Effect of palatine tonsil hypertrophy on tongue posture and maxillofacial dentition: A pharyngeal airway computational fluid dynamics study

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ABSTRACT

Objectives: This study aimed to clarify the effect of palatine tonsil hypertrophy-induced ventilation obstruction on maxillofacial dentition morphology using computational fluid dynamics (CFD) to represent tongue posture and maxillofacial dentition three dimensionally.

Materials and Methods: We analyzed data of 20 patients with tonsil hypertrophy (tonsil hypertrophy group (TG); 9.0 years old, seven boys) and a comparison group (CG) of 20 patients without tonsil hyperplasia (comparison group; 9.4 years old, 10 boys). Cone-beam computed tomography and CFD data were used to assess the effects of palatine tonsil hypertrophy on pharyngeal airway ventilation, tongue posture, and morphology of the maxillofacial dentition.

Results: The TG exhibited significantly greater depth, narrower width, smaller cross-sectional area of the pharyngeal airway, and narrower maxillary dental arch with Class II than the CG. Additionally, the tongue was positioned significantly more anteriorly and inferiorly in the TG than that in the CG.

Conclusions: Our data suggest that hypertrophy of the palatine tonsils narrows the pharyngeal airway, resulting in a smaller cross-sectional area. Widening of the pharyngeal airway may occur due to compensatory anterior displacement of the tongue to prevent ventilation obstruction. This may decrease palatal support, disturbing the pressure balance of the maxillary molar region between the buccal and palatal sides and resulting in lateral undergrowth of the maxillary bone and narrowing of the maxillary dental arch.

Keywords: tonsil, tongue posture, maxillofacial dentition, pharyngeal airway, computational fluid dynamics

INTRODUCTION

Numerous studies have investigated the influence of maxillofacial dentition morphology on respiratory function during development.[1] Pharyngeal airway obstruction due to palatine tonsil hypertrophy has been proposed to affect the morphology of the maxillofacial dentition and inhibit the lateral growth of the maxillary dental arch.[2-5] Moreover, some studies have reported associations of pharyngeal airway obstruction with posterior crossbite and/or a Class II malocclusion.[4, 6] However, these associations remain controversial.[4] The effect of palatine tonsil hypertrophy on the morphology of the pharyngeal airway exhibits a complex relationship with ventilation via other airways (e.g., nasal and nasopharyngeal airways [NNAs]), making it difficult to clarify the effects of obstructions related to this phenomenon on the maxillofacial dentition.

Computational fluid dynamics (CFD), a method for reproducing airflow during actual breathing,[7] can be used to evaluate ventilation status despite the complex morphology of the upper airway. Furthermore, CFD can be used to evaluate the ventilation conditions in different parts of the upper airway, including the individual nasal, nasopharyngeal, oropharyngeal, and hypopharyngeal airways.[8] Therefore, CFD allows for the exclusion of cases involving NNA obstruction and can aid in the assessment of ventilation obstructions related to palatine tonsil hypertrophy.

Previous studies[2, 9, 10] regarding the effect of nasal airway obstruction on maxillofacial dentition morphology have reported inferior displacement of the tongue, indicating that the tongue may change position due to palatine tonsil hypertrophy, thereby leading to ventilation obstruction in the pharyngeal airway.[11, 12] This may then affect the morphology of the maxillofacial dentition. However, previous studies have conventionally used two-dimensional lateral cephalometry to evaluate tongue posture.[6] To the best of the authors' knowledge, no studies have utilized three-dimensional (3D) methods, indicating that assessments of tongue posture may have been inadequate.

The present study aimed to clarify the effect of ventilation obstruction caused by palatine tonsil hypertrophy on the morphology of the maxillofacial dentition.

MATERIALS AND METHODS

This study was approved by the institutional review board of XXX University (180073 (657) Epi-ver. 8), and the requirement for informed consent was waived due to the retrospective nature of the study.

Eligible participants who had undergone orthodontic treatment between January 2010 and September 2021 were retrospectively selected from the archives of a large private orthodontic practice (n = 2,761, Fig. 1). The inclusion criteria were as follows: age of 7–12 years; dental problems, such as supernumerary teeth, impacted teeth, congenitally missing teeth, and Class I–III malocclusion; a craniocervical inclination between 95° and 105°, [13] the patients were divided into two groups according to tonsillar size (hypertrophy and without hypertrophy tonsil, Fig 2A). And non-NNA ventilation obstruction according to the evaluation based on CFD. Cases with suspected ventilation obstruction in the NNA were excluded (Fig. 2B-D). The exclusion criteria were as follows: nasal disease, previous tonsillectomy or adenoidectomy, previous orthodontic treatment, craniofacial or growth abnormalities, systemic disease, or temporomandibular joint disorder. Thus, 40 non-consecutive patients were included in the study.

Patients with tonsils extending more than three-quarters of the way to the midline were included in the tonsil hypertrophy group (TG).[14] Patients without hyperplasia of the tonsils were included in the comparison group (CG).[14]

All patients underwent diagnostic cone-beam computed tomography (CBCT) for non-routine orthodontic treatment. To minimize radiation exposure, the scans were performed only when the diagnostic benefits outweighed the risks of radiation exposure. Obstruction was defined as a resistance of greater than 0.5 Pa/mL/s.[7]

On average, patients in the TG exhibited skeletal Class II abnormalities (ANB 6.0 ± 2.5°, Frankfort–mandibular plane angle (FMA) 26.9 ± 5.2°). Participants in the CG were matched with those in the TG according to skeletal tendency (ANB 5.2 ± 1.3°, FMA 27.1 ± 4.3°). The TG included seven boys and 13 girls (average age, 9.5 ± 1.0 years), while the CG consisted included 10 boys and 10 girls (average age, 9.4 ± 1.2 years).

CBCT scans

All CBCT scans (Alphard 3030; Asahi Roentgen, Kyoto, Japan) were acquired with the participants seated in a chair with the Frankfort horizontal plane parallel to the floor.[10] The CBCT parameters were set to a maximum of 80 kV, a maximum of 2 mA, and an exposure time of 17 s. Data were sent directly to a personal computer and stored in digital imaging and communications in medicine format.

Morphological analysis

Two-dimensional analysis

The cephalometric images, horizontal cross-sectional images parallel to the Frankfurt plane at the gonion, and frontal cross-sectional images of the maxillary and mandibular first molar axis were constructed using the origin of the 3D-coordinate medical system (Imagnosis VE□; Imagnosis, Kobe, Japan), as described in a previous report (Table 1, Fig. 3).[15]

Cephalometric image analysis

Landmarks, reference planes, and cephalometric angular measurements[7, 16] were based on cephalometric images (Fig. 3A). Traditional measurements were used to determine the dentofacial angles and positions of the maxilla and mandible. The authors measured the FMA, the angle between the sella/nasion plane and the nasion/A plane (SNA angle), and the angle showing the anterior limit of the mandibular basal arch in relation to the anterior cranial base (SNB angle). Distances from the posterior wall of the pharyngeal airway to the tongue at the midpoint of the maxillary and mandibular central incisor tips (D_{MI}) and to the epiglottis base (D_{EB}) parallel to the Frankfurt plane were also measured.

In this study, the anteroposterior posture of the tongue was defined as the value obtained by subtracting D_{EB} from D_{MI} (D_{MI} - D_{EB}). A positive value indicated an anterior tongue posture.

Horizontal analysis

Using horizontal cross-sectional views, the anteroposterior pharyngeal airway depth (OA_{APD}), the left and right narrowest pharyngeal airway width (OA_{W}), and the cross-sectional area (OA_{CSA}) of the pharyngeal airway section were measured parallel to the Frankfurt plane at the gonion (Fig. 3B).[15]

Frontal analysis

Angular measurements were recorded. The angle between the long axis of the palatal root of the maxillary first molar teeth and the reference line parallel to the palatal plane was measured (Axis $_{U6}$, Fig. 3C).[17] The angle between the long axis of the mesial root of the mandibular first molars and the reference line passing through the lower borders of the mandible was also measured (Axis $_{L6}$, Fig.3D).[17] The averages of the bilateral measurements were used.

Three-dimensional analysis

Volume-rendering software (INTAGE Volume Editor□; https://www.intage.co.jp/english/service/platform/intage-connect/) was used to create the 3D images and evaluate the 3D values. The intraoral airway volume (IA_V) was also measured (Fig. 3E). The IA_V was defined as the space between the palate and the tongue. In this study, positive IA_V values indicated an inferior tongue posture.[15] In addition, the maxillary width (W_{MAX}) and the maxillary first molar dental arch widths (W_{U6}) were measured (Fig. 3F).[14] Similarly, the mandibular width (W_{MAN}) and the mandibular first molar dental arch widths (W_{L6}) were also measured (Fig. 3G).

Functional analysis

CFD analysis of the NNA

Evaluations of ventilation status in the NNA were conducted during expiration based on CFD, and the results were analyzed as previously described (Fig. 2B).[8, 18] The NNA resistance was calculated as the pressure difference from the external nares to the pharyngeal airway at the level of the palatal plane in CFD, using the NNA model and a flow quantity of 200 mL/s. Cases with resistance >0.5 Pa/mL/s were excluded.[7]

CFD analysis of the oropharyngeal airway

The ventilation status in the oropharyngeal airway was analyzed during inspiration using CFD.[8, 18] The resulting 3D model of the oropharyngeal airway was used to evaluate $OA_{pressure}$, defined as the pressure difference from the palatal plane to the bottom of the epiglottis, which was equivalent to the level of the palatine tonsil (Fig. 2C). The CFD analysis was performed as described for the NNA.

Statistical analysis

All measurements were repeated after 2 weeks by the same investigator. The Dahlberg formula[19] was used to calculate the measurement error. The measurement error of the linear values of lateral cephalometry and 3D were 0.382 mm for lateral cephalometry and 0.538 mm for 3D. The measurement error of the angular values of lateral cephalometry and 3D was 0.438° for lateral cephalometry and 0.569° for 3D. Moreover, the measurement error of OA_{CSA} values was 1.175 mm^2, and the IA_V value was 0.024 cm^3. Intraclass correlations were used to calculate the reliability between the first and second measurements. The values ranged from 0.956 to 0.995. Thus, the methodological error was considered negligible.

Unpaired *t*-tests or Mann–Whitney U-tests were used to detect intergroup differences, depending upon the data distribution. Pearson's or Spearman's correlation coefficients were calculated to evaluate the relationships between the morphological measurements and ventilation conditions, depending on the data distribution. Only variables with the highest correlation coefficients among the same group of variables having collinearity were entered in the stepwise multiple linear regression analysis. For all tests, P values < 0.05 were considered statistically significant. Based on a similar CFD study involving morphological analysis of the pharyngeal airway in children with obstructive sleep apnea (OSA),[8] the power analysis (1-β error = 0.8, α = 0.05, two-tailed test) indicated that a minimum sample size of 18 in each group was required for the detection of significant differences.

RESULTS

Comparison

$OA_{pressure}$ was greater in the TG (-26.66 Pa) than that in the CG (-3.07 Pa) (Table 1). In terms of pharyngeal airway morphology, the TG (16.36 mm) exhibited significantly larger OA_{APD} values than the CG (10.52 mm). However, there was no significant difference in D_{EB} values between the groups. In contrast, the TG exhibited significantly lower values for OA_W

(2.57 mm) and OA_{CSA} (82.14 mm^2) than the CG (19.24 mm, 178.72 mm^2, respectively). In addition, the degree of anterior tongue displacement was significantly greater in the TG (D_{MI} - D_{EB} was positive) than that in the CG. The TG also had significantly larger IA_V values than the CG, indicative of a relatively anterior and inferior tongue posture. Both W_{MAX} and W_{MAN} values were significantly smaller in the TG than that in the CG. In terms of dentition, W_{U6} was significantly narrower in the TG than that in the CG, although there was no significant difference in W_{L6}. Therefore, $Axis_{U6}$ was significantly buccally tilted, while $Axis_{L6}$ was significantly lingually tilted in the TG.

Relationship among $OA_{pressure}$, tongue posture, pharyngeal airway morphology, and maxillofacial dentition

$OA_{pressure}$ exhibited significant positive correlations with OA_W, OA_{CSA}, W_{MAX}, W_{MAN}, W_{U6}, and $Axis_{L6}$ (Table 2). Moreover, $OA_{pressure}$ and OA_{CSA} exhibited a strong nonlinear relationship (Fig. 4C), suggesting that the pressure begins to increase from 80 mm^2 (Fig. 4C, a1) and reaches more than 100 Pa at 40 mm^2 (Fig. 4C, b1). $OA_{pressure}$ also exhibited significant negative correlations with IA_V, anterior tongue posture, OA_{APD}, and $Axis_{U6}$ (Table 2).

An anterior tongue posture was positively correlated with IA_V, OA_{APD}, and $Axis_{U6}$ and negatively correlated with airway width, OA_{CSA}, W_{MAX}, and W_{U6}. An inferior tongue posture was positively correlated with OA_{APD} and negatively correlated with airway width, OA_{CSA}, and W_{MAX} (Table 2).

OA_{APD} was positively correlated with $Axis_{U6}$ and negatively correlated with airway width, OA_{CSA}, W_{MAX}, and W_{MAN}. Airway width was positively correlated with OA_{CSA}, W_{MAX}, W_{MAN}, W_{U6}, and $Axis_{L6}$ and negatively correlated with $Axis_{U6}$. OA_{CSA} was positively correlated with W_{MAX}, W_{MAN}, W_{U6}, and $Axis_{L6}$ and negatively correlated with $Axis_{U6}$ (Table 2).

In the multivariate analysis of $OA_{pressure}$, OA_{CSA} was the only factor that remained significant, with an adjusted $R^2 = 0.343$ ($P < 0.001$). In the analysis of anterior tongue posture, OA_W was the only factor that was retained, with an adjusted $R^2 = 0.629$ ($P < 0.001$). Anterior tongue posture was the only factor retained in the multivariate analysis of the buccal inclination of the maxillary first molar, with an adjusted $R^2 = 0.281$ ($P < 0.001$).

DISCUSSION

This study evaluated the effects of palatine tonsil hypertrophy on ventilation conditions in the pharyngeal airway, tongue posture, and the morphology of the maxillofacial dentition based on CFD and 3D morphological analysis. The findings indicated that enlargement of the palatine tonsil resulted in a marked narrowing of the pharyngeal airway and reductions in OA_{CSA}, increasing the likelihood of ventilation obstruction. These changes were associated with anterior displacement of the tongue and widening of the pharyngeal airway as compensatory means for preventing ventilation obstruction. Therefore, increases in OA_{APD} were observed. The combination of anterior protrusion and inferior displacement of the tongue in turn decreases palatal support, which can disrupt the balance of muscle pressure in the maxillary molar area between the buccal and palatal sides.[2, 4, 5] Such disruptions can inhibit the lateral growth of the maxillary bone and cause narrowing of the maxillary dental arch.

Tongue posture and the pharyngeal airway

In this study, there was a nonlinear relationship between the pressure level, representing ventilation status, and the cross-sectional area of the pharyngeal airway (Fig. 4C). Negative pressure increased when the cross-sectional area was 80 mm^2 or less. A cross-sectional area of 40 mm^2 was associated with a resistance level considered to represent ventilation obstruction (100 Pa, flow rate 200 mL/s, corresponding to 0.5 Pa/mL/s).[14]

Previous studies have reported that negative pressure increases when the cross-sectional area of the airway is less than 100 mm^2 in adults[20] and less than 50 mm^2 in 6-year-old children.[18] The OA_{CSA} results revealed similar tendencies when compared with the findings of previous studies.

The CG of the present study exhibited an OA_w of 19.24 mm. When compared with this value and that for a Class I group (14.97 mm) in a previous study,[15] the OA_W was significantly reduced in the TG (2.57 mm). When the OA_{APD} was similar to that in the CG (10.52 mm), the cross-sectional area decreased markedly, and ventilation obstruction was highly likely to occur (Fig. 4C b1). As the OA_W of the TG was very narrow, the tongue protruded about 6 mm anteriorly, and the OA_{APD} and OA_{CSA} values were 16.36 mm and 80 mm^2, respectively. The results indicated that OA_{CSA} increased sufficiently for breathing in the TG (Fig 4C b2).

Inferior tongue displacement

This study evaluated the volume between the tongue and palate in 3D,[10] enabling the quantification of the inferior displacement of the tongue, regardless of the shape of the dorsum of the tongue. The IA_V values in the TG were large, suggesting an inferior tongue posture. Previous studies[9, 10] have indicated that such inferior positioning can be explained by mouth breathing due to nasal airway ventilation obstruction and increased adenoid size. However, patients without NNA ventilation obstruction were selected for the present study. Furthermore, pharyngeal airway pressure caused by palatine tonsil hypertrophy did not exceed 100 Pa (resistance level 0.5 Pa/mL/sec), at which point ventilation obstruction occurred. In other words, ventilation obstruction due to palatine tonsil hypertrophy did not occur in the TG. Additionary, the IA_V values indicating inferior tongue displacement were positively correlated. And anterior tongue posture negatively correlated with OA_W and OA_{CSA}. These results suggest that inferior tongue displacement in patients with palatine tonsil hypertrophy is associated with anterior tongue protrusion to secure ventilation and lateral constriction of the pharyngeal airway (OA_{CSA}) (Fig. 4).

Palatine tonsil hypertrophy and maxillofacial dentition morphology

Several studies have reported that children with palatine tonsil hypertrophy develop constricted maxillary dentition.[2-5] In previous studies,[2, 3] the participants were children with nasal breathing who had no cephalometric problems or any medical history of ear, nose, and throat disease. However, in this study, the authors evaluated the effect of palatine tonsil hypertrophy alone using CFD, as this allowed us to select patients without NNA obstruction based on 3D airway models. Thus, the results confirmed that reduced maxillary lateral growth and constriction of the maxillary dental arch occur specifically due to palatine tonsil hypertrophy (Fig. 5).

Further studies have indicated that when the tooth axis angle of the maxillary molar is approximately 95° in adults without missing teeth/crossbite and only minimal crowding, the angle for the mandibular molar is approximately 78°.[21] In the present study, values for the TG ($Axis_{U6}$, 104.91°; $Axis_{L6}$, 66.98°) exceeded those described in the previous report.[21] Since the reductions in maxillary lateral growth were more marked in the TG than that in the CG, greater slanting of the maxillary molar axis occurred on the buccal side.

Due to the anterior and inferior posture of the tongue in the TG, which can be interpreted as compensatory mechanisms for maintaining the airway, the tongue pressure on the palatal side of the maxillary dentition decreased, and the pressure balance in the bucco-palatal region was disturbed.[22, 23] Consequently, these changes were associated with reduced lateral growth of the maxillary bone and narrowing of the dentition occurred. Specifically, the diameter of the maxillary dentition arch decreased, and molar axial inclination occurred.

Palatine tonsil hypertrophy and Class II

The participants with palatine tonsil hypertrophy in the current study exhibited a Class II, similar to the findings of previous reports.[24, 25] Tollaro et al.[26] suggested that functional retreat of the mandible can be explained by constrictions in the maxillary dentition, resulting in a Class II. Other authors have suggested that anterior displacement of the tongue due to palatine tonsil hypertrophy biases the mandible toward the anterior direction.[27, 28] Therefore, the effect of palatine tonsil hypertrophy on the relationships involving the maxillary and mandibular jaw remains controversial. Although the results indicated that the patients exhibited no ventilation obstructions in the NNA, the authors did not evaluate the actual respiratory status in the current study. Additional studies are required to clarify the effect of palatine tonsil hypertrophy on maxillofacial dentition based on actual respiratory status.[29]

Precision of CFD in this study

In terms of the upper airway model built from CBCT data, the shape of the model varied according to the setting of the extraction range of the air Hounsfield units during model construction. Thus, the test and CFD values for the nasal airway were used to standardize the CBCT thresholds, ensuring similar CFD levels throughout the study.[8, 30] This allowed us to depict ventilation status in the airway model corresponding to that in a living body. This method demonstrated good precision.

Clinical implications

The CFD methods used in the current study can be used to exclude cases of NNA (adenoid) obstruction, allowing for specific evaluation of the effects of palatine tonsil hypertrophy in the pharyngeal airway. Several reports[2, 4, 5] have indicated that an inferior tongue posture and constriction of the maxillary dentition can be observed in patients with nasal airway ventilation obstruction. The current results support these findings, suggesting that anterior displacement of the tongue and constriction of the maxillary dentition can occur due to palatine tonsil enlargement without ventilation obstruction in the NNA. Thus, when the cephalometric OA_{APD} value is 16 mm or more, corresponding to palatine tonsil hypertrophy, treatment for ventilation obstruction may be necessary.[31]

Limitations

Strict criteria were used to select the participants in the current study. Consequently, the sample size was small. Another limitation may be the retrospective nature of the study. Nevertheless, trends were observed in the analysis. However, a random study will be required in the future. In addition, CBCT data were used to construct the rigid model for the CFD analysis, necessitating further studies involving functional methods. However, these data may still be valuable given their demonstrated correlation with polysomnography data.[8, 30, 32] In addition, since CBCT enables more accurate depictions of the tonsils, tongue, and airway, a statistical difference equal to or greater than 0.5 mm would indicate clinical significance for these measurements. Accordingly, the voxel size of the measurement error was calculated as 0.390 mm, indicating appropriate resolution for clinical use.

Future studies

Although the analysis revealed the effects of marked palatine tonsil hypertrophy, future studies should aim to examine these effects in milder cases of palatine tonsil hypertrophy. Such studies should also examine how these effects change over time, particularly after the age of 9 years, to provide insight into the appropriate timing for interventions. Moreover, future studies should perform analyses based on both 2D and 3D data to obtain an appropriate morphological evaluation of the tonsil and tongue posture.

CONCLUSIONS

The current results demonstrate that palatine tonsil hypertrophy can contribute to pharyngeal airway obstruction. Such enlargement results in the narrowing of the pharyngeal airway width, resulting in a smaller cross-sectional area. The enlarged tonsils also displace the tongue to an anterior posture while narrowing the maxillary dental arch.

Declaration of competing interest

There are no conflict of interest associated with this study.

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Figure legends

Figure 1. Flow diagrams of the subjects in this study

Figure 2. Evaluations of the morphological tonsil hyperplasia and ventilation status in the nasal and nasopharyngeal airway (NNA) and oropharyngeal airway (OA) using computational fluid dynamics (CFD).

A, upper: tonsil hypertrophy case, extend three-quarters of the way to the midline, lower: without tonsil hypertrophy case, no hyperplasia of the tonsils

B, Extraction of NNA (blue line) and 5 (yellow line)

C, CFD evaluation of NNA during expiration

Left, Volume-rendering and numeric simulation of the NNA (yellow arrow, inlet air flow; orange arrow, outlet air flow). Right, Evaluation of the ventilation status in the NNA using CFD. Maximum pressure exceeding 100 Pa indicates NNA obstruction, following which the case is excluded. Cases with maximum pressure values less than 100 Pa are not considered to have NNA obstruction and are included in the study.

D, CFD evaluation of OA during inspiration

Left, Volume-rendering and numeric simulation of OA (yellow arrow, inlet air flow; orange arrow, outlet air flow); Right, Evaluation of the ventilation status in the OA using CFD during inspiration in a case without NNA obstruction.

Figure 3. Morphological measurement of the maxillofacial dentition, tongue posture, and pharyngeal airway

A: Cephalometric landmarks and measurements

B; Horizontal cross-sectional measurement in the pharyngeal airway

C: Measurement of maxillary molar inclination

D: Measurement of mandibular molar inclination

E, Measurements of IA_V

F, Measurements of the 3D widths of the maxillofacial dentition.

G, Measurements of the dental arch width of between the left and right U6 and between the left and right L6.

Figure 4. The effect of pressure changes on the oropharyngeal airway (OA) due to palatine tonsil hypertrophy on ventilation conditions ($OA_{pressure}$) and its relationship with OA cross-sectional area (OA_{CSA}).

A, Three-dimensional morphology of the OA in a patient without palatine tonsil hypertrophy (from left; sagittal view, OA lateral view, OA frontal view, OA_{CSA} view (a1)).

B, Three-dimensional morphology of the OA in a patient with palatine tonsil hypertrophy (from left; sagittal view, OA lateral view, OA frontal view, OA_{CSA} view (b1 and b2)). The anteroposterior depth of the OA (OA_{APD}) was lengthened (yellow allow), and the lateral width of OA (OA_W) was narrowed (blue arrow) due to palatine tonsil hypertrophy. The red dotted line shows the anterior wall of the assumed pharyngeal airway when palatine tonsil hypertrophy is not present.

a1: Cross-section of the OA. The OA_W is wide, and the OA_{CSA} is large (blue area).

b1: The length of the OA_{APD} is normal, indicating no anterior displacement of the tongue. Consequently, the OA_{CSA} is small (red area). Airway obstruction was likely.

b2: The OA_{APD} is lengthened, and the OA_{CSA} is enlarged (yellow area). Thus, obstruction is unlikely.

C, Relationships between OA_{CSA} and $OA_{pressure}$

a1: The OA_{CSA} is approximately 150 mm^2 (blue point), and the $OA_{pressure}$ of the area is less than -10 Pa.

There is no obstruction of the OA.

b1: The OA_{CSA} is approximately 40 mm^2 (red point), and the $OA_{pressure}$ of the area is -90 Pa. OA obstruction is likely.

b2: The OA_{CSA} is reduced to approximately 80 mm^2 (yellow point) due to anterior displacement of the tongue. The $OA_{pressure}$ of the area is reduced to -20 Pa. OA obstruction is unlikely. OA obstruction seems to be prevented by the anterior tongue posture.

Figure 5. Anterior and inferior tongue posture due to palatine tonsil hypertrophy.

A, In the absence of palatine tonsil hypertrophy, the tongue is not positioned anteriorly or inferiorly. The mandibular and maxillary dental arches are relatively wide. The dotted line represents the tongue posture, and the lower boundary represents the mylohyoid inferior margin.

B, Hypertrophic palatine tonsil. The tongue is positioned anteriorly and inferiorly (yellow arrow) due to hypertrophy of the palatine tonsil (blue arrow). Since the tongue pressure on the palatal side of the maxillary dentition is decreased, the pressure balance between the bucco-palatal region is disturbed (red arrow). Consequently, the maxillary bone is underdeveloped laterally, and the dentition has narrowed.

Table I. Definition of the measurement items variables

item	definition
CFD	computational fluid dynamics
TG	tonsil hypertrophy group
CG	comparison group
NNA	nasal and nasopharyngeal airway
OA	oropharyngeal airway
S	sella turcica
N	nasion
Po	porion
Or	orbitale
A	point A
B	point B
Is	incisal edge of the maxillary central incisor
Ii	incisal edge of the mandibular central incisor
Go	gonion
EB	the lowest point of epiglottis
FH plane	Frankfort horizontal plane
D_{MI}	distance parallel to the Frankfurt plane from the posterior wall of the pharynx to the tongue at the height of the midpoint of the tips of the maxillary and mandibular cent incisors
D_{EB}	distance parallel to the Frankfurt plane from the pharyngeal posterior wall to EB.
OA_{CS}	Horizontal cross-sectional area of the oropharyngeal airway measured parallel to the FH plane at Go
OA_{APD}	anteroposterior depth of OA_{CS}
OA_{W}	narrowest lateral width of OA_{CS}
OA_{CSA}	cross-section area of OA_{CS}
$Axis_{U6}$	Angle between the long axis of the palatal root of the maxillary first molar teeth and a horizontal reference line parallel to the palatal plane.
$Axis_{L6}$	Angle between the long axis of the mesial root of the mandibular first molar teeth and a horizontal reference line passing through the lower borders of the mandible.
IA_{V}	intraoral airway volume between the palate and the tongue.
Mx	Point indicating the greatest depth of the concavity of the maxillary contour
W_{MAX}	maxillary width between the left and right Mx
W_{MAN}	mandibular width between the left and right Go.
U6	most lingual point of the maxillary first molar
W_{U6}	maxillary dental arch width between the left and right U6
L6	most lingual point of the mandibular first molar
W_{L6}	mandibular dental arch width between the left and right L6.

Table 2 Comparison of Tonsil group and Comparison group

	Comparison group (n = 20)		Tonsil group (n = 20)		
	mean	SD	mean	SD	P
age (year)	9.38	1.29	9.04	1.08	0.365
SNA (degree)	82.74	4.18	83.18	3.20	0.710
SNB (degree)	77.56	4.26	77.20	3.72	0.774
ANB (degree)	5.18	1.35	5.99	2.53	0.218
FMA (degree)	27.08	4.33	26.93	5.22	0.922
Anteriorly tongue posture (mm)	0.01	1.70	5.83	2.51	0.000
D_{EB} (mm)	13.31	3.14	12.64	3.41	0.522
$Axis_{U6}$ (degree)	99.63	3.45	104.91	3.55	0.000
$Axis_{L6}$ (degree)	70.62	5.12	66.98	4.19	0.019
OA_{APD} (mm)	10.52	1.88	16.36	1.97	0.000
OA_{W} (mm)	19.24	3.70	2.57	1.25	0.000
OA_{CSA} (mm^2)	178.72	49.25	82.14	18.86	0.000
IA_{V} (cm^3)	0.17	0.43	1.13	1.18	0.002
W_{MAX} (mm)	61.89	2.04	57.72	2.49	0.000
W_{MAN} (mm)	85.77	4.06	82.95	3.54	0.024
W_{U6} (mm)	33.76	2.12	32.08	1.26	0.005
W_{L6} (mm)	32.21	2.06	32.41	2.42	0.782
$OA_{pressure}$ (Pa)	−3.07	1.44	−26.66	23.90	0.000

Table 3 Correlation of among pharyngeal airway ventilation condition and morphology of maxillo-mandibular dentition

	IA_V	Anteriorly tongue posture	OA_{APD}	OA_W	OA_{CSA}	W_{MAX}	W_{MAN}	W_{U6}	W_{L6}	$Axis_{U6}$	$Axis_{L6}$	SNA	SNB	ANB	FMA
$OA_{pressure}$	−.406**	−.729**	−.651**	.890**	.915**	.589**	.321*	.522**		−.467**	.349*				
IA_V		.395*	.406**	−.413**	−.350*	−.379*									
Anteriorly tongue posture			.692**	−.799**	−.678**	−.502**		−.347*		.576**					
OA_{APD}				−.778**	−.516**	−.446**	−.372*			.527**					
OA_W					.896**	.690**	.414**	.513**		−.615**	.467**				
OA_{CSA}						.615**	.369*	.561**		−.495**	.461**				
W_{MAX}							.595**	.555**		−.650**	.453**				
W_{MAN}								.549**	.315*	−.356*	.379*				
W_{U6}									.732**		.528**		.367*		
W_{L6}											.415**				

** $P < 0.001$, * $P < 0.05$

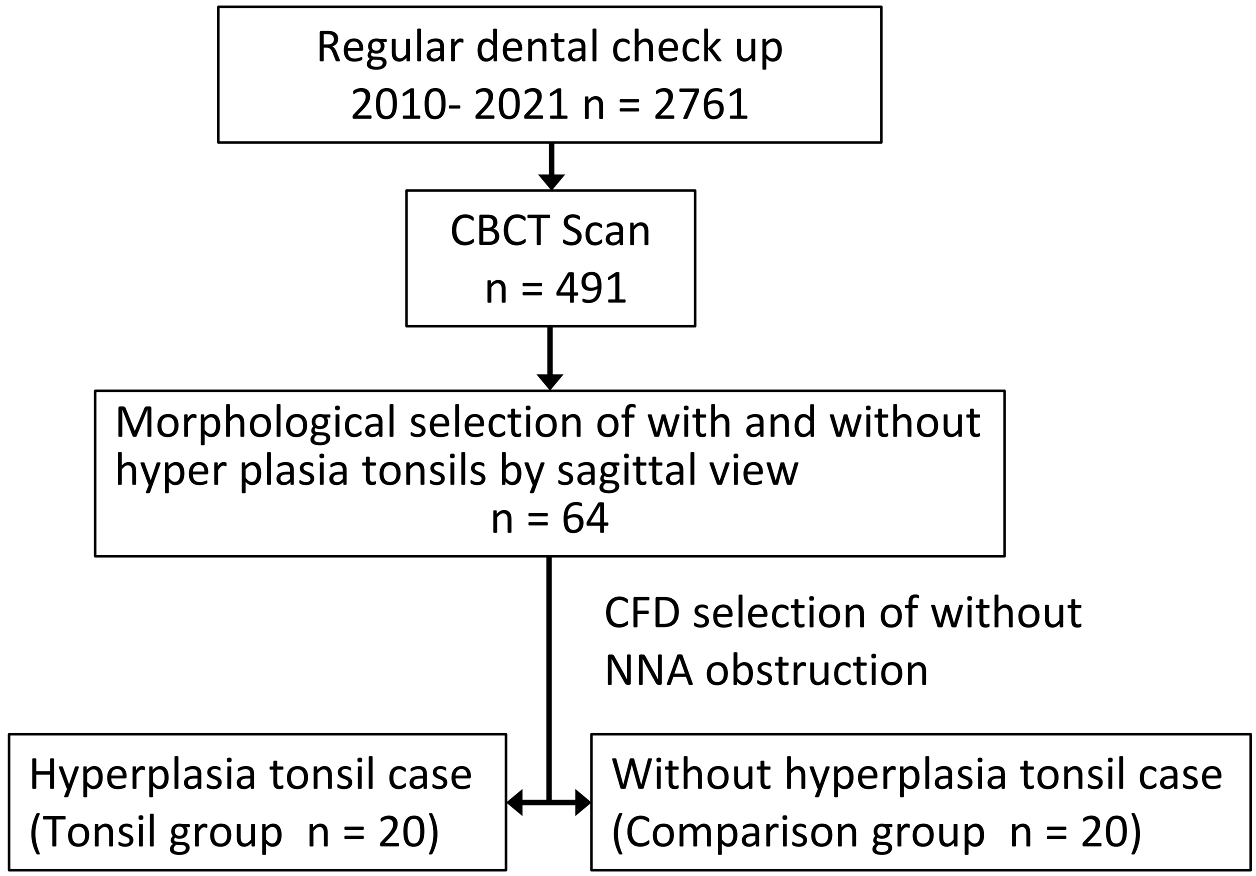

Regular dental check up
2010- 2021 n = 2761
CBCT Scan
n = 491
Morphological selection of with and without hyper plasia tonsils by sagittal view
n = 64
CFD selection of without NNA obstruction
Hyperplasia tonsil case
(Tonsil group n = 20)
Without hyperplasia tonsil case
(Comparison group n = 20)

Fig 1

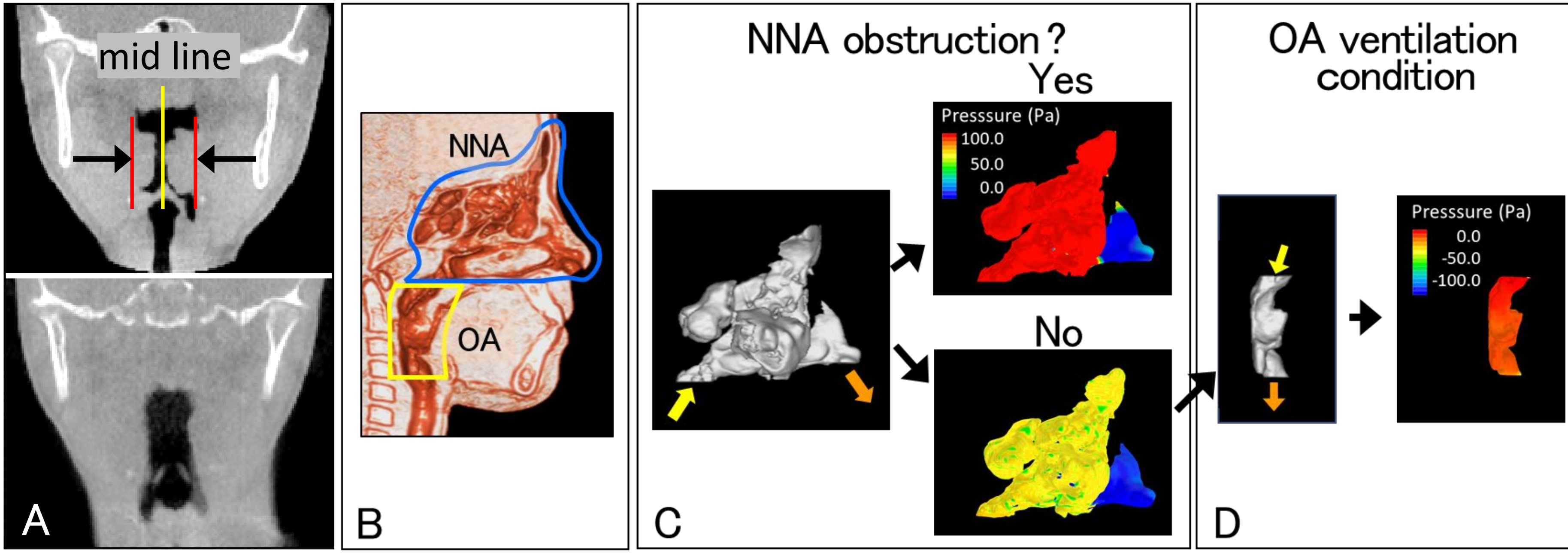
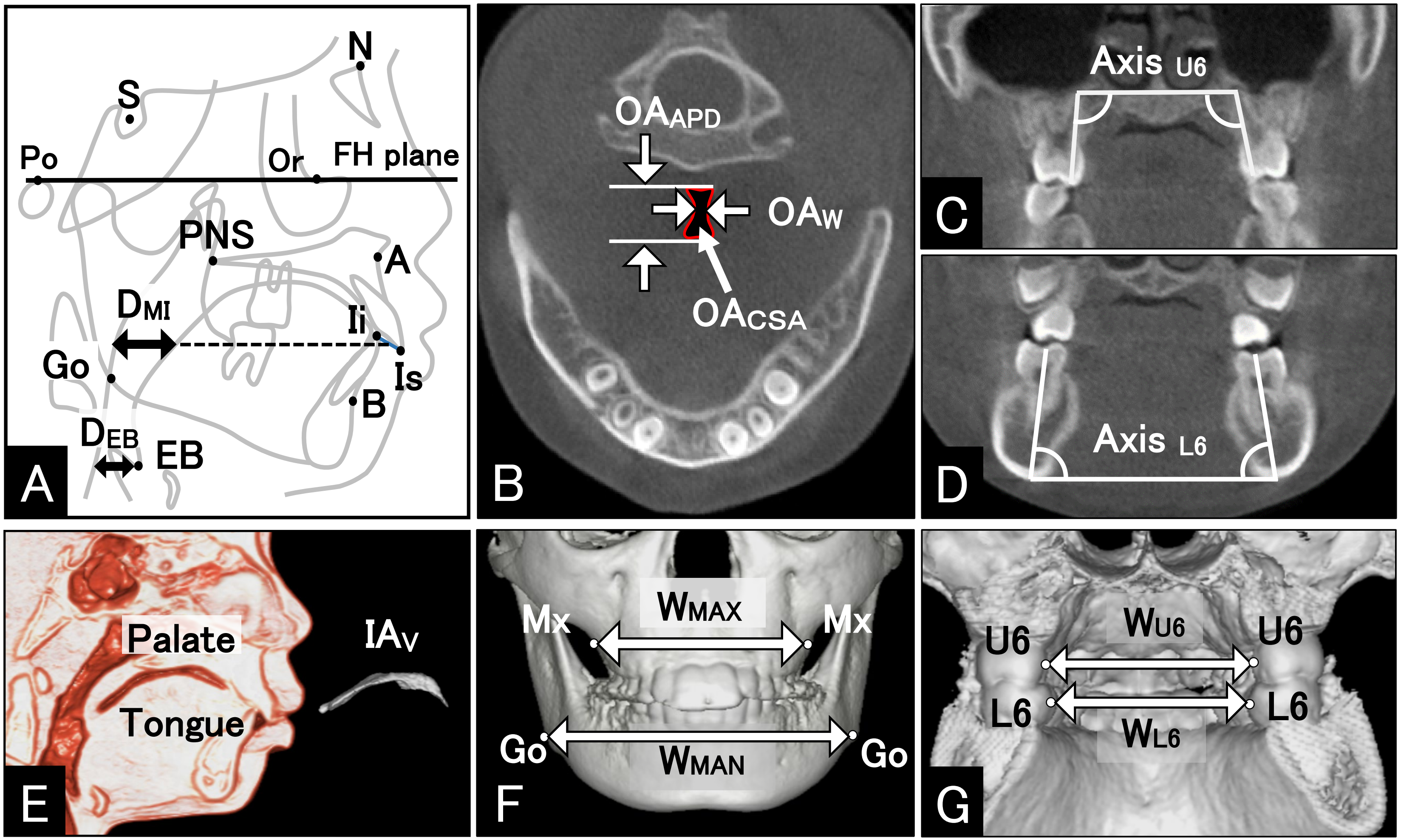
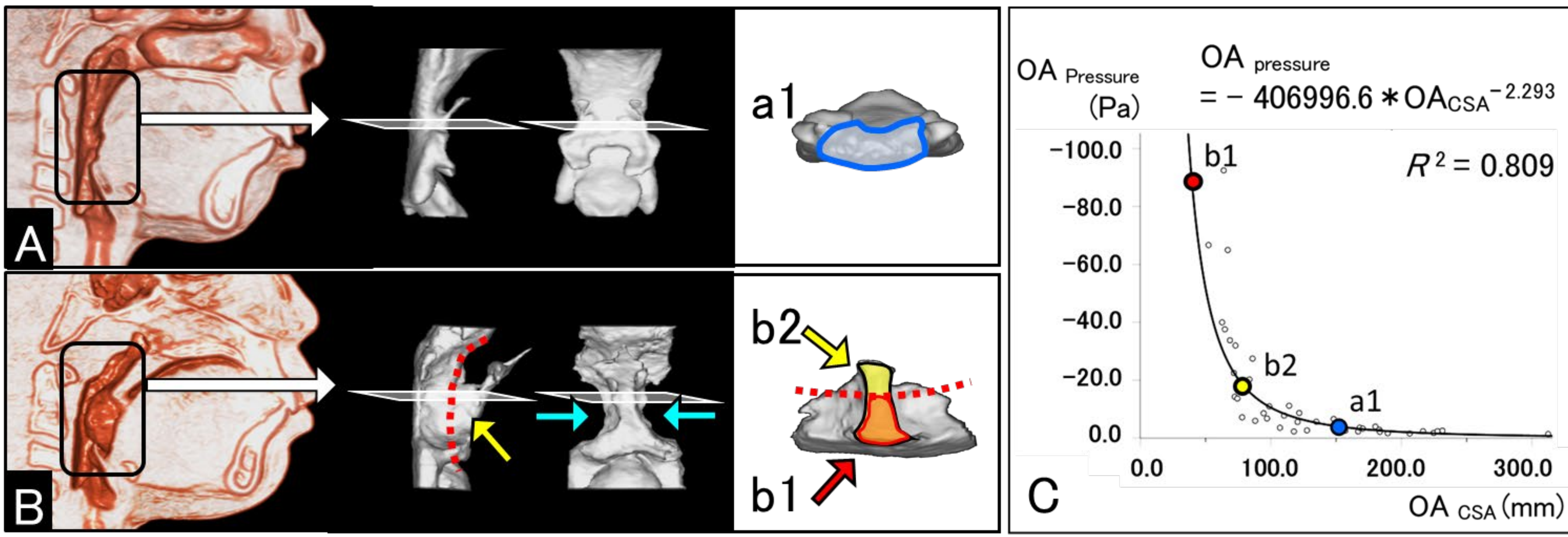

mid line
A
NNA
OA
B
NNA obstruction ?
Yes
Presssure (Pa)
100.0
50.0
0.0
No
C
OA ventilation condition
Presssure (Pa)
0.0
-50.0
-100.0
D

Fig 2



N
S
Po
Or
FH plane
PNS
A
DMI
Ii
Go
Is
B
DEB
EB
A
OAAPD
OAW
OACSA
B
Axis U6
C
Axis L6
D
Palate
Tongue
IAV
E
WMAX
Mx
Mx
Go
WMAN
Go
F
WU6
U6
U6
L6
L6
WL6
G

Fig 3



A
a1
B
b2
b1
OA Pressure (Pa)
OA pressure = − 406996.6 ∗ OACSA −2.293
−100.0
−80.0
−60.0
−40.0
−20.0
0.0
b1
R 2 = 0.809
b2
a1
0.0
100.0
200.0
300.0
C
OA CSA (mm)

Fig 4

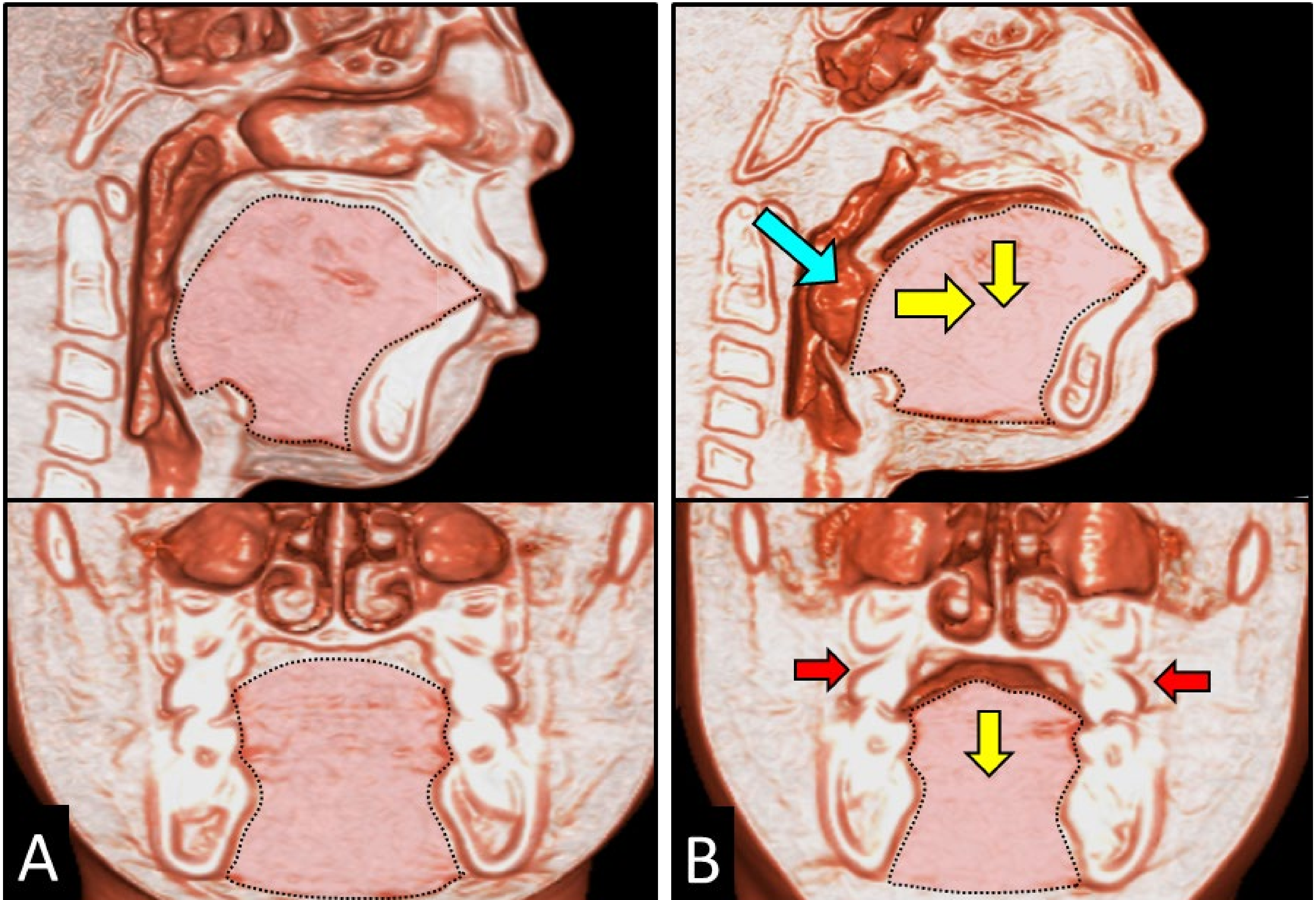


Fig 5