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Assessment of interobserver reliability in localization of hard and soft tissue landmarks and three-dimensional measurements of the upper airway based on these landmarks using CBCT images

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ABSTRACT

Aim: To assess reliability in localization of hard and soft tissue landmarks of the upper airway and three-dimensional measurements of the upper airway based on these landmarks using CBCT images.
Setting & Design: 22 full field of view (FOV) CBCT scan volumes were selected randomly and retrospectively made at the CBCT unit of Department of Oral Medicine and Radiology.
Materials and Methods: Six anatomic landmarks that are relevant for upper airway analysiswere located and subsequently three-dimensional measurements (volume, minimum cross-sectional area (CSA_{min}), location of the CSA_{min}, anteroposterior and lateral dimensions of the CSA_{min}) in all planes (coronal, sagittal, axial) were performed based on these land marks by two observers, using Romexis software (4.2.0 R 10/13/15).
Statistical Analysis used: Correlation analysis by Cronbach's Alpha.
Results: Interobserver reliability of the landmark localization was excellent (Internal consistency 0.97-0.99) and for the three-dimensional upper airway measurements were good (Internal consistency 0.62-0.99).
Conclusion: The interobserver reliability of anatomical landmarks localization and three-dimensional measurements of the upper airway are good to excellent using Romexis software. Therefore, this methodology can be recommended for the upper airway analysis using CBCT images.

1. Introduction

In respiratory medicine, upper airway is an important and complex anatomic structure.[1] Many studies that have been carried out till now have given attention on the airway and its potential for normal craniofacial development. In the pathogenesis of obstructive sleep apnoea, anatomic and functional abnormalities of the upper airway play very crucial role has also been suggested.[1] The development of structures and functions of the stomatognathic system may be affected by alterations in upper airway breathing, particularly during facial growth.[2] Therefore, correct diagnosis and treatment planning of sleep-disordered breathing or an abnormal craniofacial growth pattern is required which needs reliable and accurate upper airway analysis.

The whole airway is divided in two compartments that is upper and lower airway. These two compartments have numerous subdivisions. In Upper Airway the pharynx is present between the base of the skull and the oesophagus which is lined by the mucous membrane and is further subdivided in Nasopharynx, oro-pharynx and hypopharynx.[3] The airway is bordered superiorly by the bones of the skull base, posteriorly by the spine, antero-

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superiorly by the nasal septum, and anteriorly by the mandible and hyoid bone. Another portion of upper airway is the larynx which is present between the pharynx and the trachea, contains the organs for production of speech. Larynx is made up of cartilaginous skeleton which includes the important organs of the epiglottis and the vocal folds (vocal cords) which 'are the opening to the glottis.[3]

2D- Lateral or Frontal Cephalograms used previously for airway analysis does not produce accurate anatomic images. Moreover, they cannot identify the soft tissue contour, thus limiting evaluation of areas and volume. An ideal goal for imaging is to accurately constitute the anatomy as it exists in nature.[4] Three-dimensional (3-D) digital techniques creates the chance to produce anatomically accurate images. Now a days there is emergence of methods to assess anatomic constrictions in patients with symptoms of sleep-disordered breathing that may also present with craniofacial growth discrepancies with the help of three-dimensional (3-D) models of the upper airway, reconstructed from cone beam computed tomography (CBCT) scans.[5] With the help of CBCT one can evaluate measurement of upper airway for morphological abnormalities, diagnosis and treatment planning of disorders like: Obstructive sleep apnea, signs of Adenoid facies, airway problems due to Malocclusion, planning of Orthognathic surgeries, assessment of normal craniofacial growth.

Advantages of CBCT being dose reduction, multiplanar sections, image accuracy, rapid scan time and low cost as compared to CT scans.[6] Therefore, this study is carried out to find out reliability of CBCT on upper airway analysis. The aim of this study is to assess inter observer reliability of (1) localization of hard and soft tissue landmarks of the upper airway and (2) three dimensional measurements of the upper airway based on these landmarks using CBCT images. Three dimensional measurements including assessment of reliability of cross-sectional area in all planes (coronal, sagittal, axial).

2. Materials and Methods

After obtaining permission from the Institutional ethical committee and Scientific advisory committee (IEC/2020/03), the study was carried out at CBCT unit of Department of Oral Medicine and Radiology in college. Samples were selected randomly and retrospectively. 22 full field of view (FOV) CBCT scan volumes of 11 males and 11 females were selected randomly and retrospectively were analysed. All the CBCT scans with the area of interest that have been made at the CBCT unit of Department of Oral Medicine and Radiology, Sinhgad Dental college & Hospital, Pune was included in study.

2.1. *Inclusion criteria*

CBCT scans which were full FOV which reveal upper airway (normal), CBCT scans of the subjects of the age above 18 years & scans referred for dentomaxillofacial indications: - Dental implants, Orthodontics, Endodontics, Exodontia. CBCT scan volumes covering the entire extent of upper airway from the level of hard palate to the base of epiglottis, High quality reconstructed images of upper airway without any imaging artifacts.

2.2. *Exclusion criteria*

Presence of a palatal cleft, craniofacial syndrome or craniofacial surgery in past, presence of any developmental anomaly and patients with trauma, CBCT scans with artifacts and low-quality images.

22 data sets of the patients who fulfilled the inclusion criteria were selected by convenience sampling in this study. Each scan was made using Planmeca ProMax3D Mid Proface CBCT unit and opened in the software viewer Romexis version 4.2.0 R 10/13/15.

The CBCT data sets used in this study were obtained by using the Planmeca ProMax3D Mid Proface CBCT unit according to the department's standard imaging protocol. During the imaging procedure, the patients were positioned in the upright position, with the Frankfort horizontal (FH) plane parallel to the floor. Maintenance of maximum intercuspation, avoiding swallowing and other movements during the scanning period were the instructions given to patients before scans were carried out. The exposure settings were 90 kV, 8 mA, 20 x 17 cm^2 field of view, 400 μm voxel size, 20 seconds scanning time. For further analysis, the images were saved as digital imaging and communications in medicine (DICOM) files, and these data sets were opened in the software viewer Romexis version 4.2.0 R 10/13/15. for upper airway measurements.

Six anatomic landmarks that are relevant for upper airway analysis[7–9] were located by two observers, oral and maxillofacial radiologists who were trained using two data sets that were not included in this study. These two observers then localized anatomical landmarks of upper airway (Table 1)[9] individually using all three planes of CBCT data sets (Figure 1). After localization of anatomic landmarks of upper airway, the two observers subsequently performed three dimensional measurements of upper airway (Table 2)[9] (Figure 2).

A cube was drawn in sagittal Grayscale view at the area of an airway using the 'to draw a cube' button. The superior and inferior limit of the cube was at the PNS level and anteroinferior aspect of the vertebral body of the second cervical vertebra. The anterior and posterior limit of the cube was created by certifying that the airway boundaries were included. The '3D region growing' tool was then used to set the airway parameter. In the'3D region

Table 1: Definitions of anatomical landmarks localized by two observers

S. No.	Landmark	Definition
1	Anterior nasal spine (ANS)	Protrusion of maxilla at the base of nose.
2	Posterior nasal spine (PNS)	Posterior tip of the nasal crest of the hard palate.
3	Anteroinferior aspect of the vertebral body of the second cervical vertebra (AICV)	Middle inferior point of the second cervical vertebra.
4	Tip of the uvula (TUV)	Inferior point of caudal margin of the uvula at the mid-sagittal plane.
5	Tip of the epiglottis (TEP)	Mid-superior point of the epiglottis.
6	Base of epiglottis (BEP)	Bottom of epiglottis crypt.

Table 2: Definitions of upper airway measurement sperformed by two observers

S. No.	Variable	Definition
1	Volume of the upper airway	Volume of the upper airway with threshold ranging from -1000 to -500
2	Minimum cross-sectional area (CSA_{min})	At axial view, the minimum cross-sectional area (CSA_{min}) of upper airway
3	Location of the CSA_{min}	The number of the axial slice where CSA_{min} was located
4	Lateral dimension of the CSA_{min}	At coronal view, width of CSA_{min}.
5	Anteroposterior dimension of the CSA_{min}	At sagittal view, length of CSA_{min}.

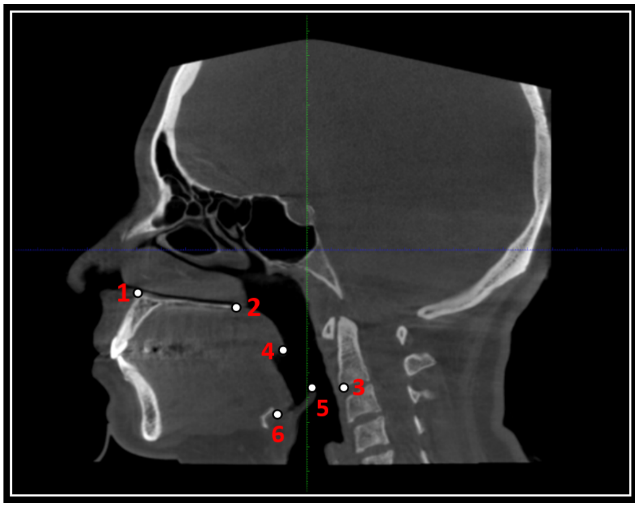


Fig. 1: Location of the anatomic landmarks on the conebeam computed tomography (CBCT) images on the midsagittal plane, **1:** ANS, anterior nasal spine; **2:** PNS, posterior nasal spine; **3:** AICV, anteroinferior aspect of the vertebral body of the second cervical vertebra; **4:** TUV, tip of the uvula; **5:** TEP, tip of the epiglottis; **6:** BEP, base of epiglottis

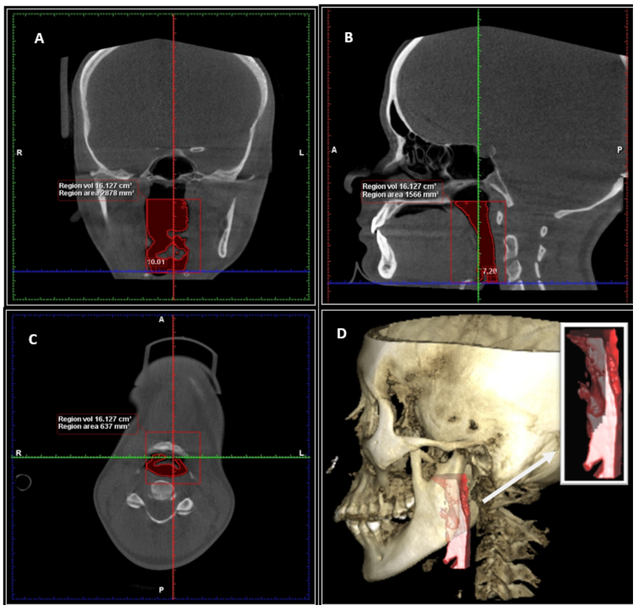


Fig. 2: **A-**Coronal section showing volume (16.127 cm^2) and lateral dimension of CSA_{min} (10.1mm), **B**- Sagittal section showing volume and Anteroposterior dimension of the CSA_{min} (7.2 mm), **C**- Axial section showing volume, CSA_{min} (637 mm^2) and location of the CSA_{min} (green line), **D**- Segmented upper airway volume.

growing' window, the 'pre-set' box was set as 'air cavity', the threshold was set at 300, the colour was set as solid red. Then the cursor was clicked on a space in the airway. Romexis then presented the airway and displayed the air volume and the area of the airway.

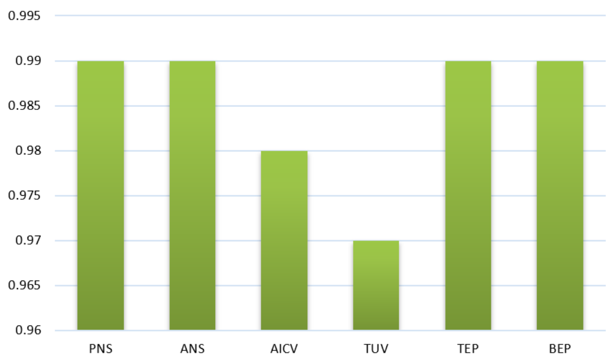
The total upper airway volume and the cross-sectional area (CSA) of every axial slice were automatically calculated by the software. On the basis of these results, the minimum cross-sectional area (CSA_{min}) and its location (axial slice number) were identified. On the specific slice where the CSA_{min} was located, the anteroposterior dimension and lateral dimension of CSA_{min} were measured in sagittal and coronal sections respectively by the observer.

2.3. Data management and analysis

1. Data collected was sorted and categorised based on the parameters recorded.
2. Data was analyzed using descriptive statistical methods (Table 3). Parameter-wise percentage tables were used to present the data.
3. Frequency analysis was done by using Statistical Package for social sciences (v.21.0).
4. Data were analyzed using Correlation analysis by Cronbach's Alpha.

3. Results

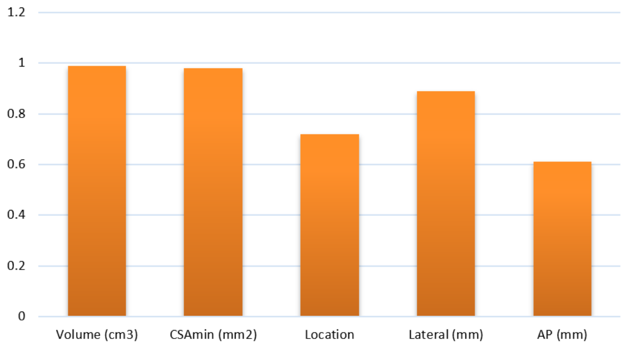
Cronbach's Alpha of interobserver reliability of the anatomic landmark localization (Table 4) and of three-dimensional upper airway measurements are shown in (Table 5). The internal consistency of Cronbach's Alpha used for reference is shown in (Table 6). Interobserver reliability of the landmark localization was excellent (0.97-0.99) (Graph 1). Similar results were found for the upper airway measurements, where in interobserver reliability of the upper airway measurements were good (0.62-0.99) (Graph 2).



Graph 1: Graphical representation of interobserver reliability of anatomical landmarks

4. Discussion

Assessment of lateral and frontal cephalograms has allowed dentist to observe possible upper airway obstructions. However, measurements in the only coronal or sagittal plane are not precise, the rationale to this is attributed to a two-dimensional representation of complex three-dimensional structures.[10] CBCT is playing an important role for recording three dimensional structures of Oral and Maxillofacial regions and gaining increasing role in the diagnosis of morphologic abnormalities.[11] There are currently more than 15 third-party DICOM viewers for oral and maxillofacial radiology[12], in our study Planmeca



Graph 2: Graphical representation of interobserver reliability of three-dimensional measurements of the upper airway

ProMax3D Mid Proface CBCT unit was used for scans and measurements were done with software viewer Romexis version 4.2.0 R 10/13/15 was used. Currently, there is no normal value for airway volume or any other three-dimensional measurement, the reason for this perhaps because the airway volume is extremely variable, depending on head posture, breathing stage and tongue position.[13] And these values may also vary on different software.

In a study conducted by Hakan El et al, reliability and accuracy of 3 DICOM viewers (Dolphin3D, InVivoDental and OnDemand3D) were compared and they were highly reliable in their airway volume calculations and showed high correlation of results but poor accuracy, suggesting systematic errors.[13] Similarly, in a study conducted by Kamaruddin N et al, no significant difference was found between Invivo5 and Romexis and excellent intrarater reliability values were found for the both measurement on both software.[14]

In our study reliability of CBCT was evaluated between two observers using Romexis version 4.2.0 R 10/13/15. Although CBCT does not have the same excellent soft tissue contrast as magnetic resonance imaging, in our study it was shown that the inter-observer reliability of anatomic landmarks localization and overall, three-dimensional upper airway measurements were good.

After localization of anatomic landmarks relevant to upper airway analysis (0.99 - excellent internal consistency), three dimensional measurements for the same was performed by both the observers. The internal consistency came out to be excellent for volume measurement (0.99), excellent for minimum cross-sectional area (0.98), good for Lateral minimum cross-sectional area (0.8), acceptable for Location of minimum cross-sectional area (0.7) and questionable for anteroposterior minimum cross-sectional area (0.6). However, the overall inter observer reliability is good for all the three-dimensional measurements in upper airway.

Table 3: Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	22	19.00	70.00	29.7727	14.11494
Volume for Observer 1	22	4.50	27.00	13.1909	5.70187
Volume for Observer 2	22	5.30	26.30	13.1727	5.51251
CSA_{min} for Observer 1	22	117.00	774.00	348.0455	187.20716
CSA_{min} for Observer 2	22	116.00	765.00	349.9091	180.23474
Location of CSA_{min} (mm) for observer 1	22	8.00	158.00	70.9545	51.37674
Location of CSA_{min} (mm) for observer 2	22	16.00	154.00	78.2727	43.03175
Lateral CSA_{min} (mm) for observer 1	22	8.00	32.80	18.7545	6.35158
Lateral CSA_{min} (mm) for observer 2	22	7.60	28.00	17.5727	5.24715
Antero-posterior CSA_{min} (mm) observer 1	22	1.60	17.20	5.7955	3.35552
Antero-posterior CSA_{min} (mm) observer 2	22	1.80	9.60	5.5318	2.25840
Valid N (listwise)	22				

Table 4: Interobserver reliability of anatomical landmarks of upper airway

S. No.	Anatomical Landmarks	Interobserver reliability
1	PNS	0.99
2	ANS	0.99
3	AICV	0.98
4	TUV	0.97
5	TEP	0.99
6	BEP	0.99

Table 5: Interobserver reliability of three-dimensional measurements

S. No.	Three dimensional measurements	Interobserver reliability
1	Volume (cm^3)	0.99
2	CSA_{min} (mm^2)	0.98
3	Location	0.72
4	Lateral (mm)	0.89
5	AP (mm)	0.61

Table 6: The internal consistency of Cronbach's alpha

Cronbach's alpha	Internal Consistency
$\alpha > 0.99$	Excellent
$0.9 > \alpha > 0.8$	Good
$0.8 > \alpha > 0.7$	Acceptable
$0.7 > \alpha > 0.6$	Questionable
$0.6> \alpha > 0.5$	Poor
$0.5 > \alpha$	Unacceptable

A study carried out by Souza, K. R. S. de et al. showed excellent volume measurements and Oropharyngeal CSA_{min}.[10] Similarly, a study carried out by Chen H. et al showed excellent interobserver reliability of the localization of the anatomic landmarks (ICC=0.97-1.00) and three-dimensional measurements of upper airway (ICC = 0.78-1.00).[9]

However, Mattos et al. in his study reported excellent internal consistency for volume measurements and not excellent internal consistency with CSA_{min} (0.86). CSA_{min} in this study is not consistent with our study. This difference may arise due to use of different software in different studies. Zimmerman J N (2016) et al conducted a systematic review on reliability of upper pharyngeal airway assessment using dental CBCT concluded moderate-to-excellent intra- and inter-examiner reliability for volume and minimum cross-sectional area.[15]

In our study, after localization of landmarks of the upper airway and formation of cube for measuring volume of upper airway, the calculation of the CSA of every axial slice was performed automatically, which made it appropriate to detect the CSA_{min} and measure its area. To determine the upper boundary of the upper airway ANS and PNS were used as landmarks. To define the lower boundary of the upper airway, the BEP (base of epiglottis) was used and to define posterior most boundary the antero inferior aspect of the vertebral body of the second cervical vertebra was used. Segmentation of upper airway essentially needs localization of these landmarks. Anatomical landmarks used in this study are taken from other studies.[7–9]

In respiratory phase, the position of the uvula can be influenced which possibly can bring inconsistent results during localization in all patients. In our study however, the reliability of overall three-dimensional measurements of upper airway were good, suggesting that the definition of the soft tissue landmarks applied in this study can be applied in future studies in a reliable way. Three dimensional measurements depend on localization of anatomical landmarks, if the localization of anatomical landmarks is reliable then the three-dimensional measurements are also reliable.

A high reliability for the volume measurements (0.99-1.00) of the upper airway was determined by two observers in our study, which is consistent with the results of other studies. Although the observers had different experiences with the use of the software in our study, they showed good interobserver reliabilities (0.80-0.99) in all of the measurements of the upper airway. However, only interobserver reliability was carried out in this study, interobserver reliability needs to be determined. Furthermore, standardization evaluation needs to be done as different software are being used in different studies for upper airway evaluation. Assessment of the reliability of upper airway measurements on same patients also needs to be carried out as shape of pharyngeal airway is affected by changes in head posture, tongue, epiglottis. This methodology can be in done future studies investigating role of upper airway morphology in pathogenesis of many breathing disorders. Standardization needs to be done as academicians of different fields (orthodontist, oral surgeons, ENT, oral maxillofacial radiologist) look at the airway in their own clinical perspectives during airway analysis.

5. Conclusion

Although CBCT does not have the same excellent soft tissue contrast as magnetic resonance imaging, the interobserver reliability for both anatomic landmarks and three-dimensional measurements of the upper airway using software viewer Romexis was excellent. The reliability of anatomical landmarks is excellent and reliability of three-dimensional measurements (volume, CSA_{min}, location, AP, Lateral) is moderate to excellent. Therefore, this methodology can be used for airway analysis in future studies using Romexis software. However, there are certain limitations mentioned in this study that needs to be carried out to adequately determine the reliability of upper airway assessment using CBCT.

6. Source of Funding

None.

7. Conflict of Interest

None.

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