Original paper

Effect of the application of software on the volumetric and cross-sectional assessment of the oropharyngeal airway of patients with and without an open bite: A CBCT study

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Abstract

Background. Using different software to evaluate the airways, with different thresholds, but within the range for airway recognition, could yield different measurements in the same patient with or without craniofacial disharmony.

Objectives. The aim of the present study was to compare the volume and the most constricted area (MCA) of the oropharynx in individuals with or without an open bite by using 2 software programs meant for cone-beam computed tomography (CBCT).

Material and methods. This comparative study included 60 cases selected from 137 CBCT scans obtained from individuals with the presence or absence of an open bite. Each group included adults of both genders – in total 30 women and 30 men – with a mean age of 27.57 ±11.85 years in the open bite group and 26.23 ±6.78 years in the control group. The oropharyngeal volume and MCA were measured with 2 three-dimensional (3D) software packages: Planmeca Romexis®; and Nemotec NemoStudio®. Two calibrated orthodontists trained in the use of the software made the measurements. Data was analyzed using Student's t tests for independent and paired samples ($p < 0.05$).

Results. In general, the oropharynx volume measurements obtained with the NemoStudio software were significantly higher than those obtained with Romexis (19,007.17 ±8005.79 mm^3 and 17,823.47 ±7148.62 mm^3, respectively) ($p = 0.020$). However, when the groups were analyzed separately, the measurements of the group with an open bite did not differ according to the software used ($p = 0.352$). The measurements of the MCA of the oropharynx were significantly higher when obtained with the NemoStudio software (MD (mean difference) = 19.02 mm^2) ($p = 0.005$). In contrast, no difference in the MCA results for the 2 software packages was found in the open bite group ($p = 0.728$).

Conclusions. The volumetric and cross-sectional measurements of the oropharyngeal airway, particularly in individuals without an open bite, were affected by the software used.

Keywords: airways, software, cone-beam computed tomography, CBCT, open bite

Introduction

Craniofacial disharmony is considered a predisposing factor for respiratory disorders during sleep in children.[1] The symptoms of respiratory disorders are reportedly associated with facial and dental morphometry,[2] highlighting the important role of craniofacial and airway morphology.[3] Hence, an open bite accompanied by clockwise mandibular rotation and different associated factors, including the skeletal pattern, influence the airway dimensions. The repositioning of the mandible significantly affects these dimensions.[4]

In context of the above, conducting airway studies is vital. The research was initially performed using lateral radiographs. However, with the emergence and development of new technologies, computed tomography (CT) is currently being applied.[5,6] The measurements based on two-dimensional (2D) images have been questioned, taking into account the three-dimensional (3D) structures of the airways. However, studies have found a similarity between the linear measurements obtained with lateral radiographs and those obtained with cone-beam computed tomography (CBCT),[7] as well as a correlation between the sagittal and axial areas and the volume on 2D images.[8] In the search for more reliable information about the airways, recent research findings have validated the use of both lateral radiographs and CBCT.[9,10]

With technological advancement, different software packages for airway analysis have been developed. A systematic review conducted in 2011 reported 18 software packages for airway studies.[5] However, this review did not mention the threshold (automatic or interactive) or the measurement method (automatic or manual) used,[5] which only a few studies specified. Indeed, only one study determined the ideal threshold for the airway volume under experimental conditions[11]; therefore, this threshold cannot be used as a standard protocol for airway assessment. Another study used a fixed threshold, which was based on the average of previously determined thresholds for each tomography scan.[12] The objective of that study was to delimit the airways by using reliable references based on the 3D images obtained with the use of the Dolphin™ software in order to establish a protocol and to set normative upper airway values for patients with the following characteristics: Caucasian; adult (23–35 years); healthy; Class I occlusion; and a Class I profile without asymmetries.[12] In terms of the measurement method used, studies have examined the use of different software packages and found high reliability for automatic measurements, which differed from manual measurements.[13] Software packages are continually updated and improved, prompting the question of whether the above issues have been corrected. Several studies have used prototypes or phantoms to verify the obtained results.[6,11,14,15] However, if such devices are to be used to represent the airways, the materials they are made of should have the same density as soft tissues to ensure that the threshold values obtained with these prototypes are representative.[16] Furthermore, using different tomography modalities to scan the same tissue can lead to significant differences in the results,[17] and differences in the voxel and artifact sizes can affect CBCT images.[18,19] Recently, a study comparing 2 software packages, Invivo™ and Dolphin, was conducted, using fixed and interactive thresholds, respectively. It aimed to propose normative values for children to be used in the diagnosis and early management of pediatric sleep apnea, and they found differences depending on which software was used.[20] The same software packages were applied to make measurements in adults and in prototypes used as a control in another recent study measuring the volume, the minimum area and the location of the minimum area.[21] The authors of that study also found overestimated values when Dolphin was used and underestimated values when Invivo was used, though both software packages were considered reliable and strongly correlated.[21]

The aforementioned issues raised the question of whether different software packages used with different thresholds, but within the range for airway recognition, would yield different measurements in a sample of patients with craniofacial disharmony, in whom the dimensions of the airways may be altered. Therefore, the objective of the present study was to determine the volume and the most constricted area (MCA) of the oropharynx in individuals with and without an open bite and with different skeletal patterns by using the automatic software mode for Romexis® (Planmeca, Helsinki, Finland) and NemoStudio® (Nemotec, Madrid, Spain) in 3D, applying different thresholds.

Methodology

This retrospective and cross-sectional study was approved by the Research Committee and Ethics Committee of the Scientific University of the South (Universidad Científica del Sur – UCSUR), Lima, Peru, and Federal University of Rio Grande do Sul (Universidade Federal do Rio Grande do Sul – UFRGS), Porto Alegre, Brazil (No. of approval: 2018-00014). The sample for this study included 60 cases selected from 137 CBCT scans obtained from a private imaging center in Lima, Peru. The CBCT scans were done for reasons other than the present study. Gender and the skeletal pattern were considered inclusion criteria. Based on different skeletal patterns, both anteroposterior and vertical, the sample was divided into 2 groups: 30 CBCT images from individuals with an open bite; and 30 CBCT images from individuals without an open bite (the control group). To describe the sagittal and vertical features of both groups, we evaluated the skeletal relationship (A point–nasion–B point angle (ANB)), facial divergence (Frankfort mandibular plane angle (FMA)) and the vertical overbite depth indicator (ODI), as shown in Table 1.

For this purpose, cephalograms were derived from the CBCT scans. To get an adequate distribution of the sample related to the anteroposterior skeletal patterns, Class I (ANB = 2 ±2°), Class II (ANB > 4°) and Class III (ANB < 0°) were included in both groups, and the following characteristics of overbite were considered: the open bite group – 0 mm or negative; and the non-open bite group – positive. The CBCT images were taken from 30 males and 30 females, with 15 males and 15 females in each group, with or without an open bite, and aged between 15 and 56 years. The mean age was 27.57 ±11.85 years for the open bite group and 26.23 ±6.78 years for the non-open bite group. All excess CBCT images were excluded after the required number of 60 was achieved. The sample was obtained as scrutinized in the flow chart (Fig. 1).

Image acquisition

Cone-beam computed tomography was performed according to the standardized protocol of the radiological center and the images were obtained by means of the Picasso Master 3D scanner/E-woo model (Vatech, Hwaseong, South Korea). The CBCT scans were acquired with the patient in a seated and erect position, and with a craniocervical alignment of 90–110°. The sagittal midline, the Frankfort plane, the occlusal plane, and the incisor line were the anatomical points used to position the head. Instructions were given to the patients to keep their eyes open, not to move their head, not to swallow, to breath slowly, and to be in maximum intercuspation during scanning. The following settings of the 3D scanner were used to acquire the images: 8 mA; 90 kVp; flat-panel detector 25 × 20 cm^2 with a field of view (FoV) of 20 × 19 cm^2; an isotropic voxel size of 0.3 mm; and an exposure time of 20 s.

Table 1. Initial characteristics of the samples in both groups

Measurement	Group	*n*	*M* ±*SD*	*p*-value
SNA [°]	non-open bite	30	85.30 ±4.48	0.112
	open bite	30	83.64 ±3.41	
SNB [°]	non-open bite	30	82.90 ±5.88	0.571
	open bite	30	82.02 ±6.08	
ANB [°]	non-open bite	30	2.41 ±3.81	0.501
	open bite	30	1.63 ±5.01	
FMA [°]	non-open bite	30	29.27 ±5.76	0.244
	open bite	30	31.05 ±5.98	
ODI [°]	non-open bite	30	61.70 ±10.36	0.042*
	open bite	30	56.65 ±8.31	
Age [years]	non-open bite	30	26.23 ±6.78	0.595
	open bite	30	27.57 ±11.85	

SNA – sella–nasion–A point angle; SNB – sella–nasion–B point angle; ANB – A point–nasion–B point angle; FMA – Frankfort mandibular plane angle; ODI – vertical overbite depth indicator (ODI); *M* – mean; *SD* – standard deviation; * statistically significant (independent *t* test).

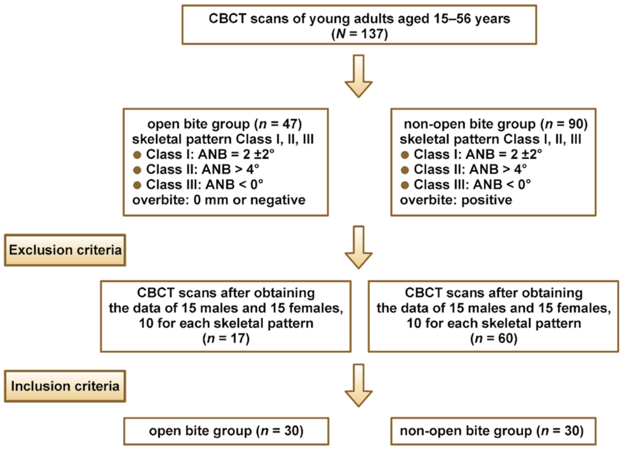

Fig. 1. Flow chart of the sample collection

CBCT – cone-beam computed tomography.

The CBCT images were converted into the DICOM (Digital Imaging and Communications in Medicine) format, and analyzed with the Planmeca Romexis software, v. 5.1.1.R, and the Nemotec NemoStudio software, v. 2017 (NemoFAB).

Calibration

In order to ensure uniform intra- and inter-observer measuring procedures, a calibration process was performed. Ten CBCT scans were randomly selected from the sample and the variables of interest were measured twice at an interval of 15 days between the 2 measurements for both software packages studied.

Measurement of variables

A Toshiba Satellite L845, Intel Core i3, 8 GB RAM computer, with a 64-bit operating system (Toshiba, Tokyo, Japan), was used for the selected upper airway measurements. The orientation of the head in the reconstruction of all 3D images was standardized by aligning the Frankfort plane (porion–orbitale (Po–Orb) on both sides) with the horizontal guideline in the sagittal and coronal sections. The anterior nasal spine (ANS) and the posterior nasal spine (PNS) were aligned with the vertical guideline, and the pupils were aligned with the horizontal guideline. Both alignment procedures were performed in the axial section.

For some years, the automatic airway measurement method has been used by most, if not all, software packages. The Romexis and NemoStudio software require a manual procedure to establish the limits of the selected part of the airway being measured. Indeed, these software packages, when used for the detection of the airway at the level of the oropharynx, define limits by prism, cube, or by locating points along the airway, including the location of the seed point (s-point), and the established threshold or tolerance.

For the measurements of volume and MCA in Romexis, the head icon was used to perform the measurements in an automatic mode. The procedure for demarcating the airway limits involved locating the vertical guide as central as possible in the oropharynx and perpendicular to the horizontal guide. Next, one point was located at the intersection of the vertical guide with the upper limit of the oropharynx, which begins in PNS, and then runs posteriorly toward the vertebrae. The horizontal guide was located at the lower limit of the oropharynx, tangent to vertebra C3 in its most caudal medial portion, which is directed forward. The 2nd point was placed at the lower limit of the oropharynx, following the projection of the 1st point at the intersection with the vertical guide. With this 2nd point, the manual procedure to demarcate the airway limits was completed by clicking 'done'. The anterior limit of the oropharynx was automatically defined by the formation of a cube where the anterior vertical line starts from PNS and extends toward the lower limit, and where the posterior limit of the oropharynx is defined by a line parallel to the anterior limit located on the vertebrae. The lateral walls of the pharynx and the total extensions of the lateral projections were included automatically. The measurement of the airway was done automatically. In order to standardize the protocol, a threshold of 300 HU (Hounsfield unit) was used for all of the images. The value was chosen while establishing the protocol as with this threshold, the researcher could visualize all images of the upper airways clearly (Fig. 2).

In NemoStudio, the NemoFAB component containing a tool for measuring the airways was used. In this program, the procedure was performed by demarcating the upper limit of the oropharynx. Starting at PNS, the procedure continued in a posterior direction along the horizontal guide until the middle of the vertebra was visible at that height, and then descended to the lower limit of the oropharynx, passing the horizontal guide line, tangent to the middle caudal portion of C3. From this point, the procedure was directed forward until a point that was in the direction of PNS was reached. From that point, and in the direction of the upper limit of the oropharynx, PNS was reached again, forming a prism. Next, an s-point was placed on the epiglottis within the demarcated area and the measurement of the airway was done automatically. The tolerance was defined as 500 HU (Fig. 3).

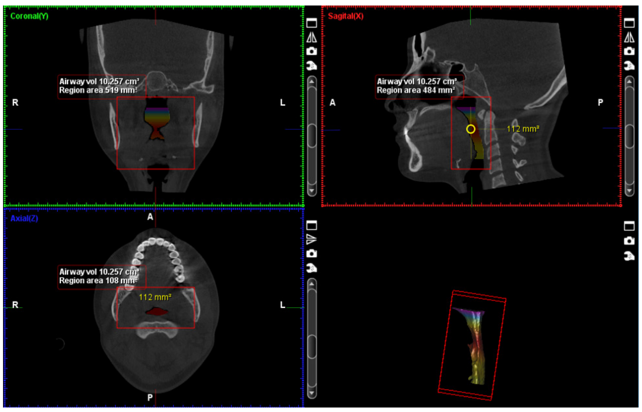

Fig. 2. Evaluation with the use of the Romexis software – upper airways, oropharynx, volume, and the most constricted area (MCA)

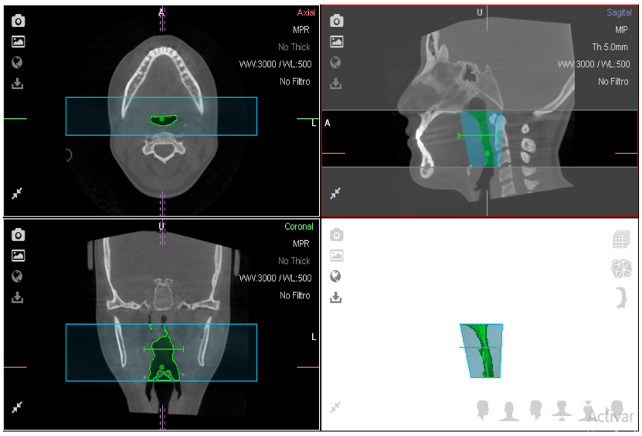

Fig. 3. Evaluation with the use of the NemoStudio software – upper airways, oropharynx, volume, and the most constricted area (MCA)

Statistical analysis

For this study, the statistical program IBM SPSS Statistics for Windows, v. 22.0 (IBM, Inc., Armonk, USA), was used. The normality of the distribution of quantitative variables was assessed with the Shapiro–Wilk test. Thereafter, the sample characteristics were evaluated by applying Student's independent-samples t test. To compare the mean values of the volume and the MCA of the oropharynx determined by the different software packages for both the total sample and each group, Student's paired-samples t test was used for related samples. The statistical tests were performed at a significance level of $p < 0.05$. A calibration process was performed previously by applying the intraclass correlation coefficient (*ICC*) for both software packages.

Results

The results from the *ICC* analysis showed intra-observer values of 0.999 and 0.994 for volume and MCA, respectively, and inter-observer values of 0.982 and 0.888 for volume and MCA, respectively, for Romexis. NemoStudio showed intra-observer values of 0.994 and 0.995 for volume and MCA, respectively, and an inter-observer value of 0.997 for both variables.

Table 1 displays the characteristics of both groups, which tend to show maxillary protrusion and a well-positioned but slightly protruding mandible in the group without an open bite. The ANB showed skeletal pattern variability in both directions, which was slightly more marked in the open bite group. The FMA showed that both groups were hyperdivergent, and the mean age indicated that the sample consisted of young adults. The only variable that presented a significant difference was ODI. In this regard, the open bite group presented more marked values of a skeletal open bite as compared with the group without an open bite, as well as skeletal open bite characteristics, despite a lack of clinical expression of an open bite.

Table 2 compares the measurements of the volume and the cross-sectional assessment of the MCA of the oropharynx performed with the Romexis and NemoStudio software. The table shows significant differences in the average volume for the entire sample between the two software packages (Romexis: 17,823.47 ±7,148.62 mm^3; NemoStudio: 19,007.17 ±8,005.79 mm^3) (p = 0.020). The average values of MCA for the entire sample also showed significant differences between the 2 software packages (Romexis: 227.32 ±102.61 mm^2; NemoStudio: 246.34 ±118.97 mm^2) (p = 0.005). For both the volume and MCA, higher values were observed with NemoStudio.

Table 3 compares the volume and the MCA of the oropharynx obtained with both software packages for the group with an open bite and the group without an open bite. A significant difference was observed between the 2 software packages in terms of volume for the group without an open bite (Romexis: 17,051.90 ±7,193.83 mm^3; NemoStudio: 18,747.00 ±8,496.91 mm^3) (p = 0.021). The group with an open bite did not show a significant difference in volume (Romexis: 18,595.03 ±7,140.37 mm^3; NemoStudio: 19,267.33 ±7,619.58 mm^3) (p = 0.352). However, the volume values for this group were higher with both software packages than the values obtained for the group without an open bite. The difference in MCA determined by the 2 software packages was more noticeable in the group without an open bite (Romexis: 216.43 ±111.78 mm^2; NemoStudio: 251.68 ±130.06 mm^2) (p = 0.001), while in the open bite group, the MCA values were 238.20 ±93.17 mm^2 with Romexis and 240.99 ±108.73 mm^2 with NemoStudio (p = 0.728).

Discussion

Despite the time elapsed and the efforts made, no gold standard is available for use as a reference for airway measurements,[6] even though airway problems are relatively frequent, with a prevalence of snoring of approx. 14.51%.[22] The literature on airway analysis highlights the need to address several factors with more studies. A thorough examination of the airways that includes information only on the volume would not help to identify the areas of greatest constriction.[23,24] Therefore, the development of software packages that would allow reliable, valid and efficient airway measurements, as well as the comparisons of the semiautomatic and manual measurement methods,[25] are still issues of concern for researchers.

Upper airway changes are observed over adolescence and late adolescence due to the periods of growth.[26–28] At maturity, the likelihood of changes is lower, and for that reason, the analysis of an adult sample enables the accurate comparisons of the groups.[29] Also, studies performed to determine the accuracy of the measurements of oropharyngeal morphology indicated that the images obtained with the Vatech equipment yielded more precise measurements of the volume and the axial area.[6]

Table 2. Comparison of the oropharyngeal volume and most constricted area (MCA) between the 2 evaluated software packages with regard to the total sample

Measurement	*N*	*M* ±*SD*	*p*-value	*MD*	95% *CI*	
					lower limit	upper limit
Volume with RS [mm^3]	60	17,823.47 ±7,148.62	0.020*	−1,183.70	−2,178.01	−189.39
Volume with NS [mm^3]	60	19,007.17 ±8,005.79				
MCA with RS [mm^2]	60	227.32 ±102.61	0.005*	−19.02	−31.95	−6.09
MCA with NS [mm^2]	60	246.34 ±118.97				

RS – Romexis software; NS – NemoStudio software; *MD* – mean difference; *CI* – confidence interval; * statistically significant (paired-samples *t* test).

Table 3. Comparison of the oropharyngeal volume and most constricted area (MCA) between the 2 evaluated software packages within both groups

Group	Measurement	*N*	*M* ±*SD*	*p*-value	*MD*	95% *CI*	
						lower limit	upper limit
Non-open bite	volume with RS [mm^3]	30	17,051.90 ±7,193.83	0.021*	−1,695.10	−3,113.99	−276.21
	volume with NS [mm^3]	30	18,747.00 ±8,496.91				
	MCA with RS [mm^2]	30	216.43 ±111.78	0.001*	−35.25	−54.50	−16.00
	MCA with NS [mm^2]	30	251.68 ±130.06				
Open bite	volume with RS [mm^3]	30	18,595.03 ±7,140.37	0.352	−672.30	−2,126.25	781.65
	volume with NS [mm^3]	30	19,267.33 ±7,619.58				
	MCA with RS [mm^2]	30	238.20 ±93.17	0.728	−2.79	−19.04	13.46
	MCA with NS [mm^2]	30	240.99 ±108.73				

* statistically significant (paired-samples *t* test).

The knowledge of the software being used is important, and the computer characteristics must be suitable for the software being used. The Romexis tools used for the measurements of the upper airway volume and area, as well as MCA, are easy to learn and apply. The jar icon is designated for manual procedures to demarcate limits by obtaining a cube, and then placing an s-point for the automatic measurement of the airway. Also, a human head icon is available for a simpler manual procedure to demarcate the limits of the airway. By locating at least 2 points, one at the upper limit and one at the lower limit, and then by clicking 'done', it is possible to obtain the cube and the measurement of the airway automatically. Other tools for identifying angle and linear measurements are also available. Obviously, the user must be able to recognize the anatomic structures and to establish a protocol for the measurements.

NemoStudio has an organized protocol established, since upper airway measurements are part of surgical procedures for treatment. NemoFAB is divided into sections and NemoFAB upper airway measurement tools belong to section E. With the Romexis software, it is also possible to verify all airway measurements. In the case of the Romexis software head icon and the NemoFAB software, verification is only possible after the measurements have been obtained. It may translate into the amount of time required to make the measurements and it depends on the researcher's desire to work.

Studies on the airway measurement software have mainly evaluated its accuracy, precision and reliability.[10,14,15] Several of these studies used phantoms or prototypes as the gold standard, which resulted in the underestimation of the dimensions, although the software showed the reliability of the obtained data.[14–16] Although the results were highly correlated, the software did not have good accuracy, which suggests systematic errors.[13] Other studies revealed that although some software packages provided underestimated results while others provided overestimations, they were still considered reliable.[19,20] The present study did not use any gold standard; consequently, the values may be underestimated or overestimated relative to the reference values provided in the literature. It would be desirable for upper airway studies that include the use of software packages to describe the characteristics of the software. Since many of software packages are only commercially available, the information they provide is oriented to selling, and not to the details of the approaches, especially regarding the behavior of algorithms in each software package. That is why it is difficult to find the equivalent value for each approach.

The software packages that are most frequently compared or evaluated are Mimics® and Dolphin (the measurements of the airway volume)[10]; Amira®, 3Diagnosys® and OnDemand3D® (the measurements of the volume, the minimum axial area and the length)[14]; Mimics, ITK-SNAP, OsiriX®, Dolphin 3D, Invivo, and OnDemand3D (the measurements of the volume)[15]; 3dMvultus® (the measurements of the volume, the area and the length)[16]; and Dolphin 3D, Invivo, OnDemand3D, and OrthoSegment® (the measurements of the upper airway volume).[13] One study compared the Beta NemoCeph® 3D and Invivo5 programs with lateral cephalometric radiographs, but only to determine the coincidence of the reference points used in the study.[30] Recently, a study compared Invivo5 and Romexis (v. 3.8.2.R) programs in order to test the reliability of the software in measuring the upper airways.[31] The present study compared the Romexis and NemoStudio software packages for measuring the volume and the MCA of the oropharynx. With Romexis, the head icon was used for a simpler, automatic airway measurement, and the NemoStudio program had the NemoFAB automatic airway measurement tool. Both software packages required a previous manual procedure to establish airway limits, and although it was not manual segmentation, the authors of the study would consider it as a semiautomatic method to obtain airway measurements.

The results of a study comparing 6 programs revealed that segmentation is influenced by the selected threshold, the algorithm of the software and the complexity of the airway.[15] The study also revealed that when an interactive threshold was used, significant differences were found between the volume measurements of the different software packages, and a lower error rate occurred due to the underestimation of the volume as compared to the gold standard. When a fixed threshold was used, the total differences were also significant, but the rate of error among the software packages was greater, even though they yielded the same results for the measurements of the phantom. This phenomenon may be due to differences in the algorithms used in each software package to identify the most complex morphology of the oropharynx.[15] The results of the present study are consistent with investigations using a fixed threshold, since the comparison of the measurements performed with the Romexis and NemoStudio software showed significant differences for the entire sample. However, the threshold used in both software packages was within values that can differentiate bone (250–1,000 HU) from air (between −600 and −1,000 HU).[32] Cone-beam computed tomography is not used in a routine examination, since there are specific indications for it; it offers an advantage over multi-slice computed tomography (MSCT) by generating a lower dose of radiation and being less expensive. The airways can be evaluated with MSCT, also known as multi-detector computed tomography (MDCT), or with CBCT.[6] Usually, Hounsfield units (HU) are used for MDCT, as its characteristics are adequate for mA and kVp. The HU method is used to measure the airways in CBCT. Since the pharyngeal evaluation in CBCT is made through the scale of gray tones, due to a great variability in the sensitivity of different commercially available software packages, different images are acquired, even with the same tomography equipment.

Studies have demonstrated diversity in the values obtained with the airway measurement tool available for the assessment of the pharyngeal space.[7,9] In the present study, when the values obtained from the 2 software packages were compared, no significant differences were found for the open bite group. However, significant differences were found for the group without an open bite. This difference may be related to the sample itself, since the airway dimensions determined by both software packages were smaller for the non-open bite group. Due to the intentional use of a lower threshold in the Romexis software, the values remained lower than those determined with the use of the NemoStudio software, which corresponds to the theory that "the higher the threshold used, the greater the value obtained" and vice versa.[11] Most likely, the configuration of the Romexis software algorithm compensated for using a low threshold and did not show significant differences in the open bite group, since the dimensions of the airways were greater in this group than in the group without an open bite. This was regardless of the software used due to the tendency to maxillary protrusion and non-retrognatic mandible in the individuals from our sample, and a lesser value of ANB in the open bite group. The aforementioned issue is referred to just to provide a better understanding, but the focus of this study was the influence of software, and there is no intention to draw attention to the findings of previous studies.[33–35]

Since the group without an open bite had smaller dimensions according to both software packages, and given the intentional use of a higher threshold for the NemoStudio software, as well as the relationship of this threshold with the algorithm configuration, the values obtained with NemoStudio were higher, leading to significant differences in the measurements for the non-open bite group.

Other studies measuring different structures have suggested that the influence of the threshold on the systematic error in the voxel measurement method of the programs may affect measurements in small structures, but not in large ones.[19] However, this would require a true value to obtain a constant value, which is generally provided by the measurement of a prototype or a phantom as the gold standard; however, this did not occur in the present study. Nonetheless, we might consider the possibility that the threshold could affect the airway measurements due to the complexity of the airways, and would be particularly likely in the group without an open bite, as the airways in that group were smaller. The literature also mentions the effect of partial volume and density due to the voxel size in the software depending on the threshold, where high threshold values would underestimate the measurement, whereas low values would overestimate it by forming a hybrid voxel when it includes 2 structures of different density.[19] In the present study, this theory would not apply, since the Romexis software used a lower threshold than the NemoStudio software. According to the literature, the ideal threshold value for measuring the volume has not been standardized, as the airway volume has been found to vary with regard to the selected threshold,[11,13] and greater or smaller airway volume values result from an increase or a decrease in the threshold, respectively.[11] The present study supports this direct relationship between a higher threshold and a greater volume. Finally, differences between these 2 software packages, including the time used to obtain measurements, also depends on the characteristics of the computer used. Furthermore, using an ideal graphics card, as well as the individual capability of the user factor into these differences. Based on time registration during the establishment of the protocol through the development of videos for manual procedures for automatic airway measurements, it is clear that the time spent on measurements also depends on head positioning and, to some extent, on the selected structures. In the Romexis program, obtaining information with the use of the head icon is faster than using the jar icon. It is comparable to the NemoFAB automatic airway measurement in terms of the time required, since verification can only be done after the measurements have been obtained, and only if an ideal graphics card has been used.

An advantage of the NemoStudio software is that it can delineate the soft palate. Furthermore, the time required to perform airway measurements using the automatic mode varies, depending on the computer characteristics and previous manual procedures. This gives a definitive advantage over the manual mode reported in the literature for other software packages.[24] Additionally, Romexis facilitates the visual identification of MCA through the use of color differentiation to indicate its location and value (Fig. 2), whereas NemoStudio uses solid colors and values that appear only beyond the image (Fig. 3). Both software packages require from the user the adherence to the standardized protocol in addition to the interactive thresholds reported in the literature to ensure a low error rate in the measurement of the structures.[15]

The sample of skeletal and clinical open bite group was not easy to find in CBCT records. From a clinical point of view, special care must be taken in the planning of extraction treatment or orthodontic treatment combined with surgical procedures for patients with an open bite. Indeed, the position of the tongue is usually more anterior in those patients, and treatment plans must be adapted according to the risk of malocclusion risk to the modified position of the soft palate position, commonly affected by treatment. Also, respiratory function therapy must take in account the relationship between the volume and ANB. For diagnosis, and while planning orthodontic or surgical treatment, it is important to pay attention to both groups studied. The non-open bite group had structures with small dimensions and the risk might go unnoticed, whereas in the open bite group, the greater the volume obtained, the lower the chance of finding differences between the software packages studied due to influence of the threshold or the segmentation mode. Finally, other variables related to the modification of the airways, such as obesity and apnea, have not been evaluated. However, their influence could be evaluated in future studies.

Conclusions

The volumetric and cross-sectional assessment of the oropharyngeal airway, particularly in individuals without an open bite, may affect the measurement results, depending on the use of the instruments available for particular software.

Ethics approval and consent to participate

The study was approved by the Research Committee and Ethics Committee of the Scientific University of the South (Universidad Científica del Sur – UCSUR), Lima, Peru, and Federal University of Rio Grande do Sul (Universidade Federal do Rio Grande do Sul – UFRGS), Porto Alegre, Brazil (No. of approval: 2018-00014). Written informed consent was obtained from all participants.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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