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Cone-beam computed tomography airway measurements: Can we trust them?

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Introduction: Pharyngeal airway space (PAS) assessment has been used in the past for a better understanding of orthodontic and surgical outcomes; however, this analysis could be unreliable. Our objective was to evaluate possible changes in the PAS reading in the same patient from their consecutive cone-beam computed tomography (CBCT) scans. **Methods:** We evaluated a total of 27 patients' CBCT scans obtained at 2 time points with the use of a standardized acquisition protocol. The mean age at T0 was 31 years (range 17-62 years) and the follow-up records (T1) were taken after 4-6 months. Dolphin Imaging software was used to measure the volumes of the nasopharynx, oropharynx, and hypopharynx. We also evaluated the craniocervical position with the use of a lateral cephalogram. **Results:** The variables exhibited high intraclass correlation coefficients (ICCs) when measuring the same CBCT scan twice (T0 and T0). However, The ICC between the measurements performed on the first and second CBCT scans (T0 and T1) showed that the only variable with high reproducibility between the 2 scans was cranial base, with an ICC $>$0.97. Average differences of 682.1 mm^3, 2255.3 mm^3, and 517.4 mm^3 were found for the nasopharynx, oropharynx, and hypopharynx, respectively. Regarding the cephalometric angles, average differences between T0 and T1 scans were 0.6°, 2.7°, and 0.4° for OPT.CVT, OPT.SN, and cranial base, respectively. **Conclusions:** Different CBCT exams with equal scanning and patient positioning protocols can result in different 3D PAS readings. A more careful interpretation of CBCT volumetric data to achieve adequate conclusions of the clinical outcomes is necessary. (Am J Orthod Dentofacial Orthop 2019;156:53-60)

Pharyngeal airway space (PAS) assessment has been used for a better understanding of the effects that surgical and orthodontic procedures have over this dynamic structure. Over the years, these measurements were generally done with the use of a 2-dimensional (2D) lateral skull cephalogram; however, that analysis does not provide 3-dimensional (3D) information. On the other hand, cone-beam computed tomography (CBCT) exhibits the capacity to analyze the PAS 3-dimensionally and detect adaptive changes in this structure.[1-4] It is known that craniocervical inclination has an effect over the PAS, and the 2D cephalometric assessment has shown that both head extension and flexion are responsible factors. Alterations in the other planes provoked by craniocervical "pitch" brought by slight changes in head posture during different examination periods can be assessed with the use of 3D examinations.[1,5] A standardized protocol for measuring airway volumes has been suggested for a better understanding and agreement between different studies.[6] The reliability of commercially available CBCT software has also been investigated for clinical use.[7,8] To this day, standardization of patient head positioning for CBCT scan acquisition is still a challenge.[9] To minimize distortions and obtain optimal CBCT quality without patient-related artifacts, patients must be still, avoid swallowing, and hold their breath, and the scanning period should be as short as possible.[10] Therefore, it is necessary to understand how reliable CBCT assessment of the PAS can be in these conditions. Our hypothesis was that different CBCT exams of the same patient with standardized scanning protocols can result in different 3D PAS readings.

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.

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The main objective of the present study was to quantify the volumetric variation and determine if the changes on volumetric reading are related to the craniocervical position.

MATERIAL AND METHODS

This retrospective study was approved by the Research Ethics Committee (protocol 37/11) of the Araraquara School of Dentistry, São Paulo State University, Brazil. CBCT scans from a private surgeon (L.M.W) were evaluated within intervals of 4-6 months between T0 (diagnosis scan) and T1 (evaluation/preoperative scan). Out of 278 patients, 27 met the inclusion criteria, which were ongoing presurgical fixed orthodontic treatment, female patient ≥15 years of age or male patient ≥17 years of age (to avoid growth influence), absence of surgical procedures in the craniofacial region, and complete T0 and T1 CBCT scan records. The exclusion criteria were the presence of syndromes, cleft lip and palate or facial trauma history, previous maxillomandibular, temporomandibular joint, and oropharyngeal surgeries, current use of orthopedic dental appliance, and inadequate quality of the scan records. The mean patient age at T0 was 31 years (range 17-62 years), and the follow-up records (T1) were taken after 4-6 months. Patients included in the sample were also not taking any medications associated with the presurgical treatment. The T0 scan represents the diagnostic exams of the presurgical patients. As part of treatment, the construction of a prototyped occlusal surgical guide was necessary before surgery. Patients included in the study were undergoing presurgical orthodontic treatment, so the surgical guide should be fabricated based on the most recent CBCT scan, justifying the need for a second scan (T1).

All CBCT scans were performed with the iCAT Cone Beam 3D Imaging System (Imaging Science International, Hatfield, Pa) and the patients were awake and seated in an upright position with the Frankfurt plane (tragus–infraorbital rim line) parallel to the floor. They were instructed to remain still during the scanning period and to not swallow. Centric relation was obtained and supervised with lips relaxed. A 23-cm extended field of view setting with 8.9 seconds of timing acquisition and 0.3 mm of voxel resolution was used. Diagnostic-purpose records were taken as part of clinical protocol (T0) and reevaluation (T1) follow-up records. The DICOM files were imported into Dolphin Imaging software, version 11.0 (Dolphin Imaging and Management Solutions, Chatsworth, Calif).[8,11] The 3D volumetric image was oriented by a trained investigator of this study with the use of the following protocol. (1) In the

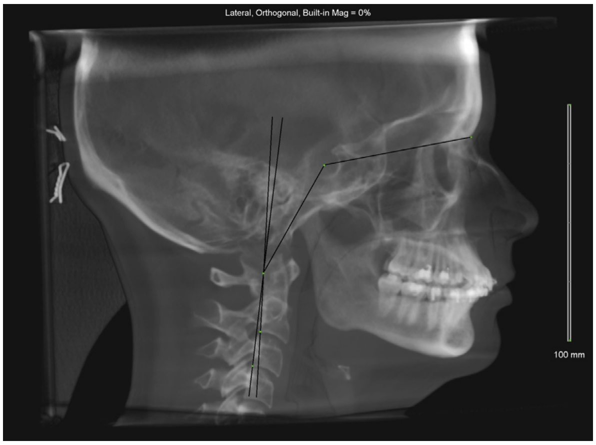

Fig 1. Lateral cephalogram tracing showing OPT.CVT and OPT.SN angles in a virtual 2D lateral image for observation of cervical curvature and inclination of the head with the cervical spine.

coronal view, the midsagittal plane was oriented to the midline of the 3D image, aligning the crista galli and anterior nasal spine, and the axial plane was oriented through both infraorbital skeletal margin landmarks. (2) In the sagittal view, the Frankfurt horizontal plane (FH) was parallel to the axial plane, placing it through the right porion and right infraorbital landmarks. Only the right side of the patient was assessed, to avoid patient asymmetry. (3) In the axial view, the external auditory meatus was oriented and it was verified that neither mandible nor zygomatic arch yaw was present.[12]

Thus, the airway was segmented into 3 distinct regions of interest: nasopharynx, oropharynx, and hypopharynx. Airway delimitation of each region was done with the boundary-line tool, following the chosen anatomic and technical cranial points with the use of a standard protocol.[12] Seed points were placed in each delimited airway subregion and the same threshold selection was used for both scanning periods.[13] The craniocervical position was evaluated using the same software to create a 2D lateral cephalogram. We evaluated the cranial base angle (CB; points: nasion, sella, and basion), OPT.CVT—formed by odontoid process (most inferoposterior point of cv 2ip) to odontoid process (most inferoposterior point of cv 4ip)—and OPT.SN—formed by odontoid process, sella, and nasion[12] (Fig 1). All studied variables of the 27 patients were repeated after a 2-week interval for the examiner calibration. The interobserver analysis for airway volume was performed in 10 patients. Statistical analysis of the data was conducted by calculation of intraclass correlation coefficients (ICCs) and nonparametric simple

Table I. Descriptive values of the variables

Variable and scan	*n*	*Min*	*Max*	*Mean*	*SE*	*SD*
NF T0 (mm^3)	27	4431.5	11376.9	7714.5	389.9	2026.2
NF T1 (mm^3)	27	4242.9	12445.6	7578.7	409.6	2128.3
OF T0 (mm^3)	27	5844.6	27481.0	14209.2	919.4	4777.2
OF T1 (mm^3)	27	6632.6	27392.2	13902.4	797.1	4141.6
HF T0 (mm^3)	24	2449.0	7845.4	4548.8	261.7	1281.9
HF T1 (mm^3)	27	2235.4	7788.9	4518.1	256.8	1334.4
OPT.CVT T0 (0)	27	−0.8	10.3	4.1	0.5	2.7
OPT.CVT T1 (0)	27	−1.0	10.4	4.0	0.6	2.9
OPT.SN T0 (0)	27	81.0	112.7	96.9	1.7	9.1
OPT.SN T1 (0)	27	77.5	117.5	96.5	1.9	9.8
CB T0 (0)	27	118.6	140.4	129.8	1.0	5.1
CB T1 (0)	27	119.1	140.7	129.8	1.0	5.2

HF, hypopharynx; *NF*, nasopharynx; *OF*, oropharynx.

Table II. Intraclass correlation coefficient (intraobserver variability) of the measurements at T0 and T0

Variable	*ICC*	*95% CI* *Lower*	*95% CI* *Upper limit*
NF	0.99	0.99	0.99
OF	0.99	0.99	1.00
HF	0.99	0.99	0.99
OPT.CVT	0.98	0.97	0.99
OPT.SN	0.99	0.99	0.99
CB	0.99	0.99	0.99

Table III. Intraclass correlation coefficient (intraobserver variability) of the measurements at T0 and T1

Variable	*ICC*	*95% CI* *Lower limit*	*95% CI* *Upper limit*
NF	0.90	0.81	0.95
OF	0.80	0.61	0.90
HF	0.83	0.66	0.92
OPT.CVT	0.95	0.89	0.97
OPT.SN	0.93	0.86	0.97
CB	0.99	0.98	0.99

Table IV. Interclass correlation coefficient (interobserver variability) of the airway measurements of 10 patients at T0

Variable	*ICC*	*95% CI* *Lower limit*	*95% CI* *Upper limit*
NF	0.97	0.91	0.99
OF	0.98	0.94	0.99
HF	0.99	0.95	0.99

Table V. Descriptive measurements of the differences between 2 scans (T1-T0)

Variable	*n*	*Mean*	*Mean**	*95% CI* *Lower limit*	*95% CI* *Upper limit*	*SD*
NF (mm^3)	27	120.8	682.1	−1860.8	1619.2	887.7
OF (mm^3)	27	−315.8	2255.3	−5735.3	5103.6	2765.0
HF (mm^3)	24	−181.5	517.4	−1473.0	1109.9	109.9
OPT.CVT (°)	27	−0.1	0.6	−1.7	1.6	0.8
OPT.SN (°)	27	−0.4	2.0	−6.1	9.6	3.5
CB (°)	27	0.0	0.4	−0.8	1.3	0.5

*Calculated converting the results to absolute values.

bootstrap technique with 1000 samples. Bland-Altman plots were used to analyze the agreements and to obtain a precise confidence interval. Finally, the Pearson correlation test was done to investigate the correlation between the variables.

RESULTS

Table I presents the descriptive statistics of the sample. The variables exhibited high ICCs when measuring the same CBCT scan twice (T0 and T0); the minimum ICC value was 0.97 (Table II). Hypopharyngeal analysis was not performed for 3 of the 27 patients owing to technical image problems. An ICC was also used to determine the degree of correlation between the measurements that were performed in the first and second CBCT scans (T0 and T1). The only variable with high reproducibility between the 2 scans was CB, with an ICC >0.97 (Table III). Thus, there was a low reproducibility for oropharynx and hypopharynx variables. Table IV presents the ICCs indicating excellent reliability between observers (all variables >0.9). Table V summarizes the descriptive measurements of the differences between T0 and T1 for all volumetric subregion data and cephalometric angles. When the absolute values were considered, average differences of 682.1 mm^3,

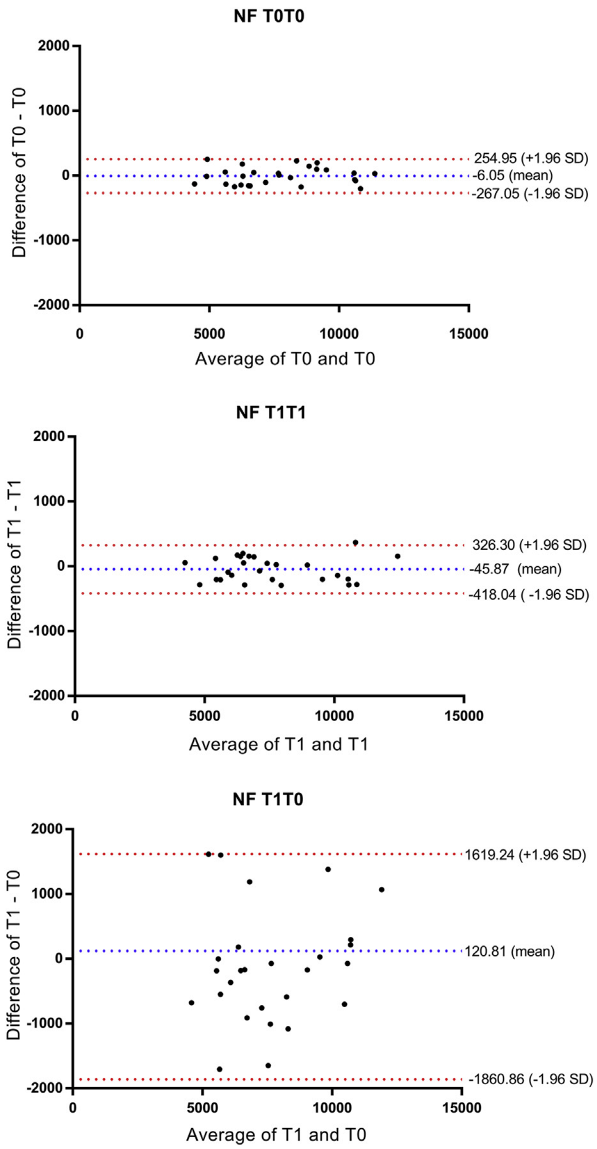

Fig 2. Bland-Altman plot for the comparison of nasopharynx measurements at T0-T0, T1-T1, and T1-T0.

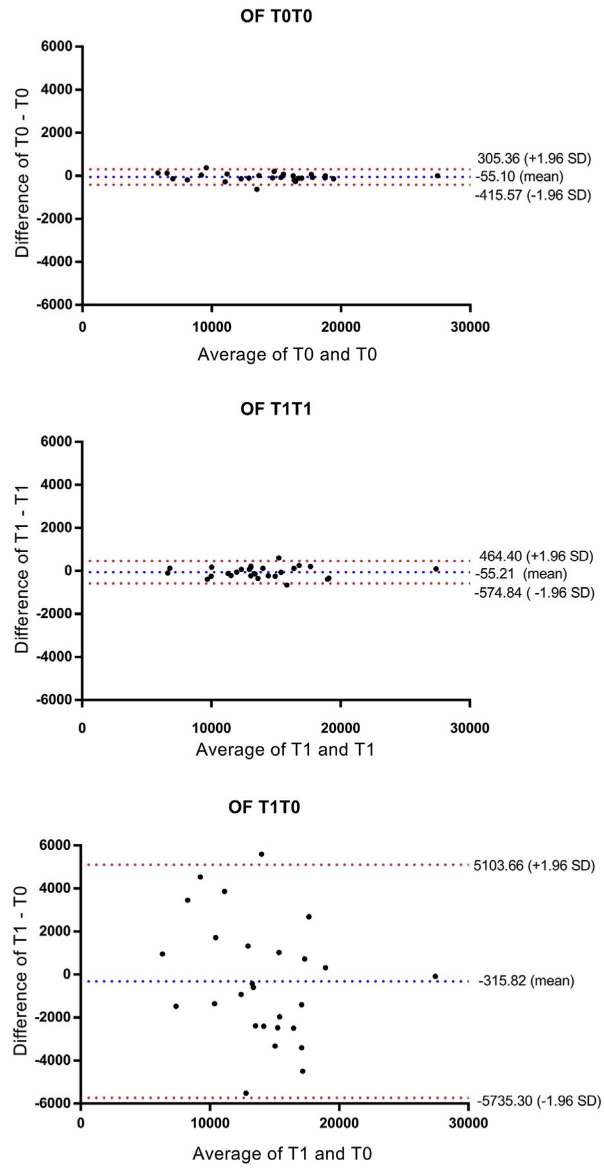

Fig 3. Bland-Altman plot for the comparison of oropharynx measurements at T0-T0, T1-T1, and T1-T0.

2255.3 mm^3, and 517.4 mm^3 were found for the nasopharynx, oropharynx and hypopharynx, respectively. As for the cephalometric angles, average differences between T0 and T1 scans were on average 0.6°, 2.7°, and 0.4° for OPT.CVT, OPT.SN, and CB, respectively.

Figures 2-4 represent Bland-Altman comparisons of the airway subregion measurements between the same-scan readings (T0-T0 or T1-T1) and compared with the follow-up scans (T1-T0). It can be noted that the limit range is higher and more dispersed in T1-T0 compared with T0-T0 or T1-T1 for all variables. The oropharynx exhibited the highest range, from −5735.3 to 5103.6 mm^3, nasopharynx from −1860.8 to 1619.2 mm^3, and hypopharynx from −1473.0 to 1109.9 mm^3, approximately. Table VI presents the results of the Pearson correlation between the craniofacial variables and airway measurements. A positive and moderately significant correlation between OPT.SN × oropharynx ($r = 0.46$; $P = 0.014$) was seen.

Point estimates and 95% confidence intervals (CIs) of mean and SD of the difference (absolute values) between 2 scans of the same patient are presented in Table VII, generated by the bootstrap method (1000 subsamples). Average variations for the volume found in this study

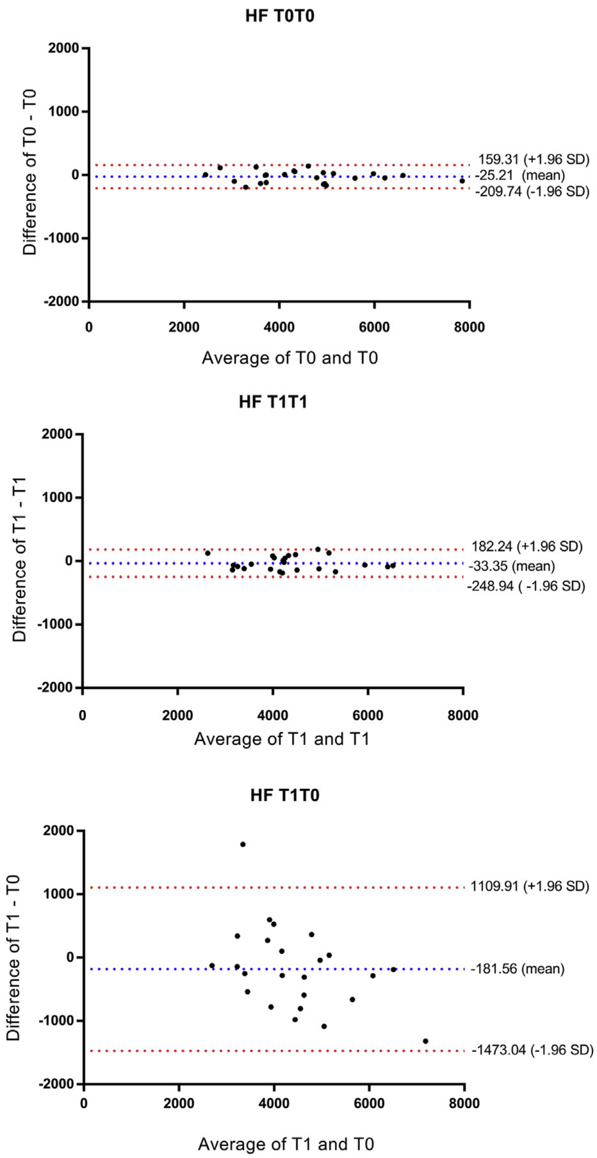

Fig 4. Bland-Altman plot for the comparison of hypopharynx measurements at T0-T0, T1-T1, and T1-T0.

ranged from 472.52 mm^3 to 896.34 mm^3 at the nasopharynx, from 1681.37 mm^3 to 2851.64 mm^3 at the oropharynx, and from 355.38 to 688.87 mm^3 at the hypopharynx. As for the cephalometric values, average variations range from 0.45 to 0.84 for OPT.CVT, from 1.99 to 3.56 for OPT.SN, and from 0.28 to 0.47 for CB.

Table VIII presents the frequency of distribution of the volumetric differences (absolute values) between 2 scans of the same individual (T0 and T1). For each volumetric variable analyzed in this study, an equation was used so that the relative difference between T0 and T1 scans was determined. In the equation, x_{i0} equals the mean of the 2 measurements of a variable in patient i at T0 and x_{i1} equals the mean of the 2 measurements of a variable in patient i at T1.

$$dr_i = |x_{i0} - x_{i1}| \times 100/[(x_{i0}+x_{i1})/2]$$

In Table IX, SD and mean estimates of the relative difference between T0 and T1 generated by the bootstrap method (1000 subsamples) are presented. The relative difference between T0 and T1 for the oropharynx is higher than the other 2 airway subregions. As presented in Table X, 25% of the patients presented a relative difference of the oropharynx between T0 and T1 >20%. The percentages decrease to 15% and 8% when the nasopharynx and hypopharynx, respectively, are considered.

Table VI. Pearson correlation between the variables (T1-T0)

Variable	*Correlation (r)*	*n*	P
OPT.CVT × NF	0.26	27	0.19
OPT.CVT × OF	−0.09	27	0.64
OPT.CVT × HF	−0.13	27	0.51
OPT.SN × NF	0.02	27	0.90
OPT.SN × OF	0.46*	27	0.01
OPT.SN × HF	0.21	24	0.21

*$P < 0.05$ (statistically significant).

Table VII. Point estimates (mm^3) and 95% CIs of the mean and SD of the difference (absolute value) between 2 scans of the same individual (T0-T1) and bias of the estimates generated by the bootstrap method (1000 replicates)

Variable		*Estimate*	*Bias*	*SE*	*95% CI Lower*	*95% CI Upper*
NF (mm^3)	Mean	681.13	−0.50	104.41	472.52	896.34
(n = 27)	SD	566.65	−14.11	54.21	435.87	648.96
	SE	109.05				
OF (mm^3)	Mean	2248.19	−0.90	306.97	1681.37	2851.64
(n = 27)	SD	1587.52	−35.88	185.03	1186.11	1910.08
	SE	305.52				
HF (mm^3)	Mean	517.37	0.28	85.23	355.38	688.87
(n = 24)	SD	435.03	−18.40	79.55	262.01	568.40
	SE	88.80				
OPT.CVT (°)	Mean	0.64	0.00	0.10	0.45	0.84
(n = 27)	SD	0.51	−0.01	0.06	0.37	0.60
	SE	0.10				
OPT.SN (°)	Mean	2.71	−0.01	0.41	1.99	3.56
(n = 27)	SD	2.15	−0.08	0.42	1.38	2.90
	SE	0.41				
CB (°)	Mean	0.37	0.00	0.05	0.28	0.47
(n = 27)	SD	0.28	−0.01	0.05	0.18	0.37
	SE	0.05				

Table VIII. Frequency distribution of differences (absolute values) of the measured volume (mm^3) between 2 scans of the same individual (T0-T1)

	Absolute frequency and percentage					
	NF		*OF*		*HF*	
Relative difference (mm^3)	*n*	*%*	*n*	*%*	*n*	*%*
0⊣500	16	44.4	3	11.1	13	54.2
500⊣1000	6	22.2	4	14.8	8	33.3
1000⊣1500	5	18.5	5	18.5	2	8.3
1500⊣2000	4	14.8	2	7.4	1	4.2
2000⊣5000	–	–	11	40.7	–	–
≥5000	–	–	2	7.4	–	–
Total	27	100.0	27	100.0	24	100.0

DISCUSSION

This study had the objective of clarifying CBCT volumetric assessment, its reliability and limitations, for routine clinical use. Although tomographic measurements of the airway space are not intended to diagnose clinical pathologies, they have been widely used to monitor treatment outcomes.[14-16] CBCT airway measurements have adequate repeatability,[8,15] as corroborated by our ICC values (Tables II and IV). The present study included of patients who were submitted to a standardized CBCT acquisition protocol where no airway changes were expected between acquisitions; however, airway differences were encountered for each studied segment. We found low ICC values for all measurements, especially for OF and HF variables, and except for CB angle. These findings show that the acquisition protocol for CBCT might not provide the necessary standardization (Table III). Therefore, the key point of this study was to investigate quantitatively these alterations. Our sample consisted of patients with a follow-up period of 4-6 months. Fixed orthodontic appliances have no power to change the airway volume; this fact is supported in the literature, showing that there is no strong evidence that orthodontic treatment has a significant effect on the pharyngeal airway, even when associated with extractions and despite the changes in incisor angulation and position.[16-18]

The superior and inferior limits of the CIs of the average error values for the population (Table VII) indicate that the errors can be clinically significant depending on the magnitude of the performed clinical procedures and their outcomes. The airway space is subject to deviations due to different breathing phases, head and tongue positioning, and craniocervical inclination.[19] Figures 2-4 represent the range of error in our samples, indicating that all of these variables must be addressed so that they may be minimized and allow a clear comprehension of the different clinical procedures that may cause changes to the airway.

Even though the patient is instructed to follow a series of instructions before CBCT scanning, these results demonstrate that changes may happen between scans (Fig 5). Changes are apparent between T0 and T1, possibly caused by a different breathing stage, swallowing, or craniocervical posture. In addition, adequate operator training and software calibration are necessary for correct airway evaluation to minimize possible measuring deficiencies and to correctly demarcate the area of interest which will be analyzed.[13] This information is supported by Table VI, presenting significant and moderate correlation between OPT.SN and OF.

Table IX. Average estimates and SD of the relative difference (%) between 2 scans of the same individual (T0-T1) generated by the bootstrap method (1000 subsamples)

					95% CI	
Variable		*Estimate*	*Bias*	*SE*	*Lower*	*Upper*
NF (mm^3)	Mean	9.84	−0.01	1.74	6.71	13.49
(n = 27)	SD	9.25	−0.30	1.28	6.27	11.21
	SE	1.78				
OF (mm^3)	Mean	17.78	−0.08	2.48	12.88	22.93
(n = 27)	SD	13.51	−0.40	1.79	9.36	16.16
	SE	2.60				
HF (mm^3)	Mean	12.01	0.07	2.22	8.29	16.97
(n = 24)	SD	11.01	−0.85	3.23	5.42	16.15
	SE	2.25				
OPT.CVT (°)	Mean	22.15	−0.10	3.92	14.86	30.40
(n = 27)	SD	20.60	−1.17	5.48	10.82	29.67
	SE	3.96				
OPT.SN (°)	Mean	2.84	−0.01	0.44	2.04	3.77
(n = 27)	SD	2.36	−0.09	0.50	1.42	3.21
	SE	0.45				
CB (°)	Mean	0.29	0.00	0.04	0.21	0.37
(n = 27)	SD	0.21	−0.01	0.04	0.13	0.27
	SE	0.04				

Table X. Frequency distribution of the relative differences (%) measured in relation to the mean of the measurements in the 2 CBCT (T0-T1): volumetric measurements

	Absolute frequency and percentage					
Relative difference (%)	*NF*	*%*	*OF*	*%*	*HF*	*%*
0⊣10	16	59.3	8	29.6	12	50.0
10⊣20	7	25.9	12	44.4	9	37.5
20⊣30	2	7.4	2	7.4	2	8.3
30⊣40	2	7.4	1	3.7	–	–
40⊣50	–	–	4	14.8	–	–
≥50	–	–	–	–	1	4.2
Total	27	100.0	27	100.0	24	100.0

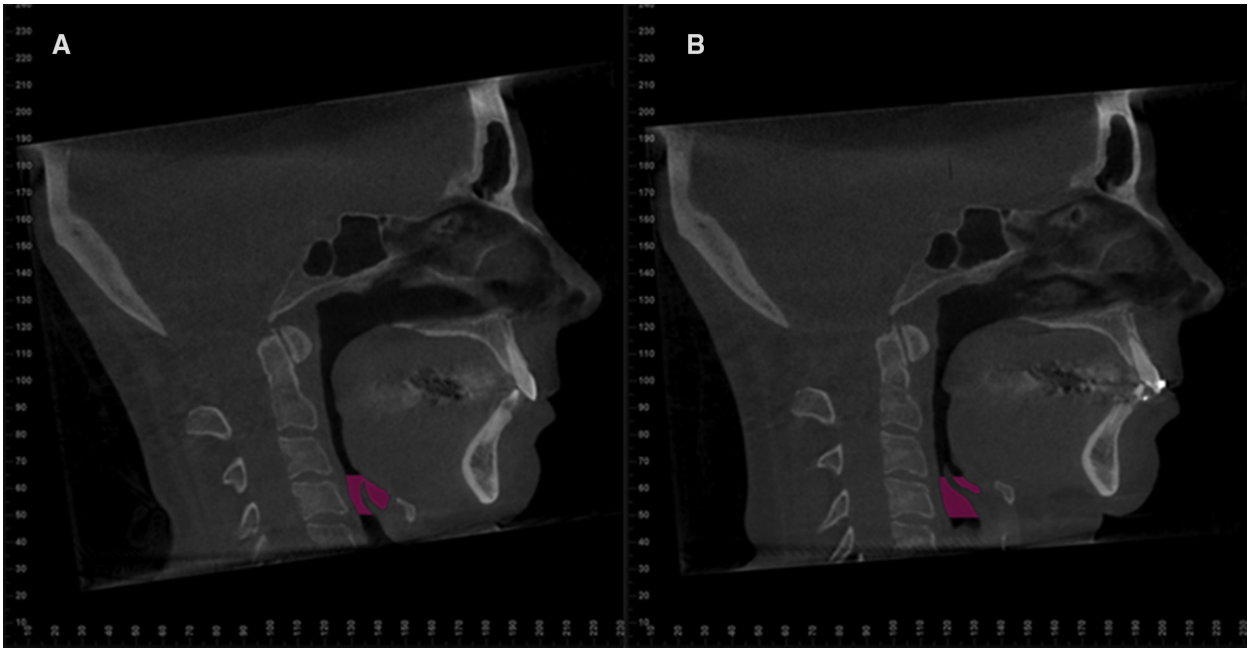

Fig 5. A, T0 CBCT sagittal airway view with delimitation of the hypopharyngeal subdivision. **B,** T1 CBCT sagittal airway view with delimitation of the hypopharynx.

As presented in Table VIII, from the superior and inferior CIs, we can presuppose that when a clinician measures the oropharyngeal airway space, it can be both overestimated and underestimated on average by 12% and 23%, respectively, of the obtained measurement.

In Table X, we can observe the difference intervals in percentages between T0 and T1. In the nasopharynx segment, 59% of the cases were placed in a 0%-10% difference between scans. For the oropharynx, 44% of the cases were found to be in a 10%-20% difference between scans. As for the hypopharynx, 50% of the encountered differences between the scanning periods were placed in the 0%-10% interval. This implies that most of the CBCT acquisitions do not influence, or influence very little, the airway volume measurement. On the other hand, we still have many cases where the acquisition has a great influence over this volume, leading to deviations that can reach >50%.

As part of being able to understand what is quantified when CBCT volumetric data is processed, our results can give a better comprehension of the real effects of airway volumetric–altering procedures such as maxillofacial and orthognathic surgeries and the influence of orthodontic appliances, giving a more accurate interpretation of clinical results. Mandibular advancement appliances or surgery may be used to improve pharyngeal airway obstructions.[20] The average airway differences found in the present study when considering 2 distinct CBCT scans are relatively small compared with the surgical outcomes of procedures such as maxillomandibular advancement; however, careful interpretations of smaller airway increases are necessary.[21] Orthopedic appliances have been used for the treatment of skeletal Class II patients and to increase the airway volume. Findings in these studies at the oropharynx level demonstrated variations between 1726 mm^3 to 5000 mm^3.[20,22,23] Our study found a possible average airway variation from −5735.3 to 5103.6 mm^3 for the oropharyngeal segment (Fig 3), suggesting that the magnitude of treatment benefit must be beyond this interval. Moreover, >50% of the patients presented an airway difference between T0 and T1 of >1500 mm^3 in the oropharyngeal segment (Table VIII). The anatomic site where most patients presented these differences coincides with the most common site of airway obstruction, that is, the oropharynx.[24,25]

Finally, no studies have addressed the repeatability of airway mensuration in 2 distinct CBCT scans of the same patient to evaluate possible interferences of scanning protocol acquisition or reading. In our understanding, a 4–6-month interval between scans is an acceptable period that minimizes weight variations and its interferences in volumetric data. It is known that there is a negative correlation between body mass index and airway volume.[26] Even after rigorous patient selection, data regarding weight and BMI was not available for both time points, which can be considered as a limitation of this study. We observed that CBCT airway assessment could be dependent on the acquisition technique and therefore should be used with caution.

CONCLUSION

Our findings supported our hypothesis; in fact, different scanning timings with equal scanning and patient's protocols can result in different 3D PAS readings. Thus, this study showed the necessity of a more careful interpretation of CBCT volumetric data to achieve adequate conclusions of the clinical outcomes. A more controlled and standardized patient positioning protocol is necessary to reduce the volumetric and craniocervical alterations between different scanning periods of follow-up.

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