Original Article

Correlation between the position of hyoid bone and subregions of the pharyngeal airway space in lateral cephalometry and cone beam computed tomography

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ABSTRACT

Objective: To correlate the pharyngeal airway subregions with the positioning of the hyoid bone.

Material and Methods: The study examined 107 lateral cephalometric (LC) and cone beam computed tomography (CBCT) images. Linear and volumetric measurements of the pharyngeal subregions were made and correlated to linear measurements using hyoid triangle analysis on images of LC and multiplanar (MPR) and three-dimensional (3D) reconstructions of CBCT.

Results: There was significant correlation between linear measurements of the pharyngeal subregions and hyoid bone position in LC images and in MPR and 3D reconstructions of the CBCT. Correlations were more frequent in the oropharynx and hypopharynx, especially for LC images. No correlations were observed between LC images or CBCT reconstructions and the volumetric measurements of the pharyngeal subregions and the position of the hyoid bone.

Conclusion: The hyoid bone position showed more correlations with oropharynx and hypopharynx airway measurements. The hyoid triangle method was not applicable to 3D images, since it showed a smaller number of measures correlated to the hyoid bone position. (*Angle Orthod.* 2017;87:688–695.)

KEY WORDS: Hyoid bone; Pharynx; Radiography; Cone beam computed tomography

INTRODUCTION

The pharynx is responsible for the functions of swallowing and breathing[1–3] and is important for the development and growth of cranial and facial bones.[4,5] This structure can be divided anatomically into the nasopharynx, oropharynx, and hypopharynx.[1,2]

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The airway is bordered superiorly by the bones of the skull base, posteriorly by the spine, anterosuperiorly by the nasal septum, and anteriorly by the mandible and hyoid bone.[6] The hyoid is the only bone that does not articulate with other bones.[1,3,7–10] It is connected to the pharynx, mandible, and skull by muscles and ligaments.[1,3,9,10] Tension generated in these structures,[7] due to movement of the head and body and resulting from oral and tongue function, will change its position.[2,9]

Changes in the positioning of mandible (physiological, surgical, or due to orthodontic treatment) are also accompanied by changes in the positioning of hyoid.[3,11] This mechanism of compensation of hyoid position may result in changes in the dimension of the pharyngeal airway and may therefore have clinical implications.[3,7,9,11] Moreover, the close relationship between the pharynx and the hyoid bone helps to make respiration possible. The hyoid bone adjusts its orientation to the physiological requirements imposed by pharyngeal obstruction and mouth breathing.

To evaluate the position of the hyoid bone, there is a set of standardized measurements known as the hyoid triangle method.[12] This method can be used to evaluate

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the hyoid position relative to the cervical vertebrae and mandible.[10,12] This method of evaluation was initially developed in lateral cephalometry (LC) exams.[12] However, the two-dimensional (2D) nature of this exam makes it impossible to accurately verify the three-dimensional (3D) aspects of the airway[5,8] as well as the relationship between the hyoid bone and adjacent structures.

In order to circumvent two-dimensional limitations, cone beam computed tomography (CBCT) has been gaining prominence in dentistry for the assessment of the 3D relationship between the upper airway and hyoid bone.[3] CBCT enables multiplanar (MPR) reconstruction and 3D assessment of the airway, thus providing more precise information compared with LC.[8,13]

Previous studies verified the relationship between the size of the airway and hyoid bone position in LC[1,2,10,11] and CBCT.[3,8,14] However, relationships among the three anatomical regions of the pharynx and the hyoid bone have not been evaluated simultaneously in LC and CBCT images. Thus, the objective of this study was to compare the position of the hyoid bone using linear and volumetric measurements of the subregions of the pharyngeal airway space (nasopharynx, oropharynx, and hypopharynx) between LC images and CBCT images (MPR and 3D reconstruction).

MATERIALS AND METHODS

This study was approved by the Research Ethics Committee (Protocol No. 099/2013). We used 107 LC images and 107 CBCT images of the same patients (40 men and 67 women, 18 to 35 years old). The images included the entire pharyngeal airway (nasion to fourth cervical vertebra) and had good quality and sharpness in the region of the airway and of the hyoid bone. Patients with a history of surgery and respiratory pathology in the pharyngeal airway and in the hyoid bone were excluded. The images were selected from an archive of images of the Oral Radiology Department, which had been obtained previously as part of the routine for the initial diagnosis of orthodontic patients. All images were obtained with the Frankfurt horizontal plane parallel to the floor, with the midsagittal plane perpendicular to the ground and in centric occlusion. The LC images were obtained with the cephalometric device Tele Funk X 15 (Funk Comerica de Equipamentos de Raios X (Funk Trade of X-Ray Equipment), Alfenas, MG, Brazil) with 20 mAs and 75 kVp exposure factors and a 1.2-second acquisition time. They were processed in an automatic processor. The CBCT images were obtained using the i-CAT tomograph (Imaging Sciences International, Hatfield, Pa), with an acquisition protocol of 8 mA, 120 kVp, FOV (field of view) of 23 $\times$ 17 cm, 0.3 mm voxel size, and a 20-second acquisition time.

Linear and Volumetric Measurements of Pharyngeal Subregions

The LC images were imported into Radiocef Studio 2 software. The DICOM files of the CBCT images were imported into OnDemand3D software (version 2, Radio Memory, Belo Horizonte, MG, Brazil). for evaluation of the MPR and 3D reconstructions. To reformat the images, all of the volume was covered using the 3D reference plan according to Katsumata et al[15] by joining the S (sella), N (nasion), and Dental points, as selected in the midsagittal plane. The coronal and axial plane were defined from a perpendicular that went through the midsagittal plane (Figure 1). After reformatting, the images were placed in the sagittal plane to identify the pharyngeal subregions (nasopharynx, oropharynx, and hypopharynx) in the MPR and 3D reconstructions.

For reconstruction of the 3D image, tools of the OnDemand3D software were used, including: Fine Tuning, Load Preset, Carestream 9300 Airway option; Task, 3D Tools plane option. Thus, a rendered 3D image of craniofacial bones and the airway was created in which the pharyngeal subregion measurements were made (Figure 2).

Linear measurements of the pharyngeal subregions in the LC images and in the CBCT reconstructions were delimited by tracing a line from sella (S) to nasion (N), another line through the posterior wall of the pharynx (PWF) to the sella-nasion line (S-N), and a line perpendicular to the PWF from basion (Ba) to the posterior nasal spine (PNS). These lines were used as references for the delimitation of the nasopharynx. Then, the oropharynx was delimited by a line starting from the third cervical vertebra (C3) to the PWF, and the hypopharynx was delimited by tracing a line perpendicular to the PWF from the fourth cervical vertebra (C4) (Figures 2A through C).

To evaluate the pharyngeal airway volume, the DICOM images were exported to the Insight ITK-SNAP 2.4.0 software (Cognitica, Philadelphia, Pa). From the multiplanar images, using the semiautomatic segmentation mode of the software, 3D volumetric models of the nasopharynx, oropharynx, and hypopharynx were reconstructed.[16]

The limits for the segmentation of the airway were determined according to Brasil et al as follows[13]: (1) anteriorly, a vertical plane going through the PNS, perpendicular to the midsagittal plane; (2) posteriorly, the posterior walls of the pharynx; (3) laterally, the lateral walls of the pharynx, including the entire length of the lateral pharyngeal projections; (4) inferiorly, a plane tangent to the medial caudal projection of the third cervical vertebra, perpendicular to the sagittal plane; and (5) superiorly, the highest point of the nasopharynx, coinciding with the posterior portion of

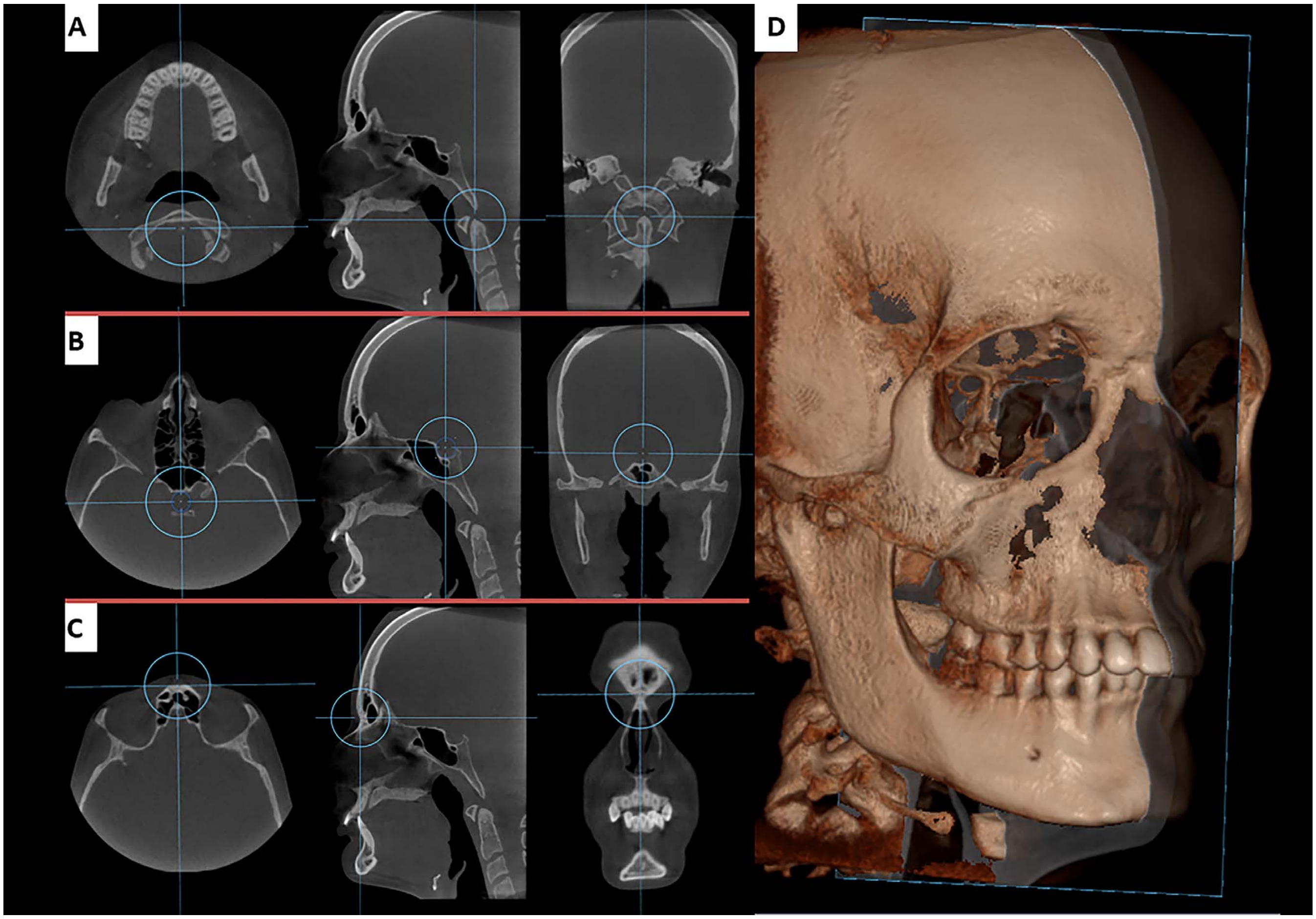

Figure 1. Points: (A) Dental (B) S. (C) N. (D) 3D reference sagittal plane.

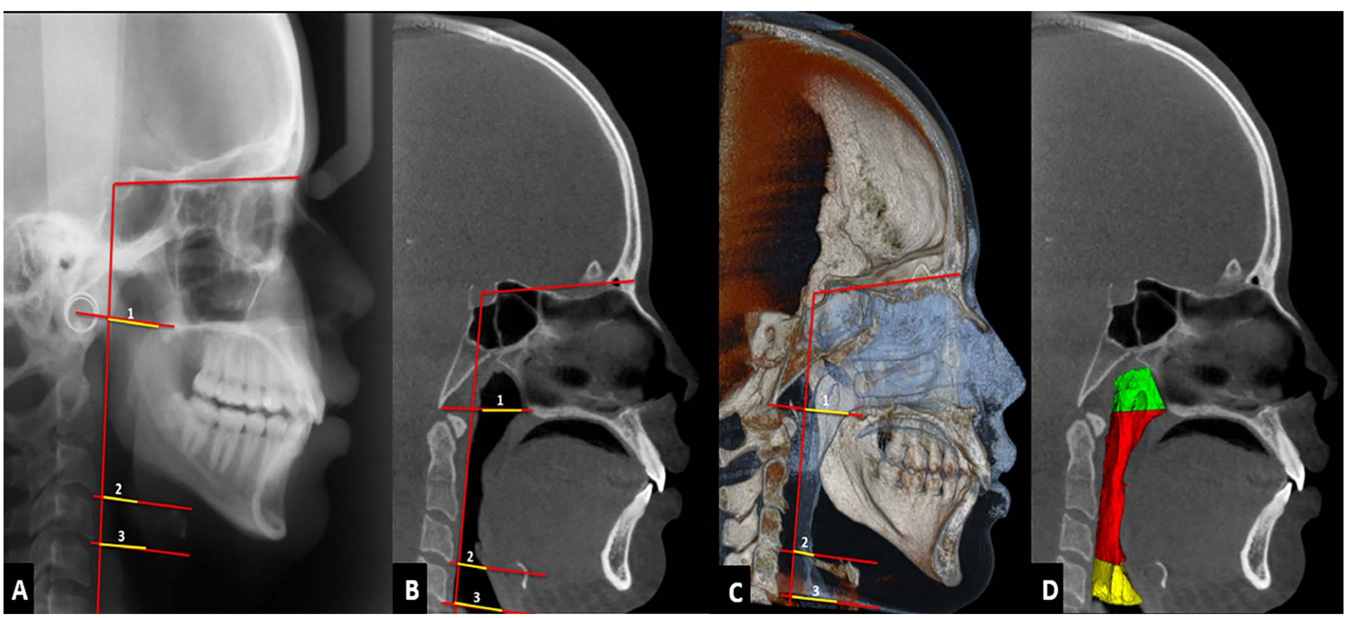

Figure 2. 1= Nasopharynx, 2= oropharynx, and 3= hypopharynx. (A) LC. (B) MPR. (C) 3D reconstruction of CBCT. (D) 3D segmentation for determination of volume.

Table 1. Definitions of the Measurements of the Hyoid Triangle Method

Symbol	Description	Diagnostic Value
1. C3-RGn	Line drawn between the third cervical vertebra (C3) and the retrognathic point (RGn)	Anteroposterior position of the mandibular anterior region
2. C3-H	Line starting from the third cervical vertebra (C3) up to the uppermost point, anterior to the hyoid bone (H)	Anteroposterior position of the hyoid bone
3. H-RGn	Line with the uppermost point, anterior to hyoid bone (H) up to retrognathic point (RGn)	
4. H-H'	Line of the C3-RGn plane perpendicular to the hyoid	Vertical position of the hyoid bone
5. HP Angle	Angle formed by the intersection of the hyoid plane (HP) (from the most anterior point of hyoid body to the most posterior and superior point of hyoid greater horn) with the C3-RGn plane	Angular position of the hyoid bone in relation to the mandible
6. AA-PNS	Line between the most anterior point of the atlas vertebra (AA) up to the posterior nasal spine (PNS)	Anteroposterior dimension of the upper bony airway
7. dhoriz-H	Distance between the most posterior point of the posterior wall of the pharynx (PWF) to the hyoid (H)	Dimension of the pharynx in the hyoid bone plane
8. dvert-H	Distance from the H point to the palatal plane parallel to the PTM line (PTM line: line of the center of the pterygomaxillary fissure perpendicular to the palatine plane)	Position of the hyoid bone in relation to the middle facial third
9. PH-BaN	Angle formed between the hyoid plane (HP) and the basion-nasion line (BaN)	Relation between the hyoid bone and the cranial base
10. HPPP	Angle formed by the hyoid plane (HP) and the palatal plane (PP)	Relation between the hyoid bone and the middle facial third

the choanae and consistent with the anterior limit (Figure 2D).

Hyoid Triangle Measurements

The hyoid triangle was determined by lines, planes, and angles, according to the method proposed by Bibby and Preston[12] (Table 1; Figure 3).

Statistical Analysis

The assessment of all images and measures was performed independently by three radiologists with experience in the assessment of LC and CBCT images. To determine intraexaminer agreement, 25% of the sample was reassessed a second time. Intraclass correlation coefficients were used to verify the intra- and interexaminer concordance. Data were statistically analyzed by the Pearson's correlation coefficient to investigate the relationship between the linear/volumetric measurements of the pharyngeal airway space and hyoid bone position in LC images and in 3D and MPR reconstructions of the CBCT. Interpretation of Pearson's correlation coefficient was based on Abramson et al.[17] Significance level ($\alpha = 0.05$) was adjusted for multiple comparisons using Bonferroni's correction.

RESULTS

The interexaminer ICC showed values between 0.710 and 0.983 (satisfactory to excellent), and intra-examiner ICC was greater than 0.9 (excellent) ($P <$ .01).[18]

There were no correlations between nasopharynx linear measurements and hyoid bone position ($P >$ .05), other than a poor but significant correlation ($r = 0.365$, $P <$ .05) with the anteroposterior dimension of the upper bony airway (AA-PNS). Moreover, the oropharynx and hypopharynx showed higher frequencies of significant correlations compared with the nasopharynx region (Table 2).

Anteroposterior position of the mandibular anterior region (C3-RGn) showed significant and moderate correlations with the oropharynx in LC ($r = 0.574$, $P <$ .05) and 3D CBCT ($r = 0.444$, $P <$ .05) images, but poor correlation in MPR CBCT ($r = 0.356$, $P <$ .05). In the same way, there were significant and moderate correlations between C3-RGn and the hypopharynx in LC ($r = 0.549$, $P <$ .05), MPR CBCT ($r = 0.479$, $P <$ .05), and 3D CBCT ($r = 0.535$, $P <$ .05) images (Table 2).

There were significant correlations between the pharynx dimension in the plane of the hyoid bone (dhoriz-H) and the hypopharynx dimension in MPR CBCT ($r = 0.396$, $P <$ .05) and 3D CBCT images ($r = 0.370$, $P <$ .05) (Table 2).

Vertical position of the hyoid bone (H-H') showed statistically significant negative correlations with the oropharynx ($r = -0.349$, $P <$ .05) and hypopharynx ($r = -0.3$, $P <$ .05) only in LC images. The MPR CBCT and 3D CBCT images showed negative correlations,

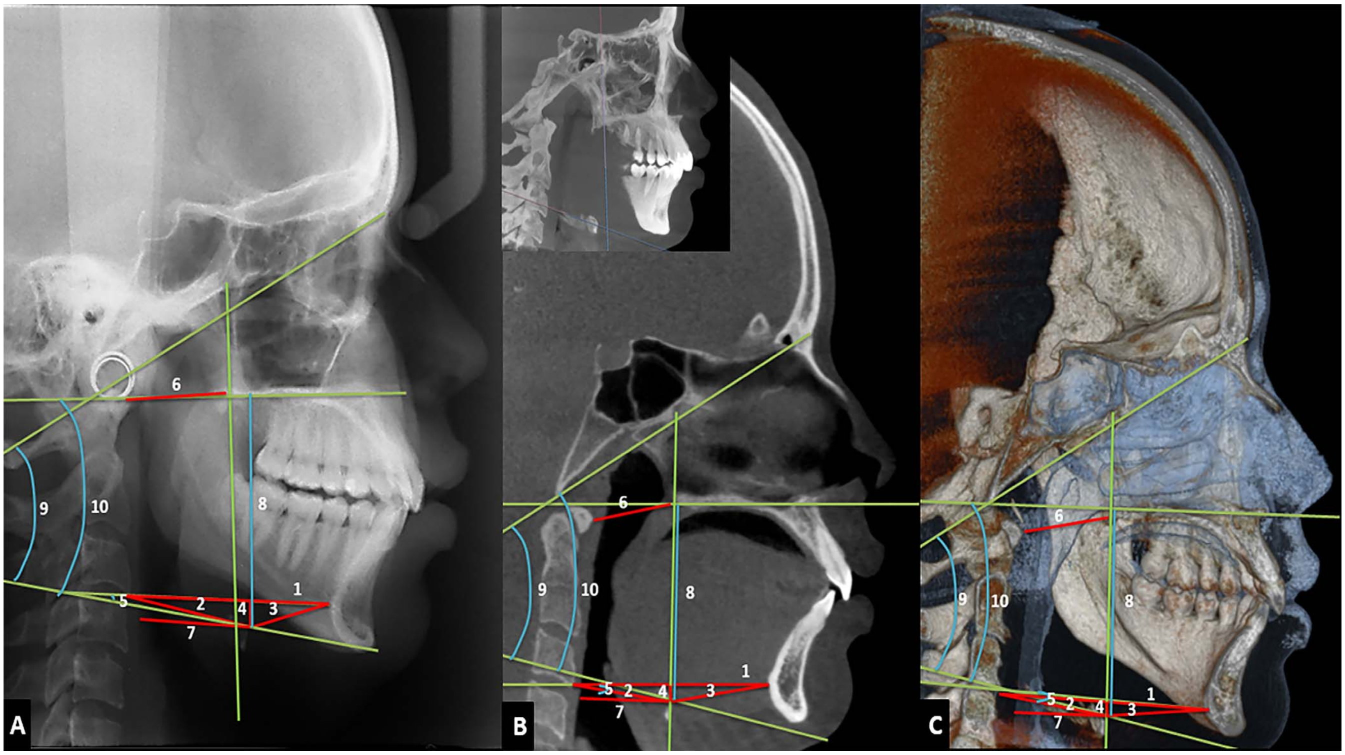

Figure 3. Hyoid triangle: (1) C3-RGn, (2) C3-H, (3) H-RGn, (4) H-H', (5) HP Angle, (6) AA-PNS, (7) dhoriz-H, (8) H, (9) HP-BaN, (10) HPPP. (A) LC. (B) MPR. Featured image: maximum intensity projection (MIP) for demarcation of the HP and dvert-H angles. (C) 3D reconstruction of CBCT.

but they were not statistically significant ($P > .05$) (Table 2).

Anteroposterior position of the hyoid bone (H-RGn) showed poor correlations with the oropharynx (r = –0.368, $P < .05$) and hypopharynx (r = –0.372, $P < .05$) in LC images and with the hypopharynx (r = –0.356, $P < .05$) in MPR images (Table 2).

Negligible to poor correlations related to hyoid bone position in LC and CBCT reconstructions were found between parameters related to the hyoid triangle and volumetric measurements of the nasopharynx, oropharynx, and hypopharynx (Table 3).

DISCUSSION

The upper airway, especially the pharynx, is important in orthodontics because it is integral to craniofacial growth and development.[4,5] Similarly, it is essential for orthodontists to evaluate the structures associated with this system, such as the hyoid bone,

Table 2. Correlations of the Linear Measurements Between the Pharyngeal Airway (Nasopharynx, Oropharynx, and Hypopharynx) and the Hyoid Bone in LC Images and in CBCT Reconstructions (MPR and 3D)[a]

	Hyoid Triangle Measurements									
Linear Measurements	C3-RGn	C3-H	H-RGn	H-H'	HPAngle	AA-PNS	dhoriz-H	dvert-H	PH-BaN	HP-PP
LC										
Nasopharynx	0.221	0.147	0.125	–0.147	–0.121	0.365*	0.090	–0.013	–0.093	–0.114
Oropharynx	0.574*	0.303	0.368*	–0.349*	–0.130	0.213	0.309	–0.147	–0.289	–0.293
Hypopharynx	0.549*	0.233	0.372*	–0.350*	–0.072	0.095	0.306	–0.225	–0.268	–0.301
MPR CBCT										
Nasopharynx	–0.091	–0.106	–0.043	–0.242	–0.174	0.346*	–0.133	–0.219	–0.126	–0.230
Oropharynx	0.356*	0.191	0.287	–0.138	0.027	0.046	0.294	–0.068	–0.099	0.000
Hypopharynx	0.479*	0.215	0.356*	–0.241	–0.108	0.071	0.396*	–0.163	–0.086	–0.032
3D CBCT										
Nasopharynx	0.122	–0.187	0.194	–0.142	0.074	–0.077	0.400	–0.256	0.129	0.045
Oropharynx	0.444*	0.224	0.303	–0.171	–0.129	0.053	0.248	–0.051	–0.231	–0.040
Hypopharynx	0.535*	0.284	0.319	–0.255	–0.282	0.149	0.370*	–0.141	–0.322	–0.066

[a] LC indicates lateral cephalometric; CBCT, cone beam computed tomography; MPR, multiplanar; 3D, three-dimensional; * Represents a significant correlation, $p \leq 0.05$.

Table 3. Correlations Between the Volume of the Pharyngeal Airway (Nasopharynx, Oropharynx, and Hypopharynx) and the Hyoid Bone in LC Images and in CBCT Reconstructions (MPR and 3D)[a]

Measurements of Volume in CBCT	Hyoid Triangle Measurements									
	C3-RGn	C3-H	H-RGn	H-H'	HPAngle	AA-PNS	dhoriz-H	dvert-H	PH-BaN	HP-PP
LC										
Nasopharynx	–0.128	0.105	–0.229	0.030	–0.158	0.095	0.053	0.280	–0.014	–0.073
Oropharynx	–0.070	0.027	–0.106	0.024	–0.115	–0.058	–0.027	0.189	0.171	0.031
Hypopharynx	0.021	0.139	–0.079	0.014	–0.035	–0.024	0.091	0.267	0.072	–0.059
MPR CBCT										
Nasopharynx	0.041	0.145	–0.167	–0.041	–0.030	0.189	0.060	0.141	0.023	–0.171
Oropharynx	0.153	0.060	0.057	–0.076	0.087	–0.037	0.059	0.152	0.010	–0.202
Hypopharynx	0.170	0.186	–0.011	–0.059	0.015	–0.042	0.269	0.188	–0.030	–0.145
3D CBCT										
Nasopharynx	–0.045	0.133	–0.179	–0.033	–0.079	0.149	0.125	0.147	–0.051	–0.157
Oropharynx	0.103	0.073	0.029	–0.072	0.080	–0.074	0.163	0.109	0.014	–0.117
Hypopharynx	0.135	0.173	–0.006	–0.054	0.005	–0.035	0.287	0.161	–0.077	–0.076

[a] LC indicates lateral cephalometric; CBCT, cone beam computed tomography; MPR, multiplanar; 3D, three-dimensional; significant noncorrelation ($p > 0.05$).

since it is influential in maintaining the size of the upper airway.[7,9]

Changes in the development of the maxilla and mandible (due to developmental deformities, orthognathic surgery, and orthodontic treatment), may cause a predisposition for changes in the volume of the pharynx, which are also accompanied by changes in the positioning of the hyoid.[2,10] The main areas of change are the soft palate (nasopharynx), the lateral walls of the pharynx (oropharynx), and the base of the tongue (hypopharynx), thus emphasizing the importance of evaluating the different pharyngeal subregions.[2] The present study found that the hyoid bone position was more highly correlated to measures of the oropharynx and hypopharynx.

LC has limited value for assessing the airway[5,19] because it is only a 2D sagittal projection.[3] Despite this limitation, LC was included in this study because it is the tool most frequently used for diagnosis and treatment planning in orthodontics.[9] In addition, several studies have shown the diagnostic value of LC for evaluating the relationship between the hyoid bone and the airway.[1,2,10,11]

With the advent of the use of CBCT in dentistry,[20,21] there has been an improvement in the ability to analyze airway space,[5,14,21] through the assessment of the 3D airway,[5,13] and position of the hyoid bone.[3] Thus, CBCT images were also used in this study, along with MPR and 3D reconstructions. It was observed that the lateral cephalometric CBCT reconstructions had diagnostic reliability comparable to or exceeding LC's. Likewise, the 3D reconstructions have also been shown to be useful for orthodontic diagnosis and treatment planning.[21]

Considering the hyoid triangle measurements, the anteroposterior position of the mandibular anterior region (C3-RGn) showed significant and moderate correlations with the oropharynx and hypopharynx in the three imaging methods, thus demonstrating that this relationship is not affected by the image method. A correlation between the pharynx dimension in the plane of the hyoid bone (dhoriz-H) and the anteroposterior dimension of the hypopharynx was observed only in CBCT images. This was probably because the CBCT images provided better definition of soft tissue contours than LC images.

The 3D CBCT images exhibited a lower number of significant correlations compared with MPR and LC. It is known that 3D rendering image reconstruction can discard some information embedded in CBCT volumes, so caution should be used when making linear measurements on these images since the measurements can be reliable but not accurate.[22] On the other hand, LC showed a higher number of correlations since this was the image method in which the hyoid bone triangle measurements were originally performed.[12]

There was no correlation between anteroposterior dimension of the nasopharynx and hyoid bone position, other than a poor correlation with the anteroposterior dimension of the upper bony airway (AA-PNS). Although these measurements are performed in regions close to one another, cephalometric points in the spine may be influenced by head posture,[23] thus explaining this poor correlation. Moreover, correlations were more frequent in the oropharynx and hypopharynx since the hyoid bone is closer to those regions and the pharyngeal middle constrictor muscle is connected to the lesser horn and greater horn of the hyoid bone.

Linear and angular parameters derived from CBCT images in the midsagittal view may be more reliable and accurate than those in LC when used for the measurement of airway volume.[3] Despite this, in the current study the hyoid bone triangle method was valid only for linear measurements in LC, which are 2D images. A greater number of linear measurements with statistically significant correlations were found in LC, and there were no statistically significant correlations between volumetric measurements and hyoid triangle measurements. The CBCT volume landmarks in the midsagittal plane can be checked in the axial and frontal planes. However, we used MPR and 3D reconstructions only in the midsagittal plane in order to reproduce those structures as presented in LC projections.

The existence of correlations between the position of the mandible and the volumetric morphology of the upper airway has been widely investigated. The results of this study showed an absence of correlation between the anterior position of the mandible and the hypopharynx and oropharynx, which corroborated the findings of other authors in CT and CBCT studies.[14,19] Moreover, correlations were found between linear measurements of the upper airway and hypopharynx and oropharynx measurements, but they were not seen when volumetric measurements of the same airway subregions were assessed. These findings showed that linear measurements did not depict, per se, the overall anatomic morphology at the corresponding level.[5]

The hyoid triangle method is a standardized methodology for the analysis of hyoid bone position. However, the use of this analysis alone may not be sufficient to determine the relationship between the hyoid bone position and cranial reference analyses, such as facial patterning and lateral changes in the jaws.[12]

Through the results of the present research, it was observed that this method was not useful when applied to 3D images. To the best of our knowledge, there are no standardized methods that can be applied for evaluation of the position of the hyoid bone in 3D images. Thus, we suggest that professionals use cephalometric points for this analysis, as in the study by Jiang et al.[3] However, exact measurement of hyoid bone position through cephalometric analysis is difficult because even small deviations in the location of points on cranial structures may generate apparent variation of the location of the hyoid, regardless of whether its position is altered or not.[10]

CONCLUSIONS

- In the present study, the correlations found were poor to moderate, which is common in studies on humans, since other are variables involved.
- However, some of the correlations found were statistically significant.
- Among the pharyngeal subregions studied, hyoid bone position showed more correlations with oropharynx and hypopharynx airway measurements.
- The hyoid triangle method, despite being used as a standard method for assessing hyoid bone position in lateral cephalometric images, was not applicable to 3D image analysis.

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