I. Introduction

When speech-language pathologists should give intervention to cleft palate patients, they should evaluate the degree of the patients’ phonological and phonetic deficits, and that of velopharyngeal incompetence (or insufficiency, henceforth VPI), usually depending on their perceptual judgements. Severe VPI need medical treatment before speech intervention: if not, we can hardly expect the improvement of their speech. But, if the degree of VPI is mild or moderate, we should carefully consider whether medical treatment should precede speech intervention, or not. In such cases, instrumental measurement can be used for more objective evaluation and for more appropri...
I. Materials and methods

The present study analyzed the anatomy of nasopharynx using cephalometry during vowels and sentential nasalance scores using nasometry for 9 Korean cleft-palate patients (four males and five females) and 14 Korean normal subjects (seven males and seven females). Cleft palate subjects were those who have been to Dental Hospital of Yonsei University, whose development of nasopharynx had been finished, and who had no history of orthognathic surgery, pharyngoplasty, or adenoidectomy.

1. Physio-anatomical evaluation using cephalometry

For recording the cephalogram, CRANEX 3+ (Soredex Co., Finland) was used. From each subject, we obtained two pictures: one shows the relaxed velopharyngeal sphincter muscles during the comfortable inspiration, and the other shows physiological movement of the muscles during vowel /i/ production. After the recording, we used FCR system (Fuji Computerized Radiography, Model No. AC-3, Fuji Co., Japan) for digitization (Fig. 1, 2).
(1) Reference Points in Cephalometry

S  Sella (the center of sella turcica)
N  Nasion (the most anterior point of the junction between the frontal and nasal bones)
ANS anterior nasal plane
PNS posterior nasal plane
Ptm  pterygomaxillary fissure
PW1  point where intersects the posterior pharyngeal wall with the PNS - S line
PW2  point where palatal plane(a line connecting ANS with PNS) extension intersects the posterior pharyngeal wall
U  the tip of the uvula
SSP  superior surface of soft palate at its greatest thickness
ISP  inferior surface of soft palate at its greatest thickness
At  most anterior point of the anterior tubercle of the atlas
Ba  Basion
CV2  most antero-inferior point of the second cervical vertebrae
CV3  most antero-inferior point of the third cervical vertebrae
CV4  most antero-inferior point of the fourth cervical vertebrae

(2) Reference data in Cephalometry

Hard palate length  ANS-PNS
Soft palate length  PNS-U
Soft palate depth  SSP-ISP
Nasopharyngeal depth  PNS-PW2
Area of the nasopharynx  PW1-PW2-PNS
Adequate Ratio (soft palate length/nasopharyngeal depth)  PNS-U / PNS-PW2
Anatomic VPI  Direct distance between posterior pharyngeal wall and soft palate during articulation
Location of VPI  Location of contact point over the palatal plane
upper is incribed as (+) and lower is incribed as (-)
FMPW  forward movement of pharyngeal wall on the palatal plane

(1) Single vowels
/a/, /æ/, /ɒ/, /ʌ/, /ʊ/
(2) Nasal sonorant-involving sentences
① na-mu-æ ma-mi-ga na-mu ma-na-yo (There are too many leaf hoppers in a tree)
② nu-na-raq i-mo-raq ma-i-mil na-nu-o-yo.
   (My sister and aunt share their hearts each other)
(3) Oral sonorant-involving sentences
① o-wa-ro-i-ri wa-ryo-i-ri-æ-yo. (May the 5th is Monday)
② i-ryo-i-æ i-ri-ro o-æ-yo. (He said to come here on Sunday)
(4) Oral occlusive-involving sentences
① pa-da-k’a-æ-so òo-ga-ni òo-wa-ð’-æ-yo. (We picked up seashells on the seaside)
② t’o-k’i-wa ko-bu-gi-ga ʃi-ab-tli he-yo. (A rabbit and a turtle are running a race)

Fig. 3. Vowels and Sentences for Nasometer Assessment.

2. Evaluation of hypernasality using nasometry

By using Nasometer(Model No. 6200-3, Kay Elemetrics Co, U. S. A.), we measured nasalance scores during the production of single vowels, /a/, /æ/, /ɒ/, /ʊ/, and /ʌ/, and sentences including oral and nasal sonorants and oral occlusives of 10-13 syllables(Fig. 3).

We compared the results of the two instrumental measurements between cleft-palate subjects and normal subjects, and to find the relationship between the results and VPI, anatomic VPI(direct distance
between posterior pharyngeal wall and soft palate during articulation) and nasalance scores were compared. For the statistic analysis, we used paired \( t \)-test and Pearson r Correlation Coefficient through SAS(version 8.01) program.

### III. Results

1. In cephalometry, there were significant differences in soft palate length, soft palate thickness, nasopharyngeal depth, nasopharyngeal area, and adequate ratio between two groups (\( p < .05 \)) (Table 1).

2. In nasometry, there were significant differences between two groups in vowel /i/ and sentences including oral consonants (\( p < .05 \)) (Table 2).

3. In cleft palate patients, though no general correlation was found between Anatomic VPI and nasalance scores, vowel /i/ and sentences including oral consonants were slightly correlated (\( r = .87, .67 \)) (Fig. 4-6).

![Fig. 4. Correlation between Anatomic VPI and Nasalance score in Vowel /i/ of cleft palate group.](image)

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### Table 1. Reference data of two groups in cephalometry (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Cleft-palate</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard palate length*</td>
<td>56.74 ± 3.41</td>
<td>53.24 ± 5.13</td>
<td>0.0618</td>
</tr>
<tr>
<td>Soft palate length*</td>
<td>36.83 ± 2.75</td>
<td>25.21 ± 5.36</td>
<td>0.0001</td>
</tr>
<tr>
<td>Soft palate thickness*</td>
<td>10.74 ± 0.98</td>
<td>8.92 ± 0.77</td>
<td>0.0001</td>
</tr>
<tr>
<td>Nasopharyngeal depth*</td>
<td>27.77 ± 2.68</td>
<td>23.68 ± 4.29</td>
<td>0.0100</td>
</tr>
<tr>
<td>Nasopharyngeal area**</td>
<td>302.75 ± 39.95</td>
<td>172.92 ± 82.07</td>
<td>0.0012</td>
</tr>
<tr>
<td>Adequate ratio</td>
<td>1.33 ± 0.13</td>
<td>1.07 ± 0.12</td>
<td>0.0001</td>
</tr>
<tr>
<td>Anatomic VPI*</td>
<td>0.43 ± 0.63</td>
<td>1.26 ± 1.17</td>
<td>0.0777</td>
</tr>
<tr>
<td>Location of VPI*</td>
<td>-3.16 ± 2.84</td>
<td>-5.14 ± 4.25</td>
<td>0.1933</td>
</tr>
<tr>
<td>PMPW*</td>
<td>0.26 ± 1.05</td>
<td>1.00 ± 1.07</td>
<td>0.1161</td>
</tr>
</tbody>
</table>

*: \( mn \) \, **: \( ss \)

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### Table 2. Nasalance score of two groups in nasometry (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Cleft-palate</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>/a/</td>
<td>17.32 ± 9.12</td>
<td>12.60 ±12.44</td>
<td>0.6172</td>
</tr>
<tr>
<td>/e/</td>
<td>18.1 ± 9.83</td>
<td>19.25 ±14.47</td>
<td>0.8217</td>
</tr>
<tr>
<td>/i/</td>
<td>24.99 ± 15.84</td>
<td>32.96 ±21.51</td>
<td>0.3173</td>
</tr>
<tr>
<td>/o/</td>
<td>4.95 ± 5.78</td>
<td>19.02 ±15.51</td>
<td>0.0273</td>
</tr>
<tr>
<td>/u/</td>
<td>5.92 ± 7.17</td>
<td>17.98 ±20.47</td>
<td>0.1220</td>
</tr>
<tr>
<td>Nasal Sonorants( 1 )</td>
<td>36.70 ± 5.61</td>
<td>40.57 ± 9.39</td>
<td>0.2273</td>
</tr>
<tr>
<td>Nasal Sonorants( 2 )</td>
<td>37.83 ± 5.69</td>
<td>41.88 ± 7.98</td>
<td>0.1692</td>
</tr>
<tr>
<td>Nasal Sono-Mean</td>
<td>37.27 ± 5.43</td>
<td>41.23 ± 8.40</td>
<td>0.1823</td>
</tr>
<tr>
<td>Oral Sonorants( 1 )</td>
<td>10.13 ± 5.39</td>
<td>23.15 ±14.46</td>
<td>0.0282</td>
</tr>
<tr>
<td>Oral Sonorants( 2 )</td>
<td>10.86 ± 5.55</td>
<td>22.79 ±15.27</td>
<td>0.0496</td>
</tr>
<tr>
<td>Oral Sono-Mean</td>
<td>10.50 ± 5.11</td>
<td>22.97 ±14.75</td>
<td>0.0364</td>
</tr>
<tr>
<td>Oral Occlusives( 1 )</td>
<td>6.99 ± 2.98</td>
<td>14.77 ±12.24</td>
<td>0.0958</td>
</tr>
<tr>
<td>Oral Occlusives( 2 )</td>
<td>7.89 ± 3.70</td>
<td>17.45 ±12.13</td>
<td>0.0474</td>
</tr>
<tr>
<td>Oral Occl-Mean</td>
<td>7.44 ± 3.24</td>
<td>16.11 ±11.90</td>
<td>0.0625</td>
</tr>
</tbody>
</table>
IV. Discussion

By the cephalometric analysis, we found statistically significant difference between the two groups, cleft-palate patients and normal subjects in soft palate length and depth, nasopharyngeal depth and size, and adequate ratio (soft palate length/nasopharyngeal depth) (p < .05) \cite{11-13}.

The difference of the soft palate depth and length may be due to contracted and scarred tissues after the surgery, and that of nasopharyngeal depth means that cleft-palate patients' characteristic skeletal Class II malocclusion hindered the anterior development of maxillary bone, which caused the posterior settlement of the bone \cite{14,15}. Adequate ratio is the important ratio to evaluate the possibility of velopharyngeal competence, and its normative ratio is known to be 1.3 or 1.4 \cite{16,17}. However, cleft-palate subjects on the whole, showed lower rate than normal subjects. The reason is known to be the short soft palate length, rather than shallow nasopharyngeal depth, therefore we can consider that one of the primary cause of cleft palate patients’ VPI is shortened soft palate length.

When we measured the nasalance scores of vowels and sentences by Nasometer, significant difference between the cleft palate subjects and normal ones was found in oral sonorants and oral occlusives (p < .05). Comparing the mean of scores, a high vowel /i/, and back vowels /o/ and /u/ showed high scores, which means that nasalance score during the vowel production is related with the location of velopharyngeal closure and the degree of elevation of soft palate \cite{19}. Nasal sonorants are made by nasal resonance with relaxed soft palate which can be found in both cleft palate patients and normal persons, therefore we can expect that the nasalance scores of nasal sonorants will be similar between the two groups, which proved to be true. In normal subjects, oral sonorants and oral occlusives are expected to show low scores, for their proper velopharyngeal closure, on the while, in cleft palate subjects, their improper closure may be the cause of high scores in those consonants \cite{19,20}. As results, we could confirm the expectations, and now, we will consider the relationship between the abovementioned results and physioanatomical structures of nasopharynx, analyzed by cephalometer.

Anatomic VPI shows the degree of VPI, and nasalance scores shows the degree of hypernasality. In cleft palate subjects, we found no significant correlation between them with the exception of a vowel /i/ (r = .87). It is usually known that increased nasalance could result from decreased oral intensity, increased nasal intensity, or both; we can also find the same pattern when the speech sounds are produced with nasopharyngeal gap, regardless of normal or cleft palate subjects \cite{21-24}. Therefore, we can consider that physioanatomical structures and nasalance score have the significant correlation each other.
V. Conclusions

Velopharyngeal closure is a sphincter mechanism between the activities of the soft palate, lateral pharyngeal wall and the posterior pharyngeal wall, which divides the oral and nasal cavity. It participates in physiological activities such as swallowing, breathing and speech. It is called a velopharyngeal dysfunction when this mechanism malfunctions. The causes of this dysfunction are defects in (1) length, function, posture of the soft palate, (2) depth and width of the nasopharynx and (3) activity of the posterior and lateral pharyngeal wall.

The purposes of this study are to analyze the nasopharynx of cleft palate patients using cephalometry and to evaluate the degree of hypernasality using nasometry to find its relationship with velopharyngeal dysfunction.

Conclusively, when we compared the results of cephalometric and nasometric measurements, we could not find the significant difference between the cleft palate subjects and normal subjects. In the case of cleft palate subjects, the relationship between the anatomic VPJ and nasalance scores was only found in the vowel /i/ and oral consonant-involving sentences.

References

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1993.
Abstract

PHYSIOANATOMY OF NASOPHARYNGEAL SPACE
AND HYPERNASALITY IN CLEFT PALATE

Joon-Hui Cho, Wha-Young Pyo*, Hong-Shik Choi**, Byung-Jai Choi,
Heung-Kyu Son, Hyun-Sub Sim*

Department of Pediatric Dentistry, College of Dentistry, Yonsei University
*Department of Special Education & Interdisciplinary Program of Communication Disorders, Ewha Womans University
**Department of Otorhinolaryngology, College of Medicine, Yonsei University

Velopharyngeal closure is a sphincter mechanism between the activities of the soft palate, lateral pharyngeal wall and the posterior pharyngeal wall, which divides the oral and nasal cavity. It participates in physiological activities such as swallowing, breathing and speech. It is called a velopharyngeal dysfunction when this mechanism malfunctions. The causes of this dysfunction are defects in (1) length, function, posture of the soft palate, (2) depth and width of the nasopharynx and (3) activity of the posterior and lateral pharyngeal wall.

The purposes of this study are to analyze the nasopharynx of cleft palate patients using cephalometry and to evaluate the degree of hypernasality using nasometry to find its relationship with velopharyngeal dysfunction.

The following results were obtained:

1. In cephalometry, there were significant differences in soft palate length, soft palate thickness, nasopharyngeal depth, nasopharyngeal area, and adequate ratio between two groups.
2. In nasometry, there were significant differences between two groups in vowel /o/ and sentences including oral consonants.
3. In cleft palate patients, though no general correlation was found between Anatomic VPI and nasalance scores, vowel /i/ and sentences including oral consonants were slightly correlated.

In conclusion, cephalometry and nasometry results were significantly different between the two groups. Though in the cleft palate group, Anatomic VPI and nasalance scores, which are indices for velopharyngeal closure, excluding the vowel /i/ and sentences including oral consonants show generally no significance.

Key words: Velopharyngeal Dysfunction, Cephalometry, Nasometer, Hypernasality, Cleft palate