Journal of Orofacial Orthopedics (2023) 84(Suppl 2):S93–S103
https://doi.org/10.1007/s00056-022-00403-9

ORIGINAL ARTICLE

Relationship between craniofacial and dental arch morphology with pharyngeal airway space in adolescents

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Received: 30 April 2021 / Accepted: 25 February 2022 / Published online: 24 May 2022

Abstract

Purpose The aim of the study was to investigate a possible relationship between pharyngeal airway space, craniofacial variables, and dental arch form in adolescents grouped by sex.

Methods This cross-sectional study included 108 adolescents aged between 12 and 17 years. Lateral cephalometric radiographs were used to analyze sagittal craniofacial variables and the pharyngeal airway space. For evaluation of the dental arch form, we used plaster models. Statistical analysis included Student's t-test and Pearson's correlation coefficient (r).

Results Maxillary length was directly proportional to upper nasopharyngeal airway dimensions in males ($r = 0.312$, $p = 0.021$) and females ($r = 0.310$, $p = 0.022$). In the female group, upper oropharyngeal measurements showed an inverse correlation with a labial inclination of the upper incisors ($r = –0.415$, $p = 0.001$), protrusion of the upper incisors ($r = –0.364$, $p = 0.006$), and soft palate thickness ($r = –0.27$, $p = 0.043$). In the male group, upper nasopharynx measurements showed an inverse correlation with soft palate thickness ($r = –0.277$, $p = 0.042$). The upper arch form appeared to be related to oropharyngeal measurements in females, while the lower arch form was related to oropharyngeal dimensions in males.

Conclusion The findings suggest that there are sex-dependent correlations of the nasopharyngeal and oropharyngeal airway space with the sagittal craniofacial morphology and the transversal dental arch form.

Keywords Arch form · Cephalometry · Anatomy · Craniofacial analysis · Sex

Beziehung zwischen kraniofazialer und Zahnbogenmorphologie und pharyngealem Atemwegsraum bei Jugendlichen

Zusammenfassung

Zielsetzung Das Ziel der Studie war es, einen möglichen Zusammenhang zwischen pharyngealem Atemwegsraum, kraniofazialen Variablen und Zahnbogenform bei Jugendlichen, gruppiert nach Geschlecht, zu untersuchen.

Methoden Die Querschnittsstudie umfasste 108 Jugendliche im Alter zwischen 12 und 17 Jahren. Laterale kephalometrische Röntgenaufnahmen wurden verwendet, um sagittale kraniofaziale Variablen und den pharyngealen Atemwegsraum zu analysieren, zur Beurteilung der Zahnbogenform Gipsmodelle. Die statistische Analyse umfasste den t-Test nach Student und den Korrelationskoeffizienten nach Pearson (r).

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Ergebnisse Die Oberkieferlänge war direkt proportional zu den Abmessungen der oberen nasopharyngealen Atemwege bei Männern (r = 0,312; p = 0,021) und Frauen (r = 0,310; p = 0,022). In der weiblichen Gruppe zeigten die oberen oropharyngealen Messungen eine inverse Korrelation mit einer labialen Neigung der oberen Schneidezähne (r = –0,415; p = 0,001), einer Protrusion der oberen Schneidezähne (r = –0,364; p = 0,006) und der Stärke des weichen Gaumens (r = –0,27; p = 0,043). In der männlichen Gruppe zeigten Messungen des oberen Nasopharynx eine inverse Korrelation mit der Dicke des weichen Gaumens (r = –0,277; p = 0,042). Die obere Bogenform schien bei den weiblichen Probanden mit den oropharyngealen Abmessungen in Beziehung zu stehen, bei den männlichen Probanden dagegen stand die untere Bogenform mit den oropharyngealen Abmessungen in Beziehung.

Schlussfolgerung Die Befunde deuten auf geschlechtsabhängige Korrelationen des nasopharyngealen und oropharyngealen Atemwegsraums mit der sagittalen kraniofazialen Morphologie und der transversalen Zahnbogenform hin.

Schlüsselwörter Bogenform · Kephalometrie · Anatomie · Kraniofaziale Analyse · Geschlecht

Introduction

The pharyngeal airway space (PAS) is the airway space related to the three parts of the pharynx: the nasopharynx, oropharynx, and laryngopharynx. The pharynx takes part in key functions such as breathing, swallowing, and phonation, which makes evaluation of these structures fundamental for diagnosis, planning, and follow-up after orthognathic surgery and orthodontic treatment [1, 2]. An imbalance between the position of the teeth and the oral soft tissues (lips, tongue, and cheeks) can affect airway functions and vice versa [3]. In addition, soft tissue structures such as adenoids, soft palate length, and tongue dimensions may influence the PAS [4], as well as increase susceptibility to respiratory disorders (i.e., obstructive sleep apnea) [5].

In this context, different diagnostic imaging tools can be used to accurately evaluate the PAS morphology. In the sagittal plane, the relationship between the PAS and different craniofacial landmarks can be assessed through the use of different tools such as lateral cephalometric radiographs (LCRs) [6], cone-beam computed tomography (CBCT) [7], and magnetic resonance imaging (MRI) [8]. LCRs have been used for a long time to evaluate craniofacial growth and development, and they allow for the analysis of dental, skeletal, and soft tissue changes [9]. LCRs, despite being two-dimensional images, show strong correlations with measurements of PAS linear dimensions [10] and angular craniofacial measurements at the midsagittal plane taken from three-dimensional images [11].

Anatomic variables such as maxillary and mandibular retrusion, hyperdivergent facial growth pattern, and excessively inclined mandibular plane angle were described to be associated with a reduced PAS [12]. Moreover, changes in the sagittal relationship between the maxilla and the mandible caused by orthognathic surgery may affect the upper airway volume [13]. A meta-analysis indicated that rapid maxillary expansion in growing patients with transversal maxillary constriction was associated with a short-term increase in the PAS [14]. These findings suggest that both naturally occurring craniofacial dimensions and changes caused by orthodontic and surgical treatment may interfere with the PAS.

However, no previous studies have investigated the relationship between the PAS and the dental arch form. Furthermore, considering that there are sex differences in facial morphology [15], the objective of this study was to investigate the correlations between pharyngeal airway sagittal measurements with sagittal cephalometric variables and dental arches form in adolescents according to sex.

Materials and methods

Study design and sample

The present cross-sectional study was approved by the Research Ethics Committee of the Federal University of Maranhão (CAAE: 72820317.3.0000.5086). Imaging exams were obtained from the collection of a radiology center in São Luís, Maranhão, Brazil. Informed consent was obtained from all individual participants included in the study. All radiographic images and photographs used in this study were previously obtained in a standardized manner for orthodontic treatment planning purposes.

For sample calculation, the following parameters were adopted: test power at 0.8, a significance level of 0.05, a loss rate of 10%, and an expected correlation coefficient of ±0.40, which corresponds to a moderate correlation degree. A sample of at least 48 adolescents per sex category was recommended, and six sample units were added to each sex category to compensate for possible losses. The final sample size of this study was 108 adolescents (54 males and 54 females).

Inclusion criteria were patients of both sexes, aged 12–17 years, with full orthodontic documentation (lateral radiographs, panoramic radiographs, photographs, and plaster models) collected from 2016–2018. We excluded those with tooth agenesis, deciduous teeth, edentulous spaces,

Table 1 Craniofacial landmarks, planes, and measurements used in the study
Tab. 1 In der Studie verwendete kraniofaziale Orientierungspunkte, Ebenen und Messungen

	Description
Landmarks	
Sella (S)	The central point of the pituitary fossa of the sphenoid bone
Nasion (N)	The most anterior point of the frontonasal suture in the midsagittal plane
A point	The deepest anterior point in the concavity of the upper labial alveolar process
B point	The deepest anterior point in the concavity of the lower labial alveolar process
Menton (Me)	The inferior point on the mandibular symphysis
Gonion (Go)	The midpoint of the contour connecting the ramus and body of the mandible
Porio (Po)	The midpoint of the upper contour of the metal ear rod of the cephalostat (machine porion)
Orbitale (Or)	The lowest point of the infraorbital margin
Anterior nasal spine (ANS)	The tip of the anterior nasal spine
Posterior nasal spine (PNS)	The tip of the posterior spine of the palatine bone, at the junction of the hard and soft palates
Gnathion (Gn)	The center of the inferior border on the mandibular symphysis
Epiglottis base (Eb)	The base point of the epiglottis
Hyoid (H)	The anterior point of the hyoid bone
Uvula (U)	The tip of the uvula
Planes	
Frankfurt horizontal plane (FH)	An axial plane through the orbitale point and porion point
Anterior cranial base plane (SN)	An axial plane through the sella point and nasion point
Occlusal plane	An axial plane through the midpoint between the incisal edges (anterior) and the most distal point of contact of the first molar
Mandibular plane (GoGn)	An axial plane through the gonion point and gnathion point
Measurements	
SNA (°)	Angle determined by points S, N, A
SNB (°)	Angle determined by points S, N, B
ANB (°)	Angle determined by points A, N, B
ANS-PNS (mm)	Distance between ANS and PNS
FMIA (°)	Angle between FH and the lower incisor axis
SN.Gn (°)	Angle between the anterior cranial base plane and the gnathion point
SN.Occlusal plane (°)	Angle between the anterior cranial base plane and the occlusal plane
SN.GoGn (°)	Angle between the anterior cranial base plane and the mandibular plane
FMA (°)	Angle between FH and the mandibular plane
Interincisal angle (°)	Angle formed by the intersection of the long axis of the upper incisor with the long axis of the lower incisor
1.SN (°)	Angle between the long axis of the upper incisor and the SN line
1.NA (°)	Angle between the long axis of the upper incisor and the NA line
1-NA (mm)	The most labial surface of the upper incisor to the nasion-A point
1.NB (°)	Angle between the long axis of the lower incisor and the NB line
1-NB (mm)	The most labial surface of the lower incisor to the nasion-B point
IMPA (°)	Angle between the mandibular plane and the long axis of the lower central incisor
UL (mm)	Distance between the PNS and the uvula point
UD (mm)	Thickness of the soft palate at the midpoint
TGL (mm)	Tongue length, distance between the base point of epiglottis and the tongue apex
Phw-H (mm)	Distance between the hyoid and the closest point on the posterior pharyngeal wall
Go-Gn-H (°)	Angle formed between the gonion, gnathion, and hyoid bone
N-S-H (°)	Angle formed between the nasion, sella, and hyoid bone

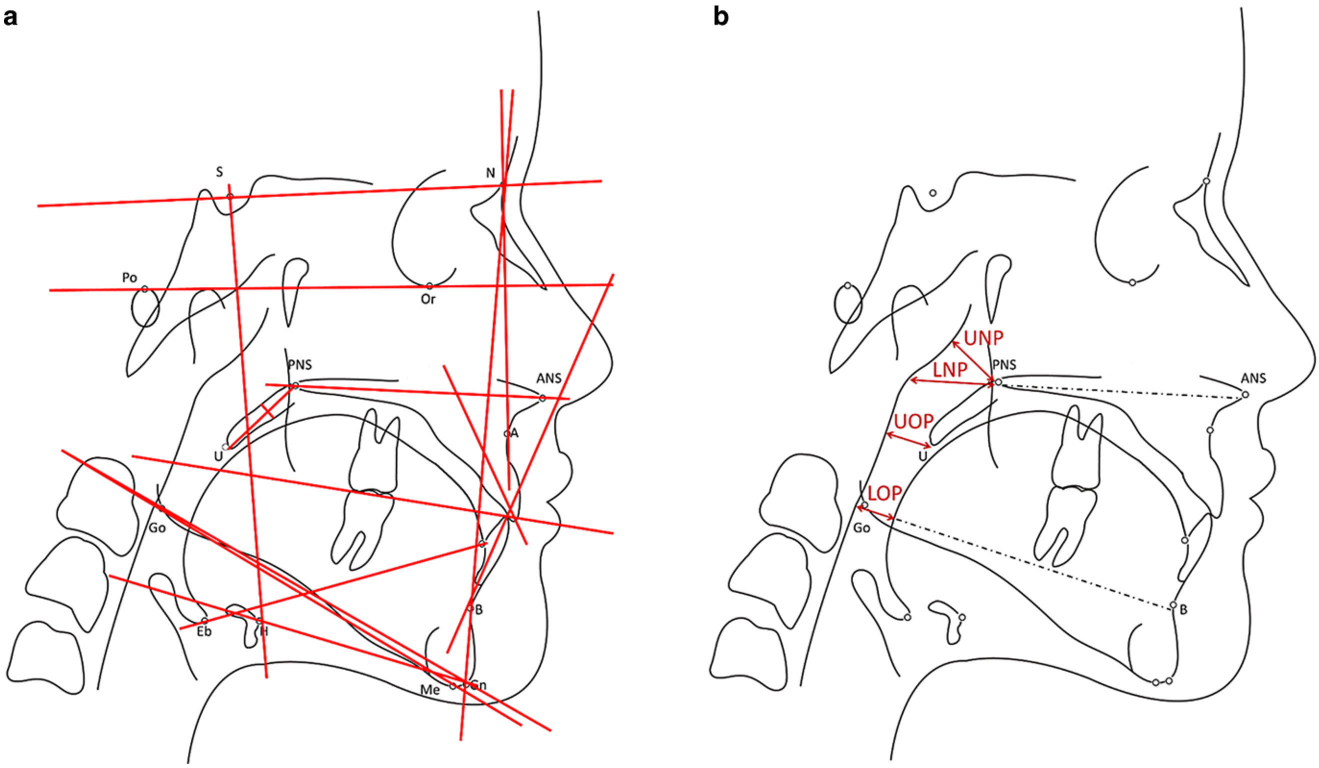

Fig. 1 Landmarks, sagittal craniofacial measurements (**a**), and pharyngeal airway space measurements (**b**). *UNP* upper nasopharynx, *LNP* lower nasopharynx, *UOP* upper oropharynx, *LOP* lower oropharynx. The reference points used for the craniofacial measurements are shown in Table 1

Abb. 1 In die Studie aufgenommene Orientierungspunkte, sagittale kraniofaziale Messungen (**a**) und Messungen des pharyngealen Atemwegsraums (**b**). *UNP* oberer Nasopharynx, *LNP* unterer Nasopharynx, *UOP* oberer Oropharynx, *LOP* unterer Oropharynx. Die für die kraniofazialen Messungen verwendeten Referenzpunkte sind in Tab. 1 aufgeführt

supernumerary teeth, dental or facial malformations, or a history of facial trauma or orthodontic or functional orthopedic treatment prior to documentation.

Craniofacial and pharyngeal airway evaluation

All measurements were performed by a single examiner. Prior to the beginning of data collection, calibration was performed for the cephalometric measurements, which consisted of the evaluation of 12 radiographic exams with a 7-day interval between the examinations. The minimum intraclass correlation coefficient observed for the continuous variables evaluated was 0.86, indicating excellent reproducibility.

Sagittal craniofacial morphology was evaluated by linear and angular measurements using LCR. The following aspects were evaluated: the relationship between the jaws and cranial base, the relationship between skeletal and dental structures, the soft palate and tongue morphology, and the hyoid bone position. The landmarks and measurements summary can be seen in Table 1 and Fig. 1a.

Pharyngeal airway dimensions were also evaluated using LCR (Fig. 1b). Sagittal measurements were assessed at four levels: the upper nasopharynx (UNP), the lower nasopharynx (LNP), the upper oropharynx (UOP), and the lower oropharynx (LOP). The UNP was measured as the distance from the posterior nasal spine (PNS) to the closest point on the posterior pharyngeal wall (PPW). The LNP was measured as the distance from the PNS to the point of intersection of the PPW following an extension of the palatal plane (PNS-ANS). The UOP was measured as the distance from the tip of the uvula to the closest point on the PPW. The LOP was measured as the distance from the posterior border of the tongue to the nearest point on the PPW along the B-Go line (or extending it).

Arch form evaluation

The upper and lower dental arch forms were evaluated using photographs of plaster models according to Grippaudo et al. [16]. A pentagon with vertices located between the central incisors, on the cusps of the canines, and at a central point on the occlusal surface of first molars was traced (Fig. 2). The internal angles of the pentagon were measured, and we calculated the ratio between the intercanine and intermolar distances. The measurements were performed on both dental arches. To standardize the dimension of plaster's photographs all photographs were obtained with a distance of

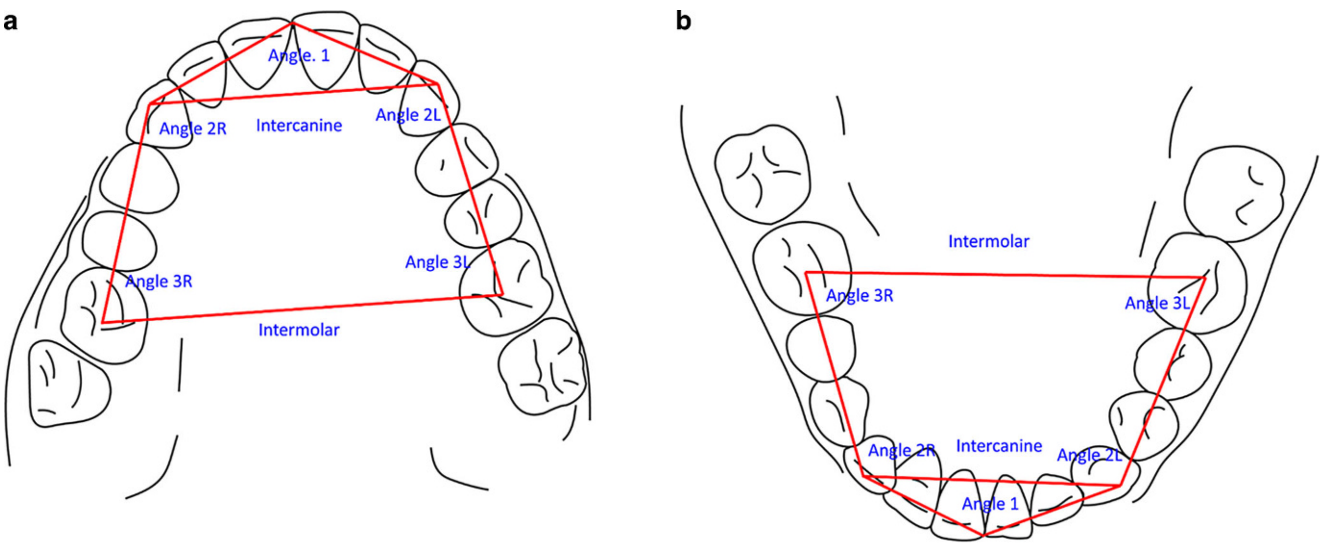

Fig. 2 Transversal measurements evaluated in the maxilla (**a**) and mandible (**b**)

Abb. 2 Ausgewertete Transversalmessungen im Oberkiefer (**a**) und Unterkiefer (**b**)

20 cm using a Nikon D7100 camera (Nikon, Tokyo, Japan). The software Radiocef Studio 3 (Radiomemory LTDA, São Paulo, Brazil) was used to draw the pentagon inscribed inside the arches.

Statistical analysis

The data were analyzed using GraphPad Prism version 9.0 (GraphPad Software Inc., San Diego, CA, USA). Descriptive statistics were calculated for the measurements of frequency, central tendency, and dispersion. The normality of the distribution of continuous variables was assessed using the Shapiro–Wilk test. After this procedure, Student's t-test was selected for the sex comparisons. Pearson's coefficient (r) was used to analyze the degree of correlation between the PAS, the sagittal craniofacial measurements, and the dental arch form. The correlation matrices were graphically represented by correlation heat-map plots. The significance level adopted was 5%.

Results

The study sample consisted of 108 adolescents (54 males and 54 females) with a mean age of 14.4 ± 1.8 years. There were no significant differences between the sex categories for the following parameters: age, nasopharynx measurements, or oropharynx measurements (Table 2). The nasopharynx measurements showed higher means than the oropharynx measurements, and the largest measurements for both sexes were for the lower nasopharynx.

Table 3 shows the comparison between sexes regarding craniofacial variables and dental arch form. Males showed a wider soft palate ($p = 0.005$) and a more anterior position of the hyoid bone than females ($p < 0.001$). Females had a greater N-S-H angle than males ($p = 0.019$).

The correlation analysis between the craniofacial and the PAS measurements is shown in Fig. 3. In the male group, the upper nasopharynx (UNP) showed a direct correlation with maxillary length (r = 0.312, $p = 0.021$) and with maxillary incisor inclination 1-NA (r = 0.277, $p = 0.042$), and an inverse correlation with soft palate thickness (r = –0.277, $p = 0.042$). The lower nasopharynx (LNP) showed a direct correlation with the IMPA (r = 0.285, $p = 0.036$) and an inverse correlation with the FMIA (r = –0.309, $p = 0.022$). The upper oropharynx (UOP) showed an inverse correlation with the SN.Occlusal plane (r = –0.282, $p = 0.038$). The lower oropharynx (LOP) showed a direct correlation with maxillary length (r = 0.268, $p = 0.049$) and with soft palate

Table 2 Comparative analysis of age and pharyngeal airway measurements between sexes

Tab. 2 Vergleichende Analyse von Alter und pharyngealen Atemwegsmessungen zwischen den Geschlechtern

Variables	Males Mean ± SD	Females Mean ± SD	*p*-value
Age (in years)	14.3 ± 1.8	14.5 ± 1.9	0.468
Pharyngeal airway sagittal measurements (in mm)			
Upper nasopharynx (UNP)	16.1 ± 3.7	15.0 ± 2.8	0.096
Lower nasopharynx (LNP)	24.9 ± 5.2	24.5 ± 5.5	0.667
Upper oropharynx (UOP)	12.4 ± 4.1	12.7 ± 3.5	0.594
Lower oropharynx (LOP)	13.0 ± 3.7	13.1 ± 4.1	0.961

SD standard deviation

Table 3 Comparative analysis of craniofacial variables and dental arch form between sexes

Tab. 3 Vergleichende Analyse von kraniofazialen Variablen und Zahnbogenform zwischen den Geschlechtern

Variables	Males Mean ± SD	Females Mean ± SD	*p*-value
Cranial base and jaws			
SNA angle (°)	84.8 ± 4.9	85.3 ± 3.9	0.593
SNB angle (°)	80.5 ± 4.9	79.2 ± 10.6	0.407
ANB angle (°)	3.8 ± 3.6	5.5 ± 10.6	0.263
ANS-PNS (mm)	54.6 ± 6.5	52.6 ± 4.6	0.073
FMIA (°)	60.2 ± 6.9	57.4 ± 10.0	0.095
Vertical analysis			
SN.Gn (°)	65.9 ± 5.7	66.3 ± 3.7	0.620
SN.Occlusal plane (°)	11.2 ± 6.7	12.3 ± 10.9	0.334
SN.GoGn (°)	33.3 ± 7.8	34.4 ± 5.9	0.426
FMA (°)	25.7 ± 7.3	26.7 ± 4.6	0.388
Dental pattern			
Interincisal angle (°)	125.6 ± 10.7	119.5 ± 23.2	0.084
1.NS (°)	105.7 ± 15.5	107.1 ± 8.6	0.546
1.NA (°)	22.0 ± 8.1	21.8 ± 8.4	0.889
1-NA (mm)	5.9 ± 4.3	5.4 ± 3.3	0.536
1.NB (°)	0.9 ± 6.8	1.3 ± 9.8	0.070
1-NB (mm)	6.5 ± 3.6	6.6 ± 2.9	0.977
IMPA (°)	92.8 ± 7.1	94.1 ± 7.9	0.360
Soft palate and tongue			
UL (mm)	30.4 ± 4.7	28.7 ± 4.9	0.073
UD (mm)	8.6 ± 1.4	7.7 ± 1.6	0.005*
TGL (mm)	68.3 ± 7.8	67.6 ± 6.1	0.341
Hyoid position			
Phw-H (mm)	31.3 ± 5.0	28.2 ± 3.9	< 0.001*
Go-Gn-H (°)	22.5 ± 6.8	20.2 ± 8.1	0.129
N-S-H (°)	85.7 ± 5.2	88.0 ± 4.6	0.019*
Upper arch form			
Angle 1 (interincisor)	123.0 ± 12.8	119.0 ± 11.5	0.110
Angle 2 (canine)	137.8 ± 8.3	140.5 ± 8.0	0.117
Angle 3 (1st molar)	71.6 ± 4.8	70.8 ± 4.8	0.420
Intercanine/intermolar ratio	0.68 ± 0.07	0.66 ± 0.05	0.305
Lower arch form			
Angle 1 (interincisor)	132.8 ± 10.5	130.0 ± 9.1	0.159
Angle 2 (canine)	137.2 ± 6.6	137.5 ± 8.6	0.834
Angle 3 (1st molar)	67.4 ± 3.6	67.6 ± 3.8	0.793
Intercanine/intermolar ratio	0.59 ± 0.05	0.59 ± 0.04	0.716

Variables are described in Table 1
SD standard deviation
*Statistically different ($p < 0.05$)

thickness (r = 0.339, $p = 0.012$). The most anterior position of the hyoid bone in relation to the mandibular plane (Go-Gn.H) showed an inverse correlation with a narrower LNP (r = –0.312, $p = 0.021$).

The findings in the female group (Fig. 3) showed that UNP had a direct correlation with maxillary length (r = 0.310, $p = 0.022$) and an inverse correlation with the interincisal angle (r = –0.290, $p = 0.032$). The UOP measurements showed a direct correlation with the lower incisor inclination in relation to the skull base (r = 0.32, $p = 0.015$), and an inverse correlation with 1.NS (r = –0.415, $p = 0.001$), 1.NA (r = –0.364, $p = 0.006$), and soft palate thickness (r = –0.275, $p = 0.043$). The LOP measurements showed an inverse correlation with tongue length (r = 0.311, $p = 0.021$).

The correlation analysis between the nasopharynx and oropharynx measurements and the dental arch form is shown in Fig. 4. In the male group, there was a direct correlation between the UOP dimensions and the lower canine

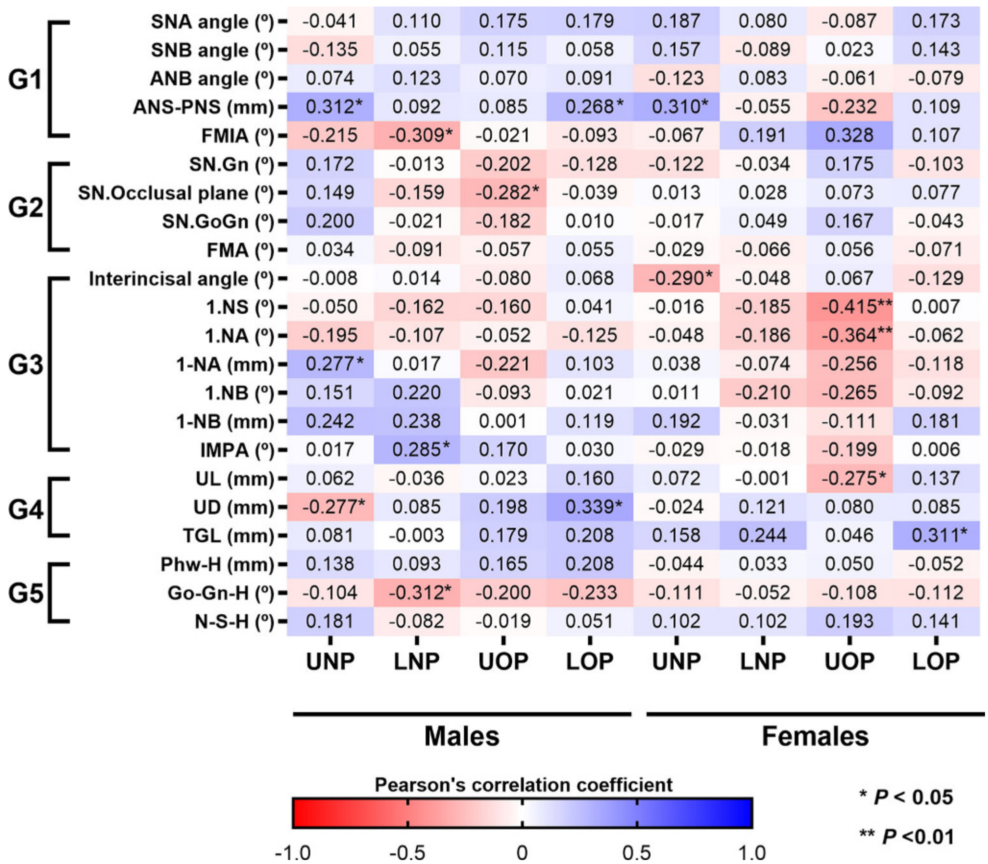

Fig. 3 Correlation heat maps of pharyngeal airway measurements and craniofacial variables according to sex. *G1* Cranial base and jaws, *G2* Vertical analysis, *G3* Dental pattern, *G4* Soft palate and tongue, *G5* Hyoid position, $*p<0.05$ and $**p<0.01$ (Pearson's correlation coefficient). *UNP* upper nasopharynx, *LNP* lower nasopharynx, *UOP* upper oropharynx, *LOP* lower oropharynx. The variables are described in Table 1

Abb. 3 Korrelations-Heatmaps von pharyngealen Atemwegsmessungen und kraniofazialen Variablen nach Geschlecht. *G1* Schädelbasis und Kiefer, *G2* vertikale Analyse, *G3* Zahnmuster, *G4* weicher Gaumen und Zunge, *G5* Hyoidstellung, $*p<0{,}05$ und $**p<0{,}01$ (Korrelationskoeffizient nach Pearson). *UNP* oberer Nasopharynx, *LNP* unterer Nasopharynx, *UOP* oberer Oropharynx, *LOP* unterer Oropharynx. Die Variablen sind in Tab. 1 beschrieben

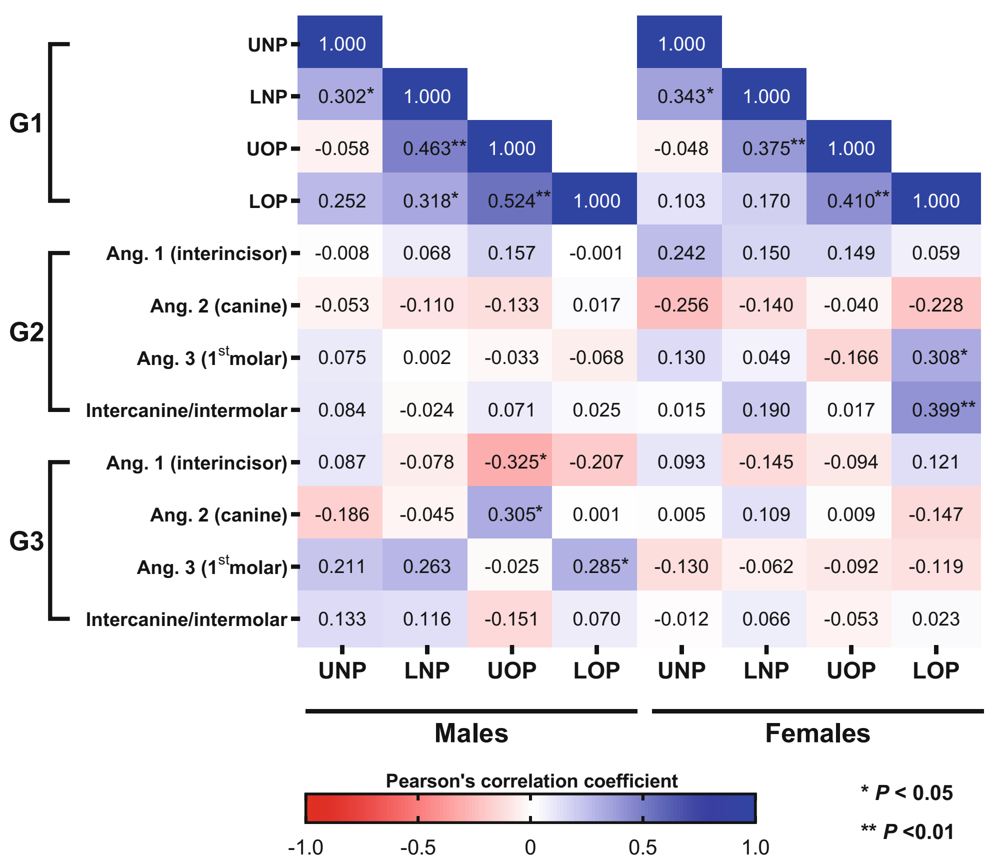

Fig. 4 Correlation heat maps of pharyngeal airway measurements and dental arch form according to sex. *G1* Pharyngeal airway space, *G2* Upper arch form, *G3* Lower arch form, $*p<0.05$ and $**p<0.01$ (Pearson's correlation coefficient), *UNP* upper nasopharynx, *LNP* lower nasopharynx, *UOP* upper oropharynx, *LOP* lower oropharynx, *Ang.* angle. The reference points used for the craniofacial measurements are shown in Table 1

Abb. 4 Korrelations-Heatmaps von pharyngealen Atemwegsmessungen und Zahnbogenform nach Geschlecht. *G1* Pharyngealer Atemwegsraum, *G2* obere Bogenform, *G3* untere Bogenform, $*p<0{,}05$ und $**p<0{,}01$ (Korrelationskoeffizient nach Pearson), *UNP* oberer Nasopharynx, *LNP* unterer Nasopharynx, *UOP* oberer Oropharynx, *LOP* unterer Oropharynx, *Ang.* Winkel. Die für die kraniofazialen Messungen verwendeten Referenzpunkte sind in Tab. 1 aufgeführt vertex angle (r = 0.305, $p = 0.027$), and an inverse correlation with the lower interincisor vertex angle (r = –0.325, $p = 0.018$). LOP measurements showed a direct correlation with the lower molar vertex angle (r = –0.285, $p = 0.039$). In the female group, the LOP showed direct correlations with the upper molar vertex angle (r = 0.308, $p = 0.037$) and upper intercanine/intermolar ratio (r = 0.399, $p = 0.005$). In addition, it was observed in both sexes that all pharynx airway measurements showed statistically significant direct correlations with their closest pharyngeal measurements.

Discussion

The main findings of this study suggest that craniofacial measurements such as maxillary length, cranial–occlusal plane relationship, teeth angulation, soft palate, tongue size, and hyoid position seem to be correlated with the sagittal pharyngeal airway parameters measured. These correlations appear to be sex-dependent in adolescent patients.

The pharyngeal airway space is mainly determined by its relationship with the surrounding dentofacial skeleton. The nasopharyngeal airway increases during pre- and early adolescence due to the concurrent increase in nasopharyngeal area and adenoid involution after reaching its maximum size in childhood [17, 18]. Besides this, respiratory activity and the PAS are factors that favor harmonious growth and development of the dentofacial complex. Thus, the growth pattern should be taken into account when interpreting the possible impact of orthodontic and surgical treatment on the upper airway in adolescents [19].

The present study found no correlation between the PAS and the sagittal position of the maxilla to the cranial base; however, we observed a direct correlation between maxillary length and the upper nasopharyngeal space in both sexes, and with the lower oropharyngeal measurements in males. Likewise, Brito et al. suggested that maxillary and mandibular length are more important determinants of the PAS volume than the sagittal position relative to the cranial base (SNA and SNB) [20].

An inverse correlation was observed between the angle SN.Occlusal plane and the lower oropharyngeal space, suggesting that a more inclined occlusal plane, which is typical for hyperdivergent facial growth, was related to a narrowing of the upper oropharynx. Wang et al. showed that there is an association between vertical facial growth and the PAS, demonstrating an association between a hyperdivergent growth pattern and pharyngeal narrowing [21]. In a study conducted with only female adolescents with class II division 1 malocclusion, patients with a hyperdivergent profile presented with an airway space that was more reduced compared to that of patients with normodivergent and hypodivergent profiles [6]. Clockwise rotation of the mandible is present in the vertical/hyperdivergent growth pattern, explaining this correlation since it alters the mandibular posture and may compress the oropharyngeal airway space.

In females, an inverse correlation between the upper oropharyngeal airway dimensions and the measurements related to maxillary incisor inclination were observed in this study; that is, the greater the labial inclination of the upper incisor, the narrower was the upper oropharyngeal space. Since upper incisor labial inclination determines overjet, which is a predictor of class II division 1 malocclusion, these findings reinforce the relationship between class II and smaller pharyngeal airway dimensions [22]. Pavoni et al. [23] evaluated the treatment and posttreatment sagittal oropharyngeal and nasopharyngeal airway dimension changes produced by treatment with functional appliances of class II malocclusions. The treatment with functional appliances produced significant favorable changes during active treatment in the oro- and nasopharyngeal sagittal airway dimensions with long-term stability. Thus, we suggest a beneficial effect of early orthodontic treatment on airway dimensions, especially in females.

In this present study, an inverse correlation was found between upper nasopharyngeal measurements and the interincisor angle in females. A reduced interincisal angle is common in patients with bimaxillary dentoalveolar protrusion, a condition characterized by upper and lower incisors proclination, a convex facial profile, and lip incompetence [24]. Studies have indicated that after maximum retraction of the anterior teeth to correct bimaxillary protrusion in class I patients, the PAS decreased, suggesting that there is a relationship between an increased interincisal angle after maxillary retraction and a decreased anteroposterior airway space [24, 25].

A positive correlation between tongue length and lower oropharyngeal airway length was found in females in this study. Interventions that generate changes in the tongue and hyoid position can be related to changes in the PAS [3]. Ozdemir et al. [26] reported that an increase in interincisal angle, mainly due to a proclined position of the lower incisors, may increase the anterior space for the tongue, avoiding compression of the oropharynx airway space. That same study also found that a retrognathic mandibular position may be associated with airway space constriction by the action of the lingual muscles and their attachment to the hyoid bone. The tongue length in the present study was measured from the base of the epiglottis to the tip of the tongue with the mouth closed, so this measurement reflects the space reserved for the tongue in relation to the length of the mandible to the epiglottis rather than the size of the tongue itself. Thus, these findings suggest that a mandibular configuration with more space for the tongue are correlated with larger dimensions of the oropharyngeal space.

The dental arch form evaluation revealed that greater oropharyngeal dimensions were correlated with a smaller interincisal vertex angle, a greater canine vertex angle, and a greater molar vertex angle in males. These values indicate that a prognathic, longer and larger mandibular shape is correlated with an increase in oropharyngeal space. This correlation can be explained by the adoption of a more anterior position of the mandible, and consequently, of the tongue, avoiding airway space constriction. Literature findings indicate that the oropharyngeal airway dimensions are smaller in adolescent patients with a retrognathic position of the mandible [27].

Another important finding of the dental arch form was the direct correlation of the lower oropharyngeal airway space with the upper molar vertex angle and the ratio between the intercanine and intermolar distances in females. This finding suggests that narrower upper arch forms are related to smaller lower oropharyngeal dimensions. This arch shape is compatible with narrower and deeper jaws, common finding in mouth breathing patients. Cretella Lombardo et al. [28] demonstrated that treatment with rapid maxillary expansion produced favorable stable changes in the airway dimensions in class III subjects. There is further literature support showing that pharyngeal airway dimensions are significantly greater when the upper arch is wider [29].

Although this study observed different correlations between PAS and some craniofacial measurements, there are some limitations of the method employed. First, the study used sagittal evaluation by LCR. Although PAS analysis using 3D CBCT imaging can be accepted as more accurate, pharyngeal airway space measurements by lateral cephalometric radiography and tomography show good reliability [30]. In addition, the use of LCR can be advantageous as they are readily available, are less expensive, deliver a low radiation dose, and have been extensively used for PAS assessment. Another limitation of this study was its cross-sectional design, which does not allow for causal inferences about the factors investigated. Thus, longitudinal studies with monitoring throughout pubertal growth and larger sample are desirable to assess the investigated relationships more thoroughly.

On the other hand, some procedures used to guarantee and control quality in this study should be highlighted. A sample calculation to ensure an adequate number of subjects was used to identify even moderate correlations and segmentation by sex. This is important as it has been reported that the pattern of growth and maturation of craniofacial structures in adolescents present differences by sex, including different tendencies for the hyoid position [31] and differences in the rate of pharyngeal airway volume growth [32]. Furthermore, a previous training process was implemented, obtaining a high degree of reproducibility of the measurements.

This study seems to be the first to analyze the relationship between the sagittal PAS and dental arch form evaluated by transverse angles drawn with vertices at upper and lower dental points. These measurements can be easily recorded using plaster models or photographs of the dental arches, and these variables can be extremely useful for diagnosis and for planning and monitoring of orthodontic treatment and orthognathic surgery.

Understanding the relationships among these measurements is essential for clinicians because of the possible repercussions on PAS and craniofacial structures caused by orthodontic treatment [33, 34]. Considering the correlations observed in this study between some craniofacial variables and PAS, future clinical trials are necessary to investigate and identify which changes during orthodontic treatment (angular and linear) may generate beneficial changes in the PAS. This information can help in the appropriate planning of more precise clinical interventions to avoid a narrowing of these pathways, especially in patients with a history of breathing disorders.

Conclusion

The findings in this study suggest that there are sex-dependent correlations between pharyngeal airway sagittal measurements and cephalometric craniofacial variables as well as dental arch form in adolescents. Direct correlations between maxillary length and upper oropharyngeal space in both sexes were observed. These results reinforce the importance of a thorough sagittal and transversal craniofacial analysis, including pharyngeal airway measurements, to guide orthodontic and orthognathic treatment planning.

Funding This work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) [Finance Code 001 and PROCAD grant 88881.357834/2019-01] and Research Support Foundation of Maranhão State (FAPEMA).

Author Contribution All the authors have made substantial contributions to the study. I. de Oliveira, R. Pinheiro and V. Rodrigues: Project development, Study Design, Data collection, Data analysis, Manuscript writing. B. Freitas and P. Reher: Study Design, Data analysis, Manuscript writing.

Declarations

Conflict of interest I. de Oliveira, R. Pinheiro, B. Freitas, P. Reher and V. Rodrigues declare that they have no competing interests.

Ethical standards This study was performed in line with the principles of the Declaration of Helsinki. The study was approved by Research Ethics Committee of the Federal University of Maranhão

(CAAE: 72820317.3.0000.5086). Informed consent was obtained from all individual participants included in the study.

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