Reliability of Upper Airway Assessment Using Cone Beam Computed Tomography

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ABSTRACT

Background

Since the late 1990s, CBCT has revolutionized dental imaging, offering 3D visualization with lower radiation than conventional CT. It is used in dentistry, for assessing the upper pharyngeal airway in OSA patients. Despite advancements in semi-automated analysis, reliable CBCT measurements remain challenging due to examiner-dependent factors like image orientation & threshold sensitivity.

Objective: To evaluate the accuracy of CBCT measurements of the upper airway's volumetric and cross-sectional areas, focusing on inter- and intra-examiner consistency.

Methods and Materials: Six examiners with varying experience analyzed CBCT images of 10 patients, performing airway orientation, slice selection, threshold adjustment, and measurements of A-P, A-W, A-L, and total airway space. After four weeks, measurements were repeated to assess reliability.

Results: The study found excellent reliability in A-P, A-W, A-L, and total airway measurements within the group across weeks 1 and 4. A-P comparisons between groups showed no significant differences, with consistent reliability for A-W, A-L, and total airway measurements across all investigators.

Conclusions: Despite advancements in 3D analysis, reliable skull & palate alignment methods are crucial. Future research should improve these techniques for accurate airway evaluation.

Keywords: *Volumetric Airway Analysis, Upper-Airway Assessment, Cone Beam Computed Tomography (CBCT), Intra-examiner Reliability, Obstructive Sleep Apnea (OSA).*

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1. INTRODUCTION

Dental radiography was transformed when CBCT became widely accessible in the late 1990s. Subsequently, then, dental research has seen an abrupt increase in interest in it. Implementation for both specialists and general dentists.[1] The inspection of the “upper pharyngeal airway” with CBCT has gained significant attention from academic and clinical communities. More precisely, CBCT may be a desirable method for evaluating the anatomy of the airways in Obstructive Sleep Apnoea (OSA) patients due to its capacity to conduct a 3-D examination of the upper airway and its diminished radiation dose when related to medical CT imaging.[2] The pharynx, larynx, and nasal cavities make up the upper airways.

The three sections of the pharynx—the area most prone to collapsing- are the hypopharynx, oropharynx, and nasopharynx. MRI, CT, CBCT, and profile teleradiography are key imaging technologies for assessment. Among them, CBCT is particularly useful for 3D airway analysis, offering lower radiation and faster imaging than CT. Using a flat panel detector and 3D reconstruction, CBCT employs a conical X-ray beam moving in a spherical motion.[3]

However, it's imperative that we demonstrate the reliability of CBCT as a measurement method before using it to quantitatively analyze the airway. Even while modern software provides a semi-automated quantitative assessment of the airway, before any measurements are taken, the examiner must first prepare the Communications in Medicine (DICOM) and Digital Imaging file through a number of stages, such as picture orientation and threshold sensitivity setting. Most remarkably, the literature's reports on procedure error and reliability have solely evaluated the inspectors' capacity to accurately section and hint the upper pharyngeal airway. Examiners' choice of slice and threshold sensitivity in the study procedures, as well as the physical alignment of the 'CBCT images', were not permitted in any of the studies that were available to assess reliability. This is an important item to remember because any airway analysis utilizing modern software must follow these stages.

Additionally, no paper has assessed the "upper airway" comprehensively or assessed the reliability of cooperation inter and intra-inspector assessments. This implies that there hasn't been enough research done to govern the dependability of 'upper pharyngeal airway' valuation using CBCT.[4] This study's goal was to use CBCT to examine the consistency of all crucial volumetric as well as "cross-sectional" area dimensions of the "upper airway".

2. MATERIALS AND METHODS

The cross-sectional data analysis was conducted in the clinical setting at the outpatient department of oral medicine and radiology. The description of the study protocol was submitted to the Institutional Ethics Committee (IEC), and approval was granted. IEC NO: KIDS/IEC/2024/I/031 .Study population were ten de-identified pre-treatment DICOM files were randomly selected from the Department of Oral Medicine and Radiology records, ensuring patient diversity while maintaining confidentiality.

Patients who are older than 18 were included as study population. Exclusion criteria were patients who were younger than 18 years old, had clefts, craniofacial syndromes, identifiable airway disease, or had undergone prior orthognathic or craniofacial surgery.

Following Walter et al.'s guidelines for trustworthiness studies, the sample size was determined. A minimum of 10 patients was sufficient for reliability analysis, with n = 2 for intra-examiner and n = 6 for inter-examiner reliability, ensuring meaningful variability assessment.

Ten de-identified pre-treatment DICOM files were randomly selected from a university. A single operator used the CS 9600 for CBCT scans, ensuring the Frankfort horizontal plane was parallel to the floor. Patients maintained tongue-to-palate contact at maximum intercuspation and refrained from eating or drinking during scanning. Five scans followed a rapid protocol, and five used a slow protocol. Images were captured in DICOM format and transferred to Carestream Imaging (version 11.5, Dolphin Imaging and Management Systems, Chatsworth, CA).[5,6]

Two academic orthodontist, two oral and maxillofacial radiologist, and two orthodontic residents were trained and standardized for upper pharyngeal airway analysis using CBCT images. A skilled physician guided the calibration, explaining the 3D measurement process with Dolphin Imaging Software. The software provided necessary tools, measurement examples, and resources, including a manual, video, and threshold sensitivity selection for airway analysis. Calibration and measurements were conducted on identical color computer monitors.

After calibration, examiners performed airway analysis. Reliability was assessed using ICC for measurements from 10 patients over two assessment periods. Inter-examiner dependability was evaluated by comparing initial and subsequent assessments, with ICC values and a 95% confidence interval calculated via SPSS 24 (SPSS Inc., Chicago, IL).

Reliability was assessed using ICC values: >0.9 (high), 0.76–0.9 (good), 0.5–0.75 (moderate), and <0.5 (low). Examiner error was calculated as the absolute difference between two recordings per parameter. Median examiner error, quartiles 1 and 3, and investigator error as a ratio to the mean were also determined.

3. STATISTICAL ANALYSIS

The data collected were then recorded in a Microsoft Excel sheet to develop a master chart and then analyzed by SPSS version 24 (SPSS Inc., Chicago, IL). The inter- and intra-examiner reliability were assessed by using descriptive and inferential statistics. The significance criterion for the analysis was set at $p < 0.05$. The ICC was used to quantify measurement dependability, and error analysis was performed to understand the variation in examiner measurements.

4. RESULTS

Table 1 shows the A-P distance within the group at the first and fourth week for the reliability of airway with no significant difference. The A-W distance within the group at the first and fourth week for the reliability of airway with no significant difference. The A-L distance within the group at the first and fourth week for the reliability of airway with no significant difference. It shows excellent between all the investigators at 1st and 4th week.

Table 2 shows the total airway within the group at the first and fourth week for the reliability of airway with no significant difference. It shows excellent between all the investigators at 1st and 4th week.

Table 3 shows the A-P dimension comparison between group for the reliability of airway at first week and fourth week with no significant difference. The A-W dimension comparison between group for the reliability of airway at 1st and 4th week with no significant difference. The A-L dimension comparison between group for the reliability of airway at 1st and 4th week with no significant difference. It shows excellent for the first week with four investigators and it shows excellent for the four investigators at the fourth week.

The total airway comparison between group for the reliability of airway at 1st and 4th week with no significant difference.

5. DISCUSSION

An existing record of orthodontic patients who had previously received treatment provided the CBCT DICOM data used in this study. It is important to remember that the SedentexCT recommendations and ALARA principles prohibit improper utilization of CBCT, stressing that its application should be saved for specific situations in which traditional radiography is unable to deliver the required diagnostic data.[8,16] Consequently, radiation exposure should be minimized, and for any orthodontic patient, the use of CBCT tests should be approved.

A recent review identified major methodological flaws in past CBCT studies on upper airway anatomy. Examiners were not allowed to adjust threshold sensitivity, select mid-sagittal slices, or manually orient images — key steps affecting accuracy. This study evaluates CBCT reliability based on examiner experience, scan speed, and these limitations.

When everything is said and done, the only component of the "upper pharyngeal airway" is the oropharynx, that exhibits exceptional dependability both within and between examiners. This was done regardless of the inspector's background, expertise, or choice of threshold sensitivity setting. This is in line with earlier research by El et al. [9] and Guijarro-Martinez et al. [10] that demonstrated the “oropharynx” to be the most reliable location. The nasopharynx and hypopharynx can be particularly vulnerable to manual cutoff selection, this depends on the operator's ability to visually identify the uneven form of the airway and is inherently unreliable, or these regions may present more difficulties in landmark identification. [7,14]

Another hypothesis offered by Alsufyani et al. is that the oropharynx's three-dimensional form is fundamentally comparable to that of a tube since it is entirely hollow.[11] This makes it possible for the imaging software to separate and handle data rather simply. However, because of the choanae and eustachian tubes' winding, tiny passageways, the structure of the nasopharynx is more intricate. Because of the epiglottis, the same can be said about the hypopharynx. This, together with perhaps noisy CBCT pictures, makes segmentation very difficult because of the challenges in identifying borders and grey-level thresholding. [11,15]

CBCT use for quantifying the upper pharyngeal airway requires careful consideration. While its reliability is established, insufficient data supports its use for diagnosing OSA. Assessing CBCT’s accuracy in measuring airway volume and cross-sectional area is complex due to confounding factors. Head, jaw, and body positions during scanning significantly impact airway dimensions. Ono et al.'s non-randomized trial examined how head adjustments and three body positions—lateral recumbent, supine, and supine with head turned—affect upper airway size.[12] When patients turned their heads to the left when supine or transitioned from the supine to the lateral recumbent posture, they showed a notable increase in capacity in the retroglossal area of the oropharynx.

Gurani et al. found that head, body, and jaw position changes significantly affected upper airway proportions and volume during image acquisition.[13] Respiratory phase and tongue posture during image capture can qualitatively and quantitatively affect oropharyngeal airway size and shape in CBCT studies. Patients should breathe gently, keep the jaw in a consistent position (centric relation or maximal intercuspation), and avoid movement to minimize these variables.[10]

6. LIMITATIONS OF THE STUDY

There has been an increasing trend in the use of CBCT for three-dimensional airway analysis, there is still a lack of a standard and reliable method of positioning the head and tongue for airway dimension assessment.

7. FUTURE PROSPECTIVES OF THE STUDY

This study highlights the need for future research to standardize patient positioning and establish accurate airway measurement criteria across imaging modalities like CBCT and MRI. This will support more consistent clinical applications, improve diagnostic standards, and enable timely disease diagnosis.

8. CONCLUSION

Natural head position during CBCT acquisition is suggested as a reference position for upper airway evaluation. However, obtaining reproducible measurements of airway volumes in clinical practice may be difficult because of differences in patient positioning. There has been an increasing trend in the use of CBCT for three-dimensional airway analysis, there is still a lack of a standard and reliable method of positioning the head and tongue for airway dimension assessment.

9. CONFLICTS OF INTEREST

There are no conflicts of interest.

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TABLES

Table 1: Depicts the airway measurements within the group at the 1st and 4th week for the reliability of airway.

Investigator	Time interval	Mean ± SD	ICC	95%CI		F Value	P Value
				LB	UB		
A-P distance							
O-I	1st	9.06 ± 4.94	0.994	0.983	0.998	346.07	**0.000***
	4th	8.93 ± 4.66					
O-II	1st	9.06 ± 4.74	0.985	0.956	0.995	126.43	**0.000***
	4th	8.86 ± 4.98					
O-III	1st	9.06 ± 5.11	0.996	0.989	0.999	497.182	**0.000***
	4th	9.13 ± 5.08					
O-IV	1st	9.06 ± 5.03	0.993	0.981	0.998	319.848	**0.000***
	4th	9.26 ± 5.00					
A-W distance							
O–I	1st	21.20 ± 5.49	0.982	0.936	0.994	142.136	**0.000***
	4th	20.66 ± 5.45					
O-II	1st	20.73 ± 5.33	0.989	0.96	0.996	212.228	**0.000***
	4th	20.33 ± 5.42					
O-III	1st	20.40 ± 4.92	0.978	0.936	0.993	96.436	**0.000***
	4th	20.80 ± 5.47					
O-IV	1st	20.86 ± 5.38	0.983	0.983	0.994	119.825	**0.000***
	4th	20.60 ± 5.17					
A-L distance							
O-I	1st	150.80 ± 130.59	1.000	1.000	1.000	91579.00	**0.000***
	4th	150.60 ± 130.23					
O-II	1st	150.40 ± 130.89	1.000	1.000	1.000	107250.00	**0.000***
	4th	150.33 ± 130.71					
O-III	1st	150.66 ± 131.26	1.000	1.000	1.000	70286.53	**0.000***
	4th	150.53 ± 131.31					
O-IV	1st	150.73 ± 131.45	1.000	1.000	1.000	85168.38	**0.000***
	4th	150.40 ± 131.11					

Table 2. Depicts the total airway within the group at the 1st and 4th week for the reliability of airway

TOTAL AIRWAY

Investigator	Time interval	Mean ± SD	ICC	95%CI		F Value	P Value
				LB	UB		
O-I	1st	12.80 ± 6.28	0.994	0.980	0.998	421.30	**0.000***
	4th	12.46 ± 6.40					
O-II	1st	12.60 ± 6.67	0.998	0.996	0.999	1433.61	**0.000***
	4th	12.46 ± 6.65					
O-III	1st	12.60 ± 6.69	0.999	0.996	1.000	1447.62	**0.000***
	4th	12.46 ± 6.69					
O-IV	1st	12.60 ± 5.64	0.978	0.937	0.993	86.148	**0.000***
	4th	12.40 ± 6.36					

Table 3: Depicts the airway measurement comparison between group for the reliability of airway at 1st week and 4th week

A-P distance							
	Investigator	**Mean ± SD**	**ICC**	**95 % CI**		**F Value**	**P Value**
				LB	**UB**		
1st week	O-I	9.06±4.94	0.99	0.977	0.996	356.93	**0.000***
	O-II	9.06±4.74					
	O-III	9.06±5.11					
	O-IV	9.06±5.03					
4th week	O-I	8.93±4.66	0.977	0.952	0.991	173.55	**0.000***
	O-II	8.86±4.98					
	O-III	9.13±5.09					
	O-IV	9.26±5.00					
A-W distance							
	Investigator	**Mean ± SD**	**ICC**	**95 % CI**		**F Value**	**P Value**
				LB	**UB**		
1st week	O-I	21.20±5.49	0.977	0.949	0.991	188.316	**0.000***
	O-II	20.73±5.33					
	O-III	20.40±4.92					
	O-IV	20.86±5.38					
4th week	O-I	20.66±5.45	0.983	0.964	0.994	237.493	**0.000***
	O-II	20.33±5.42					
	O-III	20.80±5.47					
	O-IV	20.60±5.17					
A-L distance							
	Investigator	**Mean ± SD**	**ICC**	**95 % CI**		**F Value**	**P Value**
				LB	**UB**		
1st week	O-I	150.80±130.59	1.000	1.000	1.000	50736.86	**0.000***
	O-II	150.40±130.89					
	O-III	150.66±131.26					
	O-IV	150.73±131.45					
4th week	O-I	150.60±130.23	1.000	1.000	1.000	86283.44	**0.000***
	O-II	150.33±130.71					

	O-III	150.53±131.71					
	O-IV	150.40±131.11					
T-L distance							
	Investigator	**Mean ± SD**	**ICC**	**95 % CI**		**F Value**	**P Value**
				LB	**UB**		
1st week	O-I	12.80±6.28	0.984	0.966	0.994	240.731	**0.000***
	O-II	12.60±6.67					
	O-III	12.60±6.09					
	O-IV	12.60±5.94					
4th week	O-I	12.46±6.40	0.988	0.973	0.995	299.38	**0.000***
	O-II	12.46±6.65					
	O-III	12.46±6.69					
	O-IV	12.40±6.36					

O-I (Observer one), O-II (Observer two), O-III (Observer three), O-IV (Observer four)