Original Article

pISSN, eISSN 0125-5614
M Dent J 2023; 43 (Suppl) : S37-S46

Effect of threshold configuration on accuracy in upper airway analysis using cone-beam computed tomography

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Objective: To determine the optimal threshold of Romexis software for the airway volume and minimum cross-sectional area (MCA) analysis using imageJ as a gold standard.

Materials and Methods: A total of ten CBCT images were collected. The airway volume and MCA of each patient were analyzed using the automatic airway segmentation function in the CBCT DICOM viewer (Romexis). Airway volume and MCA measurements were conducted on each CBCT sagittal view with fifteen different threshold values from the Romexis software, ranging from 300 to 1000. Duplicate DICOM files, in axial view, were imported into ImageJ for concurrent airway volume and MCA analysis as the gold standard. The airway volume and MCA measured from Romexis and ImageJ were compared using a t-test with Bonferroni correctio, and statistical significance was set at *p*<0.003.

Results: Concerning airway volume, thresholds of 600 to 850, as well as 1000, exhibited results that were not significantly distinct from those obtained through ImageJ. Regarding MCA, employing thresholds from 400 to 850 within Romexis Viewer showed no variance from ImageJ. Notably, within the threshold range of 600 to 850, there were no statistically significant differences observed in both airway volume and MCA analyses, in comparison to ImageJ.

Conclusion: This study demonstrates that the utilization of Planmeca Romexis Viewer 6.4.3.3. within the threshold range of 600 to 850 yields airway volume and MCA measurements that exhibit no statistically significant variance in comparison to measurements obtained through ImageJ. This outcome holds implications for diagnosing upper airway obstructions and post-orthodontic surgical monitoring.

Keywords: airway analysis, airway segmentation, cone-beam computed tomography, threshold, upper airway

How to cite: Fahham S, **Ngamsom S**, Pornprasertsuk-Damrongsri S. Effect of threshold configuration on accuracy in upper airway analysis using cone-beam computed tomography. M Dent J 2023;43(Suppl):S37-S46.

Introduction

The upper airway, connected to the nasal and oral cavities, is crucial for breathing, speaking, and swallowing [1, 2]. It is divided from superiorly to inferiorly into nasopharynx, oropharynx, and hypopharynx [1-4]. The upper airway comprises soft tissue and bony structures. These include a number of muscles, lymphatic tissue, the pharyngeal fat pat, tongue, soft palate, and the hyoid bone that surround the airway walls [3]. Several procedures or treatments can affect the upper airway dimension. Additionally, many patients are treated for obstructive sleep apnea by using an oral appliance or undergoing mandibular advancement surgery. These may lead to interest among dentists in the shape and dimensions of the upper airway. Studies on upper airway analysis have been published using several imaging modalities, including conventional multidetector CT (MDCT) [5], magnetic resonance imaging (MRI)[6], cine-MRI [7], endoscopy [8], optical coherence tomography [9], and cone-beam computed tomography (CBCT) [10, 11].

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Received: 17 August 2023 **Revised:** 22 September 2023 **Accepted:** 24 September 2023

CBCT has limitations in assessing the upper airway space due to poor soft tissue contrast; however, its accessibility, high resolution, and low radiation dose have established it as a valuable modality. Previous studies have explored various clinical aspects such as upper airway evaluation in normal and obstructive sleep apnea patients, correlations between the upper airway and dentomaxillofacial morphology, and sinus anatomy assessment [10]. The accuracy and reliability of CBCT's DICOM viewer have been assessed by comparing it with various imaging modalities. Aboudara *et al.* conducted a study on adolescents, comparing nasopharyngeal airway space and volume between lateral cephalometric and 3D CBCT scans, they found a significant positive correlation between airway size on lateral cephalometric and CBCT scans [12]. Yamashina *et al.* evaluate the reliability of CBCT values and dimensional measurements of oropharyngeal air spaces compared to MDCT. Although the CBCT values of air, water, and soft tissue markedly differed from the Hounsfield unit values, the measurement of the air space surrounded by soft tissue was accurate [13]. Thus, CBCT is an effective method for analyzing the airway.

The research also compares commercial CBCT's DICOM viewer with third-party software for DICOM image post-processing. Kamaruddin *et al.* found no significant differences in measuring upper airway volume and minimum area between two CBCT's DICOM viewers [14]. These studies affirm the accurate measurement of airway volume and minimum cross-sectional area (MCA) by CBCT in routine applications, potentially aiding the assessment and treatment of diverse airway disorders.

Regarding CBCT software's automatic airway segmentation, airway outlines are located by distinguishing air and surrounding soft tissue densities. Some software requires manual threshold adjustment by an operator to control airway filling. For example, the Dolphin software offers a threshold range of 0 to 100. Previous studies evaluated the airway volume using the Dolphin software with various thresholds [5, 15-17]. Alves and colleagues found the most accurate threshold value for measuring airway volume using Dolphin 3D software under specific experimental conditions. They tested eight different threshold values (25, 50, 70, 71, 72, 73, 74, and 75) and compared them with the actual volume of water filled in the airway prototype's entry space. According to the Dolphin 3D software results, the airway volume with a threshold of 73 closely matched the accurate volume, followed by thresholds 74, 72, 75, and 71, respectively [18].

In another CBCT software, Romexis, operators manually adjusted the threshold with a range of 0 to 1000 for the automatic airway segmentation function. In the previous literature, only one study measured the upper airway volume and minimum area using the Romexis version 3.8.2.R software, employing a set threshold of 300. The authors compared this with the automatic airway segmentation in Invivo 5 software (Anatomage) and found no significant differences in mean airway volume and MCA between the two [14].

Standardizing the threshold is crucial to ensure consistent airway volume measurements, as varying thresholds can yield different results. Measuring volumes with different thresholds might not accurately represent actual volumes, potentially rendering airway volume measurements from this software unreliable. Additionally, there is currently no established standard protocol for the automatic airway segmentation function in Romexis software. Therefore, this study aims to identify the most precise threshold value for airway analysis using the automatic airway segmentation function of Romexis viewer version 6.4.3.3. with imageJ as a gold standard.

Materials and Methods

This is a clinical experiment of airway analysis using the automatic airway segmentation function in the CBCT DICOM viewers. The protocol of this study was approved by the Institutional Review Board of the Faculty of Dentistry/ Faculty of Pharmacy, Mahidol University (COE.No.MU-DT/PY-IRB 2023/016.2504). Ten patients aged over 20 years were collected from the Oral and Maxillofacial Radiology Clinic, Faculty of Dentistry Mahidol University, Thailand. The inclusion criteria were the CBCT scans covering the airway from the infraorbital rim to the level of the third cervical vertebra. Patients with cleft palate, craniofacial syndrome, history of craniofacial surgery or trauma, or poor CBCT image quality such as motion-related and beam hardening artifacts obscuring the airway were excluded. The CBCT machine used was the Planmeca ProMax 3D Mid (Planmeca OY, Helsinki, Finland), and the scanning protocol included 120 kV, 5 mA, 21 x 17 cm field of view, 0.40-mm voxel size, and a scanning time of 40 seconds. The airway volume and MCA of 10 CBCT data were analyzed using Romexis viewer version 6.4.3.3 with fifteen thresholds ranging from 300-1000. Then, the DICOM files were imported into ImageJ to analyze the airway volume and MCA as the gold standard.

The sample size calculation was performed using the estimation of a finite population mean, as shown in the equation below [19, 20]:

$$n = \frac{(z_{1-\frac{\alpha}{2}} + z_{1-\beta})^2 \sigma^2}{\Delta^2}$$

The output of the sample size calculation from n4Studies:

For testing two dependent means (two-tailed test)

SD.(σ) = 107.96, Delta (Δ) = 138.00

Alpha (α) = 0.01, Z(0.995) = 2.575829

Beta (β) = 0.10, Z(0.900) = 1.281552

Sample size (n) = 10

The study of Alves *et al.* was used as the reference study [18].

Thus, the sample size (n) of the present study is 10 subjects.

Analysis of the airway volume according to the different thresholds:

Before measurement, CBCT images with the initial head orientation as the Frankfort horizontal plane parallel to the floor (0 degrees) in the sagittal view and the midline perpendicular to the floor (90 degrees) in the coronal view were selected. Then, the region of interest in the airway was defined by the airway analysis tool from the Romexis software. The superior border extended from the posterior point of the hard palate to the posterior wall of the pharynx and maintained parallelism to the Frankfort horizontal plane. The inferior border starts from the lowest point of the third cervical vertebra to the anterior wall of the pharynx and is also aligned parallel to the Frankfort horizontal plane (Figure 1). For all 10 subjects, the airway volume and MCA from each CBCT image were measured with fifteen values of the threshold tool from the Romexis software's tool. The threshold values tested were adjusted at 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, and 1000 respectively (Figure 2). The airway volume and MCA were obtained twice by the same observer (SF) using the same monitor one week after the initial measurement.

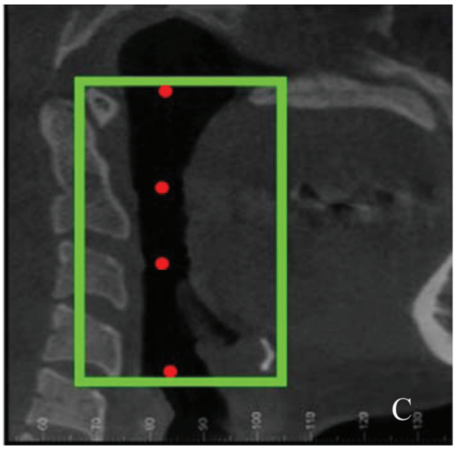

Figure 1 Showing the superior and inferior borders of the upper airway, the airway measurement was performed in a sagittal view by vertically positioning the marker (red dot) at the centre of the airway.

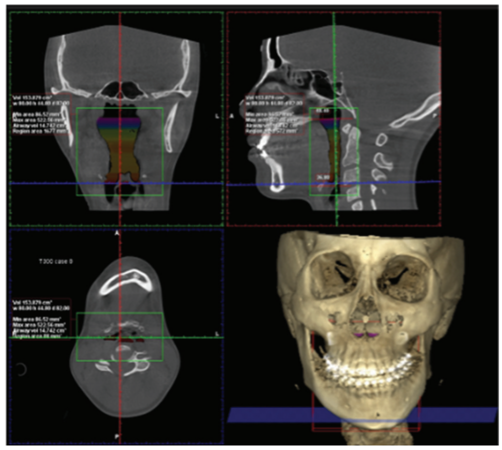

Figure 2 Presentation of the Romexis software for airway volume measurement is shown at threshold 300 of Case No. 8

The measurement of airway volume using the ImageJ software

The duplicated DICOM files, captured in the axial view, of 10 subjects were exported. The exported DICOM files were configured with a slice thickness of 0.4 mm, and the voxel size was set at 0.4 mm^3. DICOM files of the same patients were imported to ImageJ. The region of interest of the airway was drawn on axial view in every 10-slice interval with slice interpolate function. The region of interest was re-confirmation and adjustment in every slice. The measurement of the airway volume and the MCA in ImageJ were performed using the analysis tool within the ImageJ software (National Institutes of Health, Bethesda, Maryland, USA) [21]. The outcome derived from the ImageJ software served as the gold standard [22] (Figure 3). The MCA represented the smallest cross-sectional area. The airway volume was calculated by the following equation:

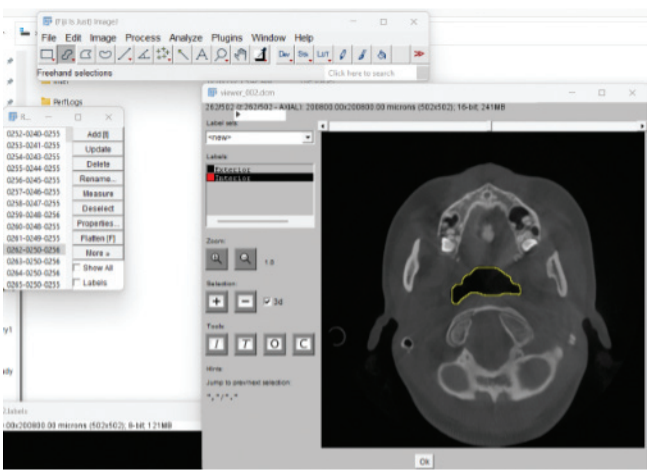

Figure 3 Display of the ImageJ (gold standard) software for airway volume measurement of case No.8. The results obtained from both Romexis and ImageJ were compared using a t-test with Bonferroni correction, and statistical significance was set at $p<0.003$.

Airway volume (cm^3) = Sum of cross-sectional area (mm^2) × slice thickness (mm) /1000

Results

For the airway volume analysis, the mean, standard deviation (SD), the outcomes of the t-test analysis, and the mean difference of airway volume across different thresholds for both software (Romexis Viewer and ImageJ) were shown in Table 1. Notably, significant differences in airway volume are observed on thresholds ranging from 300 to 550 and from 900 to 950, compared to ImageJ. However; no significant differences were found on the threshold from 600 to 850, and 1000 compared to ImageJ. Therefore, the airway volumes calculated using the thresholds 600 to 850, and 1000 in Romexis Viewer do not significantly differ from the gold standard (ImageJ) after Bonferroni correction (p<0.003).

Table 1 The comparison of airway volume between ImageJ and Romexis in different threshold levels

Thresholds	Airway volume (cm^3) mean (SD)	Paired differences mean (SD)	t	*p*-value
ImageJ	16.42 (4.62)			
Romexis				
300	11.01 (3.50)	5.41 (2.49)	6.869	<.001
350	12.35 (3.55)	4.07 (1.95)	6.586	<.001
400	13.28 (3.69)	3.15 (1.55)	6.421	<.001
450	13.90 (3.84)	2.52 (1.31)	6.090	<.001
500	14.43 (3.95)	1.99 (1.16)	5.399	<.001
550	14.88 (4.08)	1.54 (1.05)	4.665	.001
600	15.26 (4.18)	1.16 (.98)	3.749	.005
650	15.65 (4.27)	.77 (.94)	2.611	.028
700	16.04 (4.31)	.38 (.94)	1.290	.229
750	16.44 (4.43)	-.02 (.91)	-.056	.957
800	16.87 (4.51)	-.45 (.92)	-1.536	.159
850	17.46 (4.57)	-1.04 (1.05)	-3.119	.012
900	18.39 (4.47)	-1.97 (1.38)	-4.490	.002
950	20.08 (4.66)	-3.66 (2.39)	-4.837	.001
1000	22.55 (5.88)	-6.13 (5.33)	-3.638	.005

standard deviation (SD)

For the MCA analysis, the mean and SD, the results of the t-test analysis, and the mean difference in MCA across different thresholds for both software applications are shown in Table 2. There were significantly

different MCA values on the thresholds 300 and 350 as well as from 900 to 1000 compared to ImageJ. However; on the thresholds 400 to 850, there were not significantly different results compared to ImageJ. Therefore, the MCA using thresholds 400 to 850 in Romexis Viewer is not different from the gold standard (ImageJ) after Bonferroni correction ($p<0.003$).

Hence, when using thresholds ranging from 600 to 850 in the Romexis viewer, both airway volume and MCA analyses closely align with the gold standard as determined by ImageJ, revealing no significant differences.

Table 2 The comparison of the minimum cross-sectional area (MCA) between ImageJ and Romexis in different threshold levels

Thresholds	MCA (mm^2) mean (SD)	Paired differences mean (SD)	t	*p*-value
ImageJ	196.66 (67.10)			
Romexis				
300	113.46 (47.00)	83.20 (49.11)	5.357	<.001
350	145.63 (50.94)	51.03 (33.36)	4.836	.001
400	162.92 (52.04)	33.74 (26.49)	4.027	.003
450	175.20 (54.29)	21.46 (24.78)	2.739	.023
500	185.27 (55.70)	11.38 (24.34)	1.479	.173
550	194.07 (57.18)	2.59 (24.95)	.328	.750
600	203.68 (58.93)	-7.03 (29.38)	-.842	.422
650	210.57 (59.79)	-13.92 (28.23)	-1.559	.153
700	218.87 (60.43)	-22.21 (30.53)	-2.300	.047
750	226.91 (62.00)	-30.26 (32.21)	-2.970	.016
800	235.47 (63.74)	-38.82 (35.08)	-3.499	.007
850	243.99 (64.95)	-47.34 (37.34)	-4.008	.003
900	257.36 (63.97)	-60.71 (39.64)	-4.843	.001
950	276.53 (61.25)	-79.87 (44.42)	-5.686	.000
1000	301.86 (67.53)	-105.20 (65.81)	-5.055	.001

standard deviation (SD)

Discussion

In this study, the commercially available CBCT software program, Planemeca Romexis viewer, which uses automatic segmentation to calculate airway volume and MCA was tested using different threshold settings. From the t-test analysis, the *p*-value of <0.003 for both measurements indicates a significant difference. The present study reveals that when using the thresholds 600 to 850 in Romexis viewer, both airway volume and MCA analysis do not exhibit significant differences from the gold standard using ImageJ.

The present study had some limitations in airway measurement methods. The measurement obtained from the Romexis software slightly differs from the Image because these two software programs do not use the same methods for the calculation of the airway volume and MCA. Romexis performs segmentation based on the sagittal view, while Image J carries out airway segmentation using the axial view. On the other hand, due to just accessing the axial view in ImageJ software for the measurement, to define the superior and the inferior borders, the CBCT slices which were very similar to the superior and the inferior borders on the Romexis axial views were used as our reference. The difference in image plane might give a slight variation in the measurement of both software.

For the achievement of more accurate results in ImageJ, a-10 slice interval was applied for each case, accompanied by the reaffirmation of the airway outline in each slice, and the threshold range for ImageJ (approximately 35-50) was carefully set to accurately represent the airway space. In contrast, Romexis offers users the easy-to-adjust thresholds within a wide range of 0-1000.

The automatic segmentation of the airway imaged using CBCT is a feasible method for evaluating the airway volume and MCA. Compared to lateral cephalogram, Lenza *et al.* reported a weak correlation between most linear measurements in sagittal and transversal dimensions and cross-sectional area with a partial volume between CBCT and lateral cephalogram. Moreover, CBCT gives more details about the anatomical characteristics of the upper airways, leading to improvement in the diagnosis [23].

Ghoneima & Kula suggested that the three-dimensional CBCT digital measurements of the airway volume and the most constricted area of the airway are reliable and accurate. The use of CBCT imaging for airway assessment can provide clinically useful information in orthodontics and for assessing the airway after surgery [24]. This is proved by Alsufyani *et al.,* who concluded that the use of point-based analysis (from 3D CBCT) better explains the changes in clinical symptoms compared to conventional measures [25]. Yamashina *et al.* evaluated the reliability of CBCT values and dimensional measurements of oropharyngeal air spaces as compared to multidetector CT on phantoms and clinical patients, they found that air space measurements with CBCT were quite accurate [13].

The automatic airway segmentation in Romexis software calculates the airway volume and defines the MCA by placing the marker at the airway vertically in sagittal view and adjusting the threshold. The software generates the green box to define the region of interest. Then all the air space in the region of interest is generated, corresponding to the threshold. The false positive air space may occur from the patient's tongue position specially when the tongue is placed on the floor of the mouth, leading to the air space in the oral cavity. Another limitation is the oblique margin at the superior and inferior border of the calculated airway volume. The oblique margin is related to the curvature of the airway when setting 3-5 points on the centre of the sagittal view from the superior to the inferior borders and results in over-calculating the airway volume that exceeds the defined superior and inferior border in this study. The previous study by Kamaruddin *et al.* compared the airway volume and MCA between two CBCT software using Romexis (version 3.8.2) with the threshold setting at 300 and Invivo5. They reported no significant difference in both airway volume and MCA [14]. The study of Kamaruddin *et al.* study had been compared between two automatic segmentation software, in contrast with the present study, which had been compared between automatic airway segmentation (Romexis) and manual airway segmentation (ImageJ) as a gold standard. In ImageJ, the region of interest of the airway segmentation was performed in every 10 slices interval. In addition, the region of interest was confirmed and adjusted in every slice to reduce the errors. Although, the latest Romexis version (version 6.4.3.3) was defaulted at threshold 500 ranging from 0 –1000. The automatic airway segmentation method is an easy and fast method for airway measurement that can be applied in various treatments such as pre- and post-operative evaluation for mandibular advancement surgery. The present study, using Planmeca Romexis viewer (version 6.4.3.3), showed that the threshold ranges from 600 - 850 were not significantly different from the gold standard for both airway volume and MCA. From the present study, we suggest the clinicians adjust the threshold in the range of 600 – 850 to achieve accurate results for both airway volume measurement and MCA measurement. Additionally, tongue position can affect airway volume measurement. Patient preparation before taking CBCT is important, and the patient should be informed to place the tongue at the posterior area of the oral cavity during taking CBCT to avoid false positive results from the space within the oral cavity.

Conclusion

From this study, the Planmeca Romexis Viewer (version 6.4.3.3) has demonstrated no significant difference in airway volume and MCA measurement when using thresholds ranging from 600 to 850, as compared to those measurements using ImageJ.

Acknowledgments

Special thanks to all staff involved from Mahidol University Dental Clinic for their cooperation and support.

Funding sources:

None

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