Three-dimensional Relationship between Pharyngeal Airway and Maxillo-facial Morphology

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Abstract

In this study, to clarify the influence of the maxillo-mandibular bones and cranium on airway morphology, maxillo-facial morphology in patients with jaw deformation was measured using cephalograms and X-ray CT imaging data. Subjects consisted of 25 adult women in whom cephalograms and X-ray CT were taken to diagnose jaw deformation. The data obtained were classified based on skeletal and facial patterns according to Ricketts analysis, and changes in internal diameter, height and volume of the middle pharyngeal airway were observed. The results showed that the internal diameter of the inferior airway expanded anteriorly when the mandibular bone was in the anterior position, and was slightly constricted and elongated vertically when the mandibular bone was posteriorly rotated. This suggests that airway volume is influenced by the antero-posterior position of the mandibular bone, in that it compensates for decreases in its volume by extending its height inferiorly to cope with posterior deviation of the mandibular bone.

Key words: Pharyngeal airway morphology—Airway volume—Three-dimensional CT—Jaw deformation

Introduction

In the orthodontic field, it is generally believed that when disorders in the airway occur due to various causes, mouth-breathing is induced, compromising the mechanical balance of the muscles surrounding the oral cavity. This, in turn, affects maxillo-facial and cranial skeletal growth and occlusion, particularly in the growth period, causing various types of malocclusion. The tongue and suprahyoid muscles strongly influence maxillo-facial and cranial formation and growth\(^{1,13}\). Retention of the airway in the correct position is necessary for completion of normal dentition, maxillo-facial and cranial growth and development, and harmony of the masticatory muscles and muscles surrounding the oral cavity. Mouth-breathing decreases the amount of oxygen in the brain, and causes severe snoring, sleep apnea syndrome, and lethargy during the daytime. In children, mouth-breathing causes...
various systemic problems such as insufficient sleep, crying at night, and nocturnal enuresis, decreasing attentiveness and composure. When mouth-breathing occurs every day, the muscles surrounding the oral cavity show chalasia, leading to adenoid facies.

Although genetic factors, systemic diseases, deformation of the nasal septum and cervical vertebrae, infection and pollution, and physical and chemical irritants influence the airway, the influence of cervical headgear, adenoids, and hypertrophy tonsillae palatinae have also been orthodontically reported. Furthermore, there have been many studies on the relative positional relationship between the cervical vertebrae and airway. Using cephalograms accumulated over 20 years in patients with mandibular deformation, Durzo et al. reported that the growth direction of the hyoid bone differed from that in healthy persons. Evaluating the position of the hyoid bone after anterior surgical movement of the mandibular bone, Gale et al. reported that the hyoid bone horizontally moved in the anterior direction along with the anterior movement of the mandibular bone.

In this study, using cephalograms and X-ray CT imaging data in patients who were diagnosed as having jaw deformation, maxillofacial morphology was measured, and the influence of the maxillo-mandibular bones and cranium on airway morphology was evaluated.

Materials and Methods

1. Subjects

Subjects consisted of 25 adult women with a mean age of 19 years and 10 months (15 years 8 months–28 years 7 months), who visited Tokyo Dental College, Chiba Hospital, for the diagnosis of jaw deformation using cephalograms and X-ray CT. They were classified into 3 groups based on skeletal pattern: skeletal mandibular protrusion (Class III group); skeletal maxillary protrusion (Class II group); and slight antero-posterior differences between maxillo-mandibular bones (Class I group). Furthermore, according to Ricketts analysis, facial patterns were classified into 3 groups: dolicho facial pattern (Dolicho group); meso facial pattern (Meso group); and brachy facial pattern (Brachy group). Therefore, the subjects were classified into 3 groups, respectively, based on the two classification methods.

1) Classification based on skeletal patterns (Fig. 1, Table 1)

Downs-Northwestern analysis of cephalograms was performed, and SNA, SNB, and ANB

<table>
<thead>
<tr>
<th>Table 1 Classification based on skeletal pattern</th>
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<tbody>
<tr>
<td>SNA (deg.)</td>
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<td>SNB (deg.)</td>
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<tr>
<td>ANB (deg.)</td>
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Fig. 1 Cephalometric measurement of ANB

1 SNA (deg.): The angle between the SN plane and the Nasion-Point A.
2 SNB (deg.): The angle between the SN plane and the Nasion-Point B.
3 ANB (deg.): The angle from Point A to the center of the Nasion to Point B.
ANB, which are used for judging the antero-posterior position of the maxillo-mandibular alveolar bases, setting the cranial base as the reference, were measured.

We selected subjects satisfying the following conditions:

1. Facial asymmetry was absent or slight.
2. Deviation between the maxillo-mandibular anterior tooth medians was within 4 mm.
3. No prostheses larger than full cast crowns were inserted in the current teeth.
4. No previous orthodontic treatment in the pediatric period.
5. Systemic diseases and congenital deformity influencing growth were absent.
6. Neither inflammation in the pharyngeal airway nor tonsillar hypertrophy was objectively or subjectively noted.

Based on analytical values, 5 subjects (mean age, 19 years 3 months), in whom ANB was within ±1 S.D., and overjet was within normal values, were classified into the Class I group. The Class II group consisted of 10 subjects (mean age, 18 years 9 months), in whom ANB was more than +1 S.D., and overjet was positive. The Class III group consisted of 10 subjects (mean age, 18 years 9 months), in whom ANB was less than −1 S.D., and overjet was negative.

2) Classification based on facial pattern
(Fig. 2, Table 2)

Cephalographical measurement was performed according to Ricketts analysis\(^1\), and the subjects were classified into 3 groups based on 5 items determining facial pattern.

- Facial axis angle (deg.): angle between facial axis and Basion-nasion line
- Facial depth (deg.): angle between facial plane and FH plane
- Mandibular plane angle (deg.): angle between mandibular plane and FH plane
- Lower facial height (deg.): angle from anterior nasal spine to center of Xi to PM
- Mandibular arc (deg.): angle between condylar axis and corpus axis

The Brachy group (short facial type) consisted of 5 subjects (mean age, 22 years 6 months); the Meso group (middle facial type) consisted of 10 subjects (mean age, 18 years 4 months); and the Dolicho group (long facial type) consisted of 10 subjects (mean age, 18 years 1 month).

The study was approved by the Ethics Committee.

![Fig. 2 Cephalometric measurement of Ricketts analysis](image)

Table 2 Classification into 3 groups based on 5 items mean determining facial pattern

<table>
<thead>
<tr>
<th></th>
<th>Dolicho group</th>
<th>Meso group</th>
<th>Brachy group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facial axis</td>
<td>83.0°&gt;</td>
<td>86.0° ± 3°</td>
<td>89.1°&lt;</td>
</tr>
<tr>
<td>Facial depth</td>
<td>84.8°&gt;</td>
<td>87.8° ± 3°</td>
<td>90.9°&lt;</td>
</tr>
<tr>
<td>Mandibular plane angle</td>
<td>32.9°&lt;</td>
<td>28.8° ± 4°</td>
<td>24.8°&gt;</td>
</tr>
<tr>
<td>Lower facial height</td>
<td>53.1°&lt;</td>
<td>49.0° ± 4°</td>
<td>45.0°&gt;</td>
</tr>
<tr>
<td>Mandibular arc</td>
<td>22.8°&gt;</td>
<td>26.8° ± 4°</td>
<td>30.9°≤</td>
</tr>
</tbody>
</table>
Committee of Tokyo Dental College (Ethical clearance number 154). The aims and potential risks of the study were fully explained to each subject, and informed consent was obtained from each.

2. X-ray CT conditions and measurement apparatus

Study materials consisted of X-ray CT imaging data taken for the diagnosis of jaw deformation. A spiral scan-type CT (SOMATOM Plus 4 Volume Zoom, SIEMENS Co.) was used with a tube current of 117 mA, tube voltage of 120 kv, slice thickness of 1.25 mm, and slice width of 1 mm.

Using the laser beam attached to the CT as a guide, the subjects were fixed in the supine position during CT-taking, with the facial median and Frankfort horizontal plane (FH plane) perpendicular to the floor, and ear rods inserted in the opening of the external acoustic meatus, according to Matsuno’s method. The duration of CT-taking was approximately 50 seconds, and the jaw was in the intercuspal position and lip and tongue were in the resting position during this period.

The distance and volume of the middle pharyngeal airway were measured using 3-dimensional medical image treatment-display software (Real INTAGE, K.G.T. Co.). In this study, after 3-dimensionally constructing X-ray CT images (DICOM data) using Real INTAGE, the airway was displayed showing the air layer, setting the window value to −850 Hounsfield units (H.U.).

3. Establishment of range of middle pharyngeal airway

Regarding the measurement range, the pharyngeal airway not adjacent to any cavities, in which constant and highly reproducible hard tissue images could be taken at the time of the establishment of the airway range, was selected (Fig. 3).

The measurement range of the middle pharyngeal airway was established as follows: 1) The superior border was the plane parallel to the FH plane, drawn from the point of intersection (PSP) formed by the line parallel to the FH plane passing PNS and the posterior margin of the soft palate.

2) The inferior border was the plane parallel to the FH plane, coming into contact with the most superior margin of the body of the hyoid bone (HB), in which vertical influences by changes in the head position are slight according to the results of Nagai et al. and Hasegawa et al.

Furthermore, although the anterior area comprises the pathway from the airway to the oral cavity, we used images in which this path was closed with the root of the tongue and soft palate.

4. Measurement items

Three items were established as the measurement points in the middle pharyngeal airway.

- PSP: PNS part of soft palate
- ESP: End of soft palate
- HB: Most superior margin of body of hyoid bone

Regarding the distance measurement of the vertical height of the middle pharyngeal airway, a line perpendicular to the supero-inferior planes was drawn, and the distance

Fig. 3 Measurement point in middle pharyngeal airway
A plane: the vertical plane perpendicular to the FH plane, HB: the top of hyoid bone, ESP: End of soft palate, PSP: PNS part of soft palate, PW: Posterior pharyngeal wall, U: Upper, M: Middle, L: Lower
was measured as the vertical height (Fig. 4).

Setting 3 cross-sectional planes (upper, middle, and lower planes) in the middle pharyngeal airway, the lateral and antero-posterior widths of the internal diameter of the pharyngeal airway on the 3 cross-sectional planes were measured. The upper plane was the most superior cross-sectional plane in the middle pharyngeal airway, which was parallel to the FH plane, passing PSP. The middle plane was the plane parallel to the FH plane, passing ESP. The lower plane was the most inferior cross-sectional plane in the middle pharyngeal airway, which was parallel to the FH plane, passing HB. The lateral (right-to-left) diameter (RL) and antero-posterior (front-to-back) diameter (FB) were measured (Fig. 5).

- Upper (PSP-PW U): Superior section plane of middle pharyngeal airway.
- Middle (ESP-PW M): Middle section plane of middle pharyngeal airway.
- Lower (HB-PW L): Inferior section plane of middle pharyngeal airway.
- PW: Posterior pharyngeal wall.

Regarding the measurement of the volume of the middle pharyngeal airway (Volume), the space surrounded by the upper plane, internal wall of the airway, and lower plane was measured, using 3-dimensional medical image treatment-display software.

These measurement items were used for skeletal and facial pattern classification analyses, and the average value (Ave.) and standard deviation (S.D.) were calculated in each item. In the facial pattern classification analysis, the length of the mandibular body (Corpus length, Fig. 2) was additionally measured, and the average value (Ave.) and standard deviation (S.D.) were calculated. Furthermore, a multiple comparison test by the Tukey-Kramer method was performed in each classified group (p<0.05).

Results

1. Classification based on skeletal pattern

As a result of classification, the 3 measurement items were within ±1 S.D. in the Class I group. SNB was less than −1 S.D. in the Class II group, showing that the mandibular bone was posterior to the cranial bone, and it was more than +1 S.D. in the Class III group, revealing that the mandibular bone was anterior to the cranial bone. As a result of measurement in the Class I group, the average...
value (Ave.) for the Upper-RL was 22.90 mm, the Upper-FB was 16.61 mm, the Middle-RL was 14.64 mm, the Middle-FB was 7.51 mm, the Lower-RL was 27.35 mm, the Lower-FB was 10.37 mm, the Height was 52.52 mm, and the Volume was 10.19 cm³. Table 3 shows the average value and standard deviation in the Class II and III groups.

Table 3 Measurement classification by skeletal pattern

<table>
<thead>
<tr>
<th></th>
<th>U-RL (mm)</th>
<th>U-FB (mm)</th>
<th>M-RL (mm)</th>
<th>M-FB (mm)</th>
<th>L-RL (mm)</th>
<th>L-FB (mm)</th>
<th>Height (mm)</th>
<th>Volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I Ave.</td>
<td>22.90</td>
<td>16.61</td>
<td>14.64</td>
<td>7.51</td>
<td>27.35</td>
<td>10.37</td>
<td>52.52</td>
<td>10.19</td>
</tr>
<tr>
<td>Class II Ave.</td>
<td>24.51</td>
<td>14.77</td>
<td>21.17</td>
<td>8.22</td>
<td>29.15</td>
<td>9.57</td>
<td>52.44</td>
<td>11.41</td>
</tr>
<tr>
<td>S.D.</td>
<td>3.39</td>
<td>3.00</td>
<td>6.14</td>
<td>2.35</td>
<td>3.33</td>
<td>3.41</td>
<td>4.08</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>2.33</td>
<td>2.28</td>
<td>4.96</td>
<td>2.76</td>
<td>3.23</td>
<td>2.20</td>
<td>4.44</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Class I–Class II n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s.
Class I–Class III n.s. n.s. n.s. * n.s. n.s. n.s. n.s.
Class II–Class III n.s. n.s. n.s. * n.s. * n.s. n.s.

*: p<0.05, n.s.: not significant

Fig. 6 Graph of Middle-FB by skeletal pattern group

Fig. 7 Graph of Lower-FB by skeletal pattern group

Fig. 8 Pharyngeal airway morphology by classification based on skeletal pattern
H: Head, F: Foot, A: Anterior, P: Posterior, R: Right
3 groups; however, although the Height was 52.52 mm in the Class I group, and 52.44 mm in the Class II group, showing almost the same value, it was 48.22 mm in the Class III group, showing a smaller value than that in the other 2 groups. This suggested that the height of the middle pharyngeal airway in the class III group was lower than that in the other 2 groups. Regarding Volume, it was 10.19 cm\(^3\) in the Class I group, 11.41 cm\(^3\) in the Class II group, and 13.96 cm\(^3\) in the Class III group, showing that the volume of the middle pharyngeal airway in the Class III group was larger than that in the other 2 groups.

These results revealed that the thickness, height, and volume in the Class I and II groups were almost the mean value, respectively, whereas the airway in the Class III group was significantly thicker in the anteroposterior direction (not in the right-to-left direction), the airway height was lower, and the volume was slightly larger, compared with the other 2 groups.

### 2. Classification based on facial pattern

(Tables 4 and 5, Figs. 9, 10, 11 and 12)

As a result of Ricketts analysis\(^{(19,20)}\), 3 groups satisfied all the items.

Furthermore, regarding the average value (Ave.) of airway measurements, the Upper-RL was 23.32 mm, the Upper-FB was 17.78 mm, the Middle-RL was 19.72 mm, the Middle-FB was 10.99 mm, the Lower-RL was 29.71 mm, the Lower-FB was 14.79 mm, the Height was 47.11 mm, and the Volume was 12.74 cm\(^3\) in the Brachy group. Table 4 shows the average value and standard deviation in the Meso and Dolicho groups.

Statistical analysis of these values among the 3 groups showed significant differences in the Lower-FB between the Brachy and Meso groups, and between the Brachy and Dolicho groups (p<0.05) (Fig. 9), and in Height between the Brachy and Dolicho groups. No other significant differences were noted. Although the classification based on facial patterns showed no significant differences in

| Table 4 Classification based on facial pattern and Corpus length |
|------------------|------------------|------------------|
|                  | Dolicho group    | Meso group       | Brachy group     |
|                  | Ave.             | Ave.             | Ave.             |
| Facial axis      | 77.43            | 85.51            | 91.38            |
| Facial depth     | 83.25            | 88.20            | 92.96            |
| Mandibular plane | 39.86            | 28.57            | 20.32            |
| Lower facial height | 55.12         | 48.65            | 44.88            |
| Mandibular arc   | 22.19            | 30.03            | 38.04            |
| Corpus length    | 59.96            | 63.36            | 68.16            |

| Table 5 Measurement classification by facial pattern |
|------------------|------------------|------------------|------------------|
|                  | U-RL (mm)        | U-FB (mm)        | M-RL (mm)        | M-FB (mm)        | L-RL (mm)        | L-FB (mm)        | Height (mm)      | Volume (cm\(^3\)) |
| Brachy           | Ave. 23.32       | 17.78            | 19.72            | 10.99            | 29.71            | 14.79            | 47.11            | 12.74            |
|                  | S.D. 3.23        | 2.66             | 6.03             | 4.00             | 1.60             | 2.63             | 4.60             | 4.27             |
| Meso             | Ave. 25.32       | 16.07            | 20.74            | 9.54             | 28.05            | 16.69            | 50.40            | 12.80            |
|                  | S.D. 2.27        | 3.40             | 5.35             | 2.75             | 5.98             | 2.91             | 1.98             | 3.90             |
| Dolicho          | Ave. 23.94       | 15.77            | 19.56            | 8.52             | 31.21            | 10.60            | 52.96            | 11.29            |
|                  | S.D. 3.08        | 2.38             | 7.99             | 3.46             | 4.84             | 3.10             | 5.31             | 3.93             |

Brachy-Meso: n.s. n.s. n.s. n.s. * n.s. n.s.
Brachy-Dolicho: n.s. n.s. n.s. n.s. * n.s.
Meso-Dolicho: n.s. n.s. n.s. n.s. n.s. n.s.

*: p<0.05, n.s.: not significant
Volume, it was slightly smaller in the Dolicho group than in the other groups. Height was larger in the Dolicho group, and was significantly smaller in the Brachy group (p<0.05) (Fig. 10). This suggested the influence of the lower facial height. Furthermore, although differences in the Height were present, almost no differences in the Volume were found. This could be understood by focusing on differences in the Lower-FB, in that the Lower-FB was significantly larger in the Brachy group than in the other groups (p<0.05) (Fig. 9), showing that the internal antero-posterior diameter of the airway in the inferior area was larger in the Brachy group.

Corpus length was greatest in the Brachy group among the 3 groups, showing a significant difference between the Brachy and Dolicho groups (p<0.05) (Fig. 11).

These results revealed that no significant differences in Volume were present among the 3 groups. Although the Meso group showed almost the average value in all the items, the airway in the Dolicho group was supero-inferiorly long, and that in the Brachy group was supero-inferiorly short, and antero-posteriorly thick in the inferior area.
Discussion

The hyoid bone has the anatomical characteristic of having no osseous continuity, and its position is influenced by soft tissues such as the muscles and ligaments. Therefore, CT-taking conditions and the head position are important in measuring the hyoid bone. Studying growth changes in the hyoid bone, Bench reported that, although the position of the hyoid bone becomes lower with age, its relative position with the surrounding structures is maintained. Bench and Emata et al. reported that the hyoid bone is supero-inferiorly positioned in the third vertebral area at the age of 3 years, and its position gradually becomes lower with age, being stably positioned in the forth vertebral area in adults. Taking this into consideration, adults in whom growth of the maxillo-facial region was complete were selected as the subjects in this study. Furthermore, considering the influence of physique on the airway caused by gender differences, only women were eligible.

Regarding the setting of the head position, Nakamura evaluated the head position while changing it within the range of 10°, and reported that the influence of changes in the head position was negligible when the change was within 5°. Furthermore, Fujita et al. reported that the position of the tongue and hyoid bone could be ascertained in cephalograms taken with the head within the natural position between −5° and +5°, neglecting the head position. Furthermore, regarding the vertical position of the hyoid bone, Brodie, Nagai et al. and Wickwire et al. reported that changes in the head position had almost no influence on the distance between the sella and hyoid bone, showing only slight differences among individuals, compared with the horizontal position of the hyoid bone. Therefore, regarding the setting of the head position during CT-taking, we believed that when the FH plane was set parallel to the floor, the influence of the head position on the hyoid bone position could be minimized, even in cases in which the hyoid bone was taken as the reference to measure the airway.

Furthermore, regarding the influence of the mandibular position on the airway during CT-taking, Athanasiou et al. and Cobo et al. reported that the breathability of the airway increased when the mandible was in the anterior position, suggesting that changes in the mandibular position caused alterations in airway morphology. Therefore, in this study, the mandible was fixed in the intercuspal position.

According to a report by Emata et al., although the antero-posterior diameter of the airway decreased after surgical posterior movement of the mandibular bone, the level of decrease was markedly smaller than the level of posterior movement in the mental area, showing no significant differences in changes between the two levels. Skeletal pattern classification based on differences in the antero-posterior position of the mandibular bone in this study revealed significant differences in the internal antero-posterior diameter in the middle and inferior areas of the airway, with correlations between the cranium and changes in the mandibular position and airway morphology. Furthermore, Higashi et al. reported that changes in the pharyngeal airway morphology occurred on the lingual side in the posterior area of the root of the tongue, and the posterior wall area of the pharyngeal airway was not involved, suggesting that changes in the airway morphology were due to morphological alterations in the anterior wall area.

Setting the line perpendicular to the FH plane passing sella as the reference, Adamidis and Spyropoulos reported that the body of the hyoid bone was more in the anterior position in Class III group than in Class I group. Kawahara et al. reported that the deviation direction of the mandible was the same as that of the hyoid bone. Also in this study, setting the frontal cranial base as the reference, significant differences in the internal diameter of the airway were noted among the Class I, II (due to mandibular hypo-growth), and III (due to mandibular hyper-growth) groups. Similar deviations were noted in the internal...
diameter of the airway when the mandibular bone was in the anterior position, suggesting that not only the position of the hyoid bone, but also that of the pharyngeal airway was influenced by the antero-posterior position of the mandibular bone, and the pharyngeal airway was deviated in the same direction as the mandible, setting the cranium as the reference.

As a result of the facial pattern classification according to Ricketts analysis\(^{19,20}\), the 3 groups satisfied conditions in the 5 items (Table 4). Facial patterns are used for judging both horizontal and vertical components of the mandibular bone, setting the frontal bone as the reference, and making evaluation of the lower face possible. Furthermore, we believed that the length of the body of the mandibular bone (Corpus length) should also be considered, in addition to these 5 items. This was because the hyoid bone moves anteriorly after surgical anteroposterior movement of the mandibular bone according to Higashi et al.\(^{12}\), so the hyoid bone is necessarily located in the anterior position when the length of the body of the mandibular bone is long. The antero-posterior diameter of the inferior airway was significantly larger (p < 0.05) in the Brachy group, with the largest Corpus length among the 3 groups. Furthermore, as a result of the comparison of airway height in facial pattern classification, although the internal diameter of the airway was constricted due to the posterior rotation of the mandibular bone, it became longer in the vertical direction, suggesting a correlation between lower facial length and airway height.

**Conclusion**

Our results revealed that airway morphology is influenced by maxillo-facial morphology, and by the direction and amount of growth of the mandibular bone, in particular. When the mandibular bone was anteriorly deviated, the internal diameter of the airway was also anteriorly expanded. Although constriction of the internal diameter of the airway due to posterior rotation of the mandibular bone did not markedly occur, in contrast to the occurrence of expansion, it was noted that the airway became longer in the vertical direction, suggesting that the volume of the airway is retained at a constant by a horizontal and vertical compensation mechanism involving the suprahyoid muscle group connecting the mandibular and hyoid bones.

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