Three-Dimensional Measurements of Pharyngeal Airway in Patients with Unilateral Cleft Lip and Palate

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Abstract

The aim of this study was to investigate 3-dimensional (3D) airway volume in patients with unilateral cleft lip and palate (UCLP) using computed tomography (CT). The study population comprised 15 UCLP patients (UCLP group) scheduled to receive alveolar bone grafts and 15 with impacted teeth (control group). The clinical requirements for a CT scan were met in both groups. Measurements were recorded from 3D reconstructions of Digital Imaging and Communications in Medicine data obtained from the CT images. Airway volume, cross-sectional area, and linear and angular measurements were recorded. Airway volume and cross-sectional area showed no significant difference between the two groups. The narrowest section of the airway in the UCLP group was tighter than that in the control group, however \( p = 0.017 \). The results of this study suggest that this difference in the measurements of the narrowest section of the airway is involved in the particular maxillofacial morphology found in UCLP patients.

Key words: Airway volume — Cleft lip and palate — Minimum cross-sectional dimensions

Introduction

The aim of palatoplasty, an essential procedure in the repair of cleft palate, is to obtain improvements in speech, articulation, mastication, and swallowing function. The invasiveness of this procedure, however, is known to inhibit the growth of the maxilla\(^{9,16,17}\). In patients with a small and retruded maxilla, it is necessary to expand the dental arch and induce forward growth of the maxilla. It has been suggested that this type of procedure,
which is aimed at countering jaw hypoplasia, should be performed in conjunction with orthodontic treatment at the appropriate time. Relatively little information on the airway in such cases, which has a posterior location, is currently available, however. Three-dimensional (3D) morphological analysis, which has been made possible only recently due to the growing popularity of computed tomography (CT) and new types of software, has yielded information that could not hitherto have been obtained by routine cephalography. The airway, which is enclosed in soft tissues, has a complex morphology, and such 3D morphological analysis allows considerable information to be obtained on this structure. The airway is involved in breathing, speech, and swallowing. A basic understanding of the airway in cleft palate patients is essential in helping to anticipate problems associated with impaired speech production or articulation, such as hypernasality, sleep apnea syndrome, or dysphagia, which are caused by impairments to this structure. Some previous research has suggested that airway volumes are smaller in cleft palate patients\(^2,4,17\)\(^\text{2}^\text{2}\). Other studies have produced conflicting results, however\(^5,13\)\(^\text{2}^\text{2}\), which suggests that the data are as yet insufficient for a conclusion to be drawn. Hence, the purpose of the present study was to compare 3D airway measurements obtained from CT scans between unilateral cleft lip and palate (UCLP) patients and healthy controls.

**Materials and Methods**

The participants included in the present study comprised a total of 30 patients visiting the Department of Orthodontics or Department of Oral Surgery at Tokyo Dental College Chiba Hospital between 2000 and 2018; patients with syndromes were excluded. A total of 15 patients were assigned to a UCLP group: the clinical requirements for a CT scan due to an alveolar bone graft were met in all these patients; the CT scan included all the areas necessary for the purposes of the study; and all were aged between 8 and 13 years. A further 15 participants were assigned to a control group: the clinical requirements for a CT scan due to impacted teeth were met in all these patients; and all were aged between 8 and 14 years. Computed tomography scans
were obtained with the patient in the supine position. All the participants were asked to refrain from swallowing during the CT scan. Measurements were recorded from 3D reconstructions of Digital Imaging and Communications in Medicine data obtained from CT images using the ProPlan CMF 1.4 software (Materialize, Leuven, Belgium). The method suggested by Mevlut et al.\(^\text{10}\) was used to calculate the total airway volume from the 3D reconstruction of the pharyngeal airway: this involved using the Frankfurt horizontal (FH) plane as the superior margin; the tangent to the ventral inferior margin of the third cervical vertebra parallel to the FH plane as the inferior margin; a plane that passes through the posterior nasal spine (PNS) and which is perpendicular to the FH plane as the anterior margin; and the posterior pharyngeal wall as the posterior margin. Airway volume was divided into superior and inferior sections, termed the nasopharyngeal and oropharyngeal airway, respectively, by a plane that passes through the PNS and anterior-most prominence of the first cervical vertebra (Fig. 1). The area which could be subjected to the CT scan was restricted due to concerns regarding exposure to radiation. The areas that permit measurement of the sella-nasion-point A and sella-nasion-point B angles, which are ordinarily used to evaluate the anteroposterior relationship between the mandible and maxilla, were not included. Therefore, the angles formed by FH plane-right-side orbitale (Or)-point A (FH-Or-A) and FH-right-side Or-point B (FH-Or-B) were adopted instead (Fig. 2). Several maxillary parameters such as intermolar width, anteroposterior airway diameter, and vertical length of the airway were measured (Table 1). The cross-sectional dimen-

Table 1 Measurement parameters in control and UCLP groups

|   | Description                                                                 |
|---|-----------------------------------------------------------------------------|
| 1. | Intermolar width | Distance between central fossae of both first maxillary molars |
| 2. | FH-Or-A (°) | Angle formed by the Frankfurt (FH) plane and the plane formed by the right Orbitale and the A point |
| 3. | FH-Or-B (°) | Angle formed by the FH plane and the plane formed by the right Or and the B point |
| 4. | Anteroposterior airway diameter (cm) | Distance from the posterior nasal spine (PNS) to the posterior pharyngeal wall in a plane parallel to the FH plane |
| 5. | Vertical dimension (cm) of the airway | Distance from the PNS to the inferior airway margin in a plane perpendicular to the FH plane |

UCLP: unilateral cleft lip and palate

Fig. 3 A, Cross-sectional dimensions of narrowest section calculated by software; B, Measurement of distance from posterior nasal spine to narrowest section of airway.
sions of the narrowest part of the airway and the distance from the PNS to the tangent to the ventral inferior margin of the third cervical vertebra parallel to the FH plane were measured using Dolphin 3D software (V.10, Dolphin Imaging, Chatsworth, California). The vertical distance between the PNS and the narrowest section of the airway was also measured (Fig. 3). The cross-sectional dimensions of the narrowest section of the airway were automatically selected and calculated by the software from a designated range.

Statistical analysis was performed using the Mann-Whitney U-test to assess differences between measurements in the UCLP and control groups; the Spearman’s rank correlation coefficient was used to identify the relationship between total airway and various other measurements. The level of significant difference was set at $p < 0.05$; the statistical software used was SPSS version 19 (SPSS, Chicago, IL, USA).

The protocol of this study was approved by the Ethics Committee of Tokyo Dental College (approval no: 738).

### Results

The mean age of the 15 participants (8 male, 7 female) in the UCLP group was $11.14 \pm 3.48$ years, while that of the 15 participants (11 male, 4 female) in the control group was $11.31 \pm 3.44$ years. No significant age-related difference was observed between the two groups. The only parameter in which significant differences between the two groups were evident was the vertical distance between the PNS and narrowest section of the airway (Table 2). Other parameters such as intermolar width, FH-Or-A, FH-Or-B, anteroposterior airway diameter, and vertical length of the airway showed no significant differences. Similarly, no significant differences in volume in any section of the airway were evident between the UCLP and control groups. Total airway volume was $15.78 \pm 7.00 \text{ cm}^3$ in the control group and $18.08 \pm 9.05 \text{ cm}^3$ in the UCLP group; nasopharyngeal airway volume

| Age (y) | Inter- molar width (cm) | FH-Or-A (°) | FH-Or-B (°) | Anteroposterior diameter (cm) | Vertical length (cm) | Airway volume (cm³) | Narrowest section (cm²) | Distance (cm) | Mann-Whitney U-test | UCLP | Control | UCLP | Control |
|---------|------------------------|-------------|-------------|-----------------------------|---------------------|---------------------|------------------------|---------------|---------------------|------|---------|------|---------|
| 11.14±3.44 | 4.60±0.30          | 41.45±2.62  | 66.19±3.52  | 64.4±4.08                   | 4.00±0.72           | 7.89±2.21           | 1.20±1.06             | 3.85±1.19   | NS                  | 11.14±3.48 | 4.83±0.30 | 66.19±3.52 | 64.4±4.08 | 4.00±0.72 | 7.89±2.21 | 1.20±1.06 | 3.85±1.19 | NS |
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| NS       | NS                   | NS          | NS          | NS                          | NS                  | NS                  | NS                    | 0.017        | NS                  | 0.017       | NS       | 0.017       | NS       | 0.017       | NS       | 0.017       | NS |

Table 2: Comparison of measurements between groups

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was 6.44 ± 2.62 cm$^3$ in the control group and 8.34 ± 4.14 cm$^3$ in the UCLP group; and oropharyngeal airway volume was 9.34 ± 4.89 cm$^3$ in the control group and 9.75 ± 5.36 cm$^3$ in the UCLP group. None of these measurements exhibited a significant difference between the two groups (Table 2). The cross-sectional dimension of the narrowest section of the airway was 1.20 ± 0.45 cm$^2$ in the control group and 1.12 ± 0.65 cm$^2$ in the UCLP group; no significant difference was observed between the two groups. The vertical distance from the PNS to the narrowest section of the airway was 2.41 ± 1.06 cm in the control group and 3.85 ± 1.91 cm in the UCLP group, which showed that the narrowest section of the airway in the patients in the UCLP group was situated inferior to that in those in the control group (p = 0.017) (Table 2).

Thorough investigations of the relationships between total airway volume and various other measurements revealed a moderate correlation between age ($r = 0.58$, $p = 0.02$) and the cross-sectional dimensions of the narrowest section of the airway ($r = 0.70$, $p < 0.001$) in patients in the control group; and a moderate correlation between age ($r = 0.70$, $p = 0.01$) and vertical length of the airway ($r = 0.70$, $p = 0.01$) in patients in the UCLP group (Table 3).

### Discussion

Airway volume has been reported to range between 10.00 cm$^3$ and 20.00 cm$^3$ in healthy individuals, and between 15.00 cm$^3$ and 17.00 cm$^3$ in patients with CLP$^{4,14}$. Similar results were obtained from the present study, with a mean airway volume of 15.78 cm$^3$ in the controls and 18.08 cm$^3$ in the UCLP group. These values were slightly higher in the UCLP group. Previous research has found airway volume to be lower in patients with CLP$^{2,4,17}$, but conflicting results have been obtained in other reports$^{5,13}$. Some studies reported that the sections where the airway is smaller in patients with CLP vary: for example, CLP patients showed smaller oropharynges, but not total airway$^{4,17}$ or nasopharynges$^{2}$. In one previous report that found no difference in airway volumes between CLP and control groups, it was concluded that any significant difference might have been eliminated by maxillary expansion attained by use of a rapid expansion device in the patients with CLP$^{5}$. Expansion of the dental arch has been associated with expansion of the nasal cavity$^{3}$, however, leaving the oropharynx unaffected$^{6,18}$, and maxillary expansion is believed to have little impact on pharyngeal airway volume. Maxillary expansion can also change the shape of the airway, especially those areas located in the maxilla (the nasal cavity and posterior section of the PNS, for example).
Further research is required to validate the effects of maxillary expansion on the airway, however. Some of the participants in the present study had undergone maxillary expansion. To counter changes due to CLP, many patients were treated orthodontically, and preliminary orthodontic treatment is required before alveolar bone grafting, in particular.

Airway volume has been reported to increase with age in healthy individuals\textsuperscript{1,15} due to the growth of the mandible and shrinkage of the tonsils\textsuperscript{6}. Another report\textsuperscript{7}, however, found no difference in airway volume between children (aged 9–12 years) and adolescents (aged 13–17 years); and no significant difference was observed in the anteroposterior location or size of the jaw in these two groups, which also suggested that there would not be any difference in airway volume\textsuperscript{10}. The position of the mandible has been reported to affect the pharyngeal airway\textsuperscript{7,8,12}. In the present study, though, airway volume increased with age in both the UCLP and control groups. The absence of a correlation with the anteroposterior position of the jaw could be a cause for the absence of a difference in airway volume.

In the present study, the cross-sectional dimensions of the narrowest section of the airway were related to the total airway volume in the control group. In contrast, the UCLP group showed no such relationship. This could be attributed to the influence of the CLP and the palatoplasty procedure. To our knowledge, no previous studies have analyzed the cross-sectional shape of the airway in UCLP patients. It can be inferred, however, that CLP and its associated surgeries would affect cross-sectional morphology. Furthermore, total airway volume and the vertical length of the airway showed a correlation in the UCLP group. The vertical length of the airway showed a difference between the two groups, although this was not significant. The UCLP group showed shorter lengths than the control group, however, possibly because CLP inhibits the downward growth of the maxilla\textsuperscript{16}. It can be inferred that participants severely affected by this procedure have shorter vertical lengths and smaller airway volumes. Conversely, no correlation was observed between total airway volume and vertical length of the airway in the control group. This may be explained by individual differences in the vertical length of the airway.

This study may have had limitations due to concerns regarding exposure to radiation. Correction of the wings of the nose is often performed simultaneously when performing an alveolar bone graft. In this situation, the surgeon will require CT scans not only of the maxilla, but also of the maxillofacial area in diagnosing facial symmetry. Airway volume in UCLP patients can also be measured in such CT scans. The airway has a complicated morphology, so it cannot be adequately visualized using 2D technology. Computed tomography scans are indispensable in this regard.

Tracy \textit{et al.}\textsuperscript{5} reported that the cross-sectional dimension of the narrowest section of the airway was 1.16 ± 0.59 cm\textsuperscript{2} in CLP cases and 1.14 ± 0.59 cm\textsuperscript{2} in non-CLP cases, which is not a significant difference, and similar results were obtained in the present study as well. The present results also showed that the narrowest section of the airway in the patients in the UCLP group was inferior to that in those in the control group. This has been attributed to the fact that retraction of the mandible leads to narrowing of the airway in the soft palate region or root of the tongue\textsuperscript{12,15}, and changes in facial morphology, especially in CLP patients, lead to retraction of the midface and mandible\textsuperscript{10}, thus leading to increased narrowing of the lower airway. The narrowest section of the airway is important, as it is involved in breathing, speech, and swallowing, and an inferior location of the narrowest section of the airway, in particular, may be involved in sleep apnea syndrome and aspiration pneumonitis.

\textbf{Conclusion}

No difference was found in airway volume between patients in the UCLP and control
groups. The narrowest section of the airway in the patients in the UCLP group was inferior to that in those in the control group.

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