. The dashed line shows the reference plane. Yo: intersections of Area O (Y₁ in Area T₁, Y₂ in Area T₂) and the perpendicular plane including segment C-C' to the reference plane on the palatal surface. Segment C-C' is a borderline of anterior and posterior palate. Palatal slopes of anterior palate are termed \( \theta₁ \) and palate curvature is termed \( \theta₂ \).
margin, the XZ plane and the perpendicular plane, including segment C-C’ to the reference plane (posterior palatal surface area).

2) Measurements in the frontal plane
To take measurements in the frontal plane, we set three planes (Area C, Area D, and Area T) that included C, D, and T, respectively, which were parallel to the XZ plane. In Figure 2b, Area T is shown as an example. We identified and marked three points: one edge point T, another edge point T’, and the deepest point To on the images (Fig. 2b). From the measurements in three planes, we assessed palatal depth and the angle of palatal shelves in the anterior (C), middle (D), and posterior (T) parts. Furthermore, to assess the symmetry of the palate, we compared the angles of palatal shelves between the cleft side and non-cleft side, and calculated the ratio as an index of palatal symmetry. If the ratio did not equal about 1.0, the palatal form was considered asymmetric.

- Palatal depth: distance between the deepest point and the reference plane
- Angle of palatal shelves: angle between palatal shelves and the reference plane on the non-cleft side (α) and cleft side (β)
- Index of palatal symmetry: ratio of α to β (α / β)

3) Measurements in the sagittal plane
To take measurements in the sagittal plane, we set three planes (Area T1, Area T2, and Area O) that included T1, T2, and O, respectively, which were parallel to the YZ plane. As shown in Figure 1b, T1 is the midpoint of segment T-O located on the non-cleft side, whereas T2 is the midpoint of segment T’-O located on the cleft side. In Figure 2c, Area O is shown as an example. We identified and marked four points on the image: posterior edge point (O), anterior edge point of palate, deepest point, and the intersection point of the perpendicular plane, including segment C-C’ to the reference plane (Yo). From the measurements in three areas, we assessed cross-sectional palatal forms on the non-cleft side (T1), cleft side (T2), and in the midline region (O), respectively. Finally, we measured the following two angles:
- Palatal slopes of anterior palate: slope of the palate at the Y1, Y2, and Yo versus the reference plane (θ1)
- Curvature of palate: angle of the deepest point and palatal edge point (θ2)

4) Occlusion
The anteroposterior occlusal relationship in anterior and posterior regions was assessed by overjet and Terminal Plane.

4. Statistical analysis
Average measurements in P and N groups were compared statistically with Mann-Whitney’s U test. A p-value < 0.05 was considered significant.

Results

1. Measurements in the horizontal plane
Figure 3 illustrates the coordinates of landmarks in the XY plane and Table 1 shows the means of variables in the two groups. C and D were positioned significantly more posterior in the P group than in the N group, because the y-coordinates of C and D in the P group (19.3 ± 1.6 and
12.2 ± 1.5 mm, respectively) were significantly smaller than in the N group (20.6 ± 1.6 and 13.0 ± 1.4 mm, respectively) (p < 0.05). The P group had smaller palates than the N group, showing more constriction, particularly in the region around D and D’. The anterior palatal width (C-C’), anterior palatal length (A-P1), and angle of anterior palatal curvature (∠CAC’) were almost identical between the groups (Table 1). The comparison of the interdeciduous first molar width (D-D’), posterior palatal width (T-T’), and total palatal length (A-P1) showed no significant difference between the groups. While the anterior palatal surface area (S1) was larger in the P group than the N group, the posterior surface area (S2) of the P group was smaller than that of the N group, and was borderline significant (p = 0.061).

2. Measurements in the frontal plane

The means of the coordinates in each area are illustrated in the XZ planes (Fig. 4) and the means of variables are shown (Table 2). The x-coordinate of Co in the P group (−1.2 ± 2.0 mm) was significantly smaller than in the N group (0.6 ± 2.2 mm) (p < 0.05), as shown in Figure 4. This result showed that the deepest point in Area C significantly deviated to the non-cleft side in the P group.

In terms of palatal depth, there were no significant differences in Area C, D, and T between the groups.

The angle of palatal shelves in Area C, D, and T demonstrated no differences between the groups. On the other hand, the ratio of α to β calculated as an index of palatal symmetry was significantly higher in the P group (1.49 ± 0.47) than in the N group (1.02 ± 0.41) (p < 0.05) (Table 2). There were no significant differences in the index of palatal symmetry in each area except for Area C.
3. Measurements in the sagittal plane

The means of the coordinates in each area are illustrated in the YZ plane (Fig. 5) and the means of variables are shown (Table 3). The palatal form was flatter and shallower in the P group than in the N group in Area O (Fig. 5). Palatal forms in the P and N groups were similar in both Area T1 and Area T2.

The palatal slopes of the anterior palate (θ1) of the P group were smaller than those of the N group in all areas, and θ1 was significantly smaller in the P group in Area O (p < 0.05). The curvature of the palate (θ2) showed no obvious differences between groups.

4. Occlusion

The results showed that overjet was −1.56 mm (SD 1.66 mm) in the P group and −2.62 mm (SD 2.05 mm) in the N group, and there was no significant difference between groups. Regarding Terminal Plane, 30.0% had Vertical type malocclusion and 70.0% had Medial step type in the P group. On the other hand, in the N group, 11.1% had Vertical type, 11.1% had Distal step type, and 77.8% had Medial step type occlusion. Medial step type occlusion was most often observed in both groups and no differences were found in the anteroposterior occlusal relationship between the P and N groups.

Discussion

In Japan, palatalized articulation has been defined as a sound changing from a dental and/or alveolar consonant to a velar consonant, making articulatory contact using the body of the tongue instead of the tip or blade with the more posterior
portion of the palate; for example, /t/ /s/ to [k], and /d/ /z/ to [g]14; however, in the proposed universal parameters system1, palatalized articulation is defined as a minor phonetic modification of an otherwise accurate realization of the target consonant, most commonly associated with the production of fricatives 's, z, sh'1. The criteria of palatalized articulation in Japan are different from those in the proposed universal parameter system. On the other hand, one parameter of the proposed universal parameter system explains that palatalized articulation corresponds to the abnormal backing of oral targets where the articulation point of the alveolar plosives /t, d/ backs to the mid-dorsum palate and/or velum position1, and this includes Japanese consonants in which the articulation point deviates to the mid-dorsum palate and/or velar position. Therefore, palatalized articulation in Japan is thought to be equivalent to the backing articulation of oral targets to the mid-dorsum palate or velar in the proposed universal parameter system.

In our Department, 354 patients with cleft palate have been treated comprehensively since 1981, and 76 patients demonstrated articulation disorders, including 48 patients with palatalized articulation at four years of age. This incidence (48/354, 13.6%) of palatalized articulation is obviously higher than speech errors relating to the phonological process of normal Japanese children at four years of age15,16; therefore, several factors to explain palatalized articulation in cleft palate patients have been suggested, such as (1) habitual tongue movement; (2) palatal fistula; (3) abnormal occlusion; (4) abnormal morphology of the palate and (5) velopharyngeal incompetence. Among them, the relation between palatalized articulation and palatal morphology has been focused on because, when comparing cleft types, palatalized articulation occurred more frequently in cleft lip and palate rather than in isolated cleft palate in our clinic. These experiences suggest that palatal deformities or occlusion may play a role in palatalized articulation in speakers with cleft palate. Many patients with palatalized articulation have sufficient velopharyngeal function and abnormal articulations appear late in these patients3,4,17.

Regarding palatal morphology, Okazaki et al.10 analyzed plaster models of the maxilla by Moire topography, and described that palatal volume was significantly smaller in speakers with palatalized articulation than in those with normal speech; narrowing and shortening of the anterior palate might especially cause palatalized articulation. Ohyama et al.11 calculated the ratio of anterior palatal volume to total palatal volume by pressing clay into a plaster cast, and they found that the ratio was significantly smaller in patients with palatalized articulation than in those with normal articulation. Laine9 showed that palatal width was smaller in subjects with sounds produced too posteriorly; however, these previous reports gave little information about the cross-sectional form of the palate in frontal and sagittal planes. The present study demonstrated three major findings of palatal morphology in patients with palatalized articulation:

### Table 3 Measurements in the sagittal plane

<table>
<thead>
<tr>
<th>Variables</th>
<th>P group</th>
<th>N group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Palatal slope of anterior palate ( \theta 1 ) (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area T1</td>
<td>15.58</td>
<td>6.99</td>
</tr>
<tr>
<td>Area O</td>
<td>31.44</td>
<td>7.65</td>
</tr>
<tr>
<td>Area T2</td>
<td>8.54</td>
<td>8.50</td>
</tr>
<tr>
<td>Curvature of the palate ( \theta 2 ) (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area T1</td>
<td>164.87</td>
<td>7.55</td>
</tr>
<tr>
<td>Area O</td>
<td>139.34</td>
<td>9.19</td>
</tr>
<tr>
<td>Area T2</td>
<td>159.70</td>
<td>5.44</td>
</tr>
</tbody>
</table>

* p < .05
1. The posterior region of the palate was narrow in the horizontal plane.
2. The anterior palate was asymmetric in the frontal plane.
3. The palate was flat and shallow in the sagittal plane.

C and D were positioned significantly more posterior in the P group than in the N group and palatal size, especially in the posterior region, was smaller in the P group. We consider that the first finding is due to poor growth of the maxilla, because less growth in the forward, lateral, and downward dimensions was shown posteriorly, markedly in the region around the first deciduous molars (D and D'). Less growth was observed in this region in the horizontal and frontal planes: posterior position of D, palatal constriction around D and D', short interdeciduous molar width (D-D'), and small depth in Area D. In the frontal plane, the anterior palate was asymmetric and the posterior palate was symmetric in the P group. On the other hand, almost the whole palate was symmetric in the N group based on the result that the index of palatal symmetry was about 1.0 in all areas. In the sagittal plane, the palate was flatter and shallower in the P group than in the N group. In particular, the slope of the anterior palate showed a gentle curve. This reduces the space for the tongue tip to contact with the teeth or alveolar ridge. Although our results were not the same as those of Okazaki, which showed that the anterior palate was short and narrow, both results are consistent with the concept of reduced space. We assume that this disagreement may be influenced by differences in the surgical method of cheiloplasty or palatoplasty, the timing of taking impressions, landmarks identified on casts, and the 3D analysis method. From our results that patients with palatalized articulation had a flatter and shallower palate, it was suggested that palatal abnormality in the vertical dimension is associated with palatalized articulation, as well as in the horizontal dimension. Furthermore, an asymmetric palatal form may reduce the space in the anterior palate, resulting in difficult natural contact of the tongue tip with the teeth or alveolar region.

On the other hand, regarding occlusion, Albery and Grunwell indicated that the abnormal tongue position caused by Angle Class III malocclusion and lack of space caused by alveolar collapse might produce palatalized articulation, which was particularly evident at 5 and 10 years of age. Ohyama et al. studied the effects of maxillary growth on articulation by comparing measurements of maxillary casts between deciduous dentition and mixed dentition. They reported that the occurrence of palatalized articulation increased among patients who had attained normal articulation after palatoplasty, and that linguoverted teeth might bring about palatalized articulation by restricting tongue tip movement. In the present study, the anteroposterior occlusal relationship in anterior and posterior regions was assessed by overjet and Terminal Plane. However, no differences in the anteroposterior occlusal relationship between the P and N groups were found, that is, no obvious relationship between malocclusion and palatalized articulation was detected in the present study.

When considering the treatment or prevention of palatalized articulation based on the findings of the present study, a presurgical orthopedic may play a role in improving abnormal morphology of the palate. In our previous study on the incidence of palatalized articulation relating to treatment using a Hotz plate, it was suggested that the Hotz plate improved abnormal palatal morphologies and might decrease the occurrence of palatal articulation. Considering the results of the previous and the present studies, treatment of the palatal shape may be one approach for normalization from palatalized articulation by helping to alleviate one possible cause. From the point of view of normal articulation as well as sufficient maxillary growth, the surgical methods of cheiloplasty and/or palatoplasty are desirable so as not to influence the palatal form.

In the present study we have characterized palatal form associated with palatalized articulation, but have not clarified whether these three morphological characteristics are direct or indirect factors of palatalized articulation. Since the developmental history of palatalized articulation
is thought to be important, further studies on the palatal morphology at the timing of acquisition of articulation disorder will be necessary. Furthermore, studies including assessment of tongue movements by EPG, ultrasound or functional MRI during speech will be required to determine how these morphological characteristics affect the alteration of the lingual-palatal contact pattern.

Acknowledgements

This work was supported in part by Grants-in-Aid for Scientific Research (No.18650156) from the Japanese Ministry of Education, Science, Sports and Culture.

References


