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Research Article

Important Queries for the Airway Analysis in CBCT Scans: Threshold Tool and Voxel Size Protocol

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Abstract

Introduction: The purpose of this study was to analyze the threshold tool presented in post-processing software for airway volume estimation and the influence of voxel size in these measurements. 316-selected CBCT scans (0.2, 0, 25 and 0.4 voxel sizes) were retrospectively analyzed. A trained and calibrated examiner performed the volume measurements in specific sites in upper airway at 25 and chosen threshold tool using the Dolphin Software. ANOVA was used to compare the thresholds values for each voxel group and the differences of means between the preset and the chosen thresholds, while paired samples t-Test to compare differences between the chosen thresholds for voxel size groups.

Results & Discussions: The threshold values range from 26 to 43. The mean of the threshold tool value selected for voxel 0.4 was significantly lower than the mean thresholds of voxel 0.2mm to 0.25mm. As expected, small volumes were obtained with the preset threshold tool for all voxel sizes groups when compared with the chosen threshold. The mean of differences in volumes between preset and chosen threshold decreased with the increase of voxel size. The voxel size protocol influenced the threshold value choice for volume measurements in upper airway analysis. Using Dolphin Software, the thresholds near to 30 seems better filling the airway space. Thus, more studies must be performed to define scan protocols and thresholds parameters for airway evaluation.

Keywords: Dentistry, 3 d imaging, Software tool, Cone beam ct, Upper airway

Introduction

The expansion of Cone-Beam Computed Tomography (CBCT) yielded multiples benefits for dental and maxillofacial diagnosis [1-6]. In addition to hard tissues analysis, CBCT scans allow the visualization of soft tissue boundaries and airway spaces. Besides linear and area measures, some software offers a specific tool for the airway reconstruction and evaluation. This semiautomatic segmentation permits the users to determine the region of interest and adjust image threshold, according to the visual perception, which expands or reduces the software sensitivity to fill the airway space and result in estimated volume. Some researchers have shown controversial results about the consistency when evaluating airway estimation tools, as well as the phantom utilized [7-11].

For cephalometric and airway analysis, a large Field Of View (FOV) is frequently chosen to include all regions of interest. Usually, bigger voxel sizes are selected for large FOV's because it requires less scan and reconstruction time, and therefore less radiation for the patient; however, larger voxel sizes reduce spatial resolution [9,12,13]. In this view, it is essential to understand the way an image threshold tool and scan protocol can influence volume measurements. Thus, the aim of this study was to analyze the threshold tool presented in post-processing software for airway volume estimation and the influence of voxel size in this process.

This research protocol was approved by the Ethics Committee in the Federal University of Rio Grande do Sul (n 25300). The images used in this study were obtained from a database. The study sample consisted of 316 scans. The inclusion criteria were scans acquired with large field of view (FOV). All CBCT images were obtained with ani-CAT (Imaging Sciences International, Hatfield, Pa) as part of the diagnostic records for clinical patients. The scans were acquired as follows: 250 scans with 0.2mm voxel size, protocol (scanning protocol: 120 kV, 5 mA, 13X17cm field of view, scanning time of 40 seconds); 30 scans with 0.25mm voxel size (scanning protocol: 120 kV, 5 mA, 13X17cm field of view, scanning time of 40 seconds) and 36 scans with 0.4mm voxel size (scanning protocol: 120 kV, 5 mA, 13X17cm field of view, scanning time of 20 seconds).

All images were evaluated using the "airway tool" available on Dolphin 3D software (version 13.8, Dolphin Imaging & Management Solutions, Chatsworth, California).

Intra and inter-examiner calibration [L.S.M. and M.B.V.] were performed for volume measures (ICC > 0.9) and threshold choice. The scans were analyzed by one calibrated examiner [L.S.M].

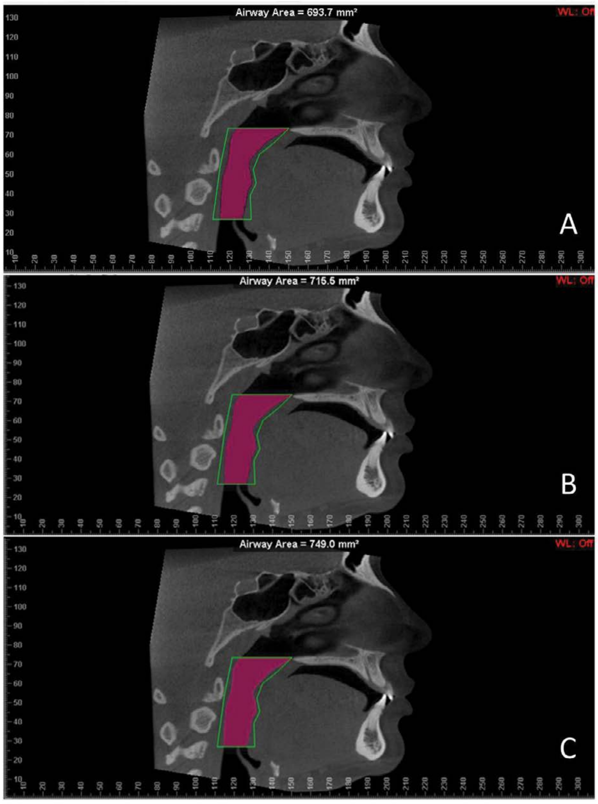

Figure 1: Borders definition to measure the oropharynx volume using the threshold tool in Dolphin Software: (A) 25 preset threshold, (B) chosen threshold [35 in this scan] and (C) 70 threshold value.

Before the measurements, the subject's head was aligned with the midsagittal plane perpendicular and the palatal plane parallel to the ground. The airway limits were defined: anterior border, a vertical plane from the posterior nasal spine (PNS) through up to skull basis, and the inferior border was a horizontal plane (parallel to ANS-PNS) at the superior point of the epiglottis. The volume from each CBCT image was calculated with two values of the threshold tool from Dolphin software: a preset sensitivity of 25 (available when the airway tool opens) and a sensitivity chosen by the examiner as the most compatible for the optimal filling of each airway space in the multiplanar analysis (Figure 1).

The statistical analysis was computed using SPSS software (version 17.0; SPSS, Chicago, Illinois). The mean and range for airway volume were calculated for each voxel and threshold used. Analysis of variance (ANOVA) was used to compare the thresholds values for each voxel group. Paired Samples t-Test was used to compare differences between the chosen thresholds for voxel size groups. The level of statistical significance was $P<0.05$. ANOVA Welch analysis, complemented by Bonferroni post-hoc test ($P < 0,000$) was used to compare the mean of differences among the voxel size groups.

Results and Discussions

Table 1 shows the frequency, percentages, quartiles, and median values for the chosen thresholds for each voxel size. The median of the chosen threshold increased as the voxel size of the image decreased. Table 2 shows that the mean of the threshold value selected for voxel 0.4 was significantly lower than the mean thresholds of voxel 0.2mm to 0.25mm. Table 3 shows mean and range for total airway volume calculated with preset and chosen thresholds in each voxel size. A paired Samples t-Test indicated statistically small volumes obtained with the preset threshold for all voxel sizes studied, when compared with the chosen threshold. Table 4 shows the mean difference between the chosen and preset threshold, indicating that the values decrease with the increase of voxel size.

The use of CBCT increases in dentistry, but specified protocols for airway analysis are not well established [3,5,14-18]. Some studies evaluated the airway space using various software and tools to calculate the volume. El and Palomo [7] evaluated three commercially available software packages: Dolphin3D (Dolphin Imaging & Management Solutions,

0.2mm voxel size			0.25mm voxel size			0.4mm voxel size		
Threshold	Frequency	Percent	Threshold	Frequency	Percent	Threshold	Frequency	Percent
26	0	0	26	0	0	26	6	16.7
27	18	7.2	27	3	10	27	*14	38.9
28	29	11.6	28	5	16.7	28	10	27.8
29	48	19.2	29	8	26.7	29	4	11.1
30	49	19.6	30	3	10	30	1	2.8
31	40	16	31	10	33.3	31	1	2.8
32	35	14	32	0	0	32	0	0
33	24	9.6	33	0	0	33	0	0
34	4	1.6	34	1	3.3	34	0	0
35	2	0.8	35	0	0	35	0	0
43	1	0.4	43	0	0	43	0	0
Total	250	100.0		30	100.0		36	100.00

Bold = percentiles 25. 50 (median) and 75. * Percentile 25 and 50

Table 1: Frequency, percentages and median for thresholds selected in airway volume measures.

Chosen Thresholds						
	Voxel	**Mean**	**SD**	**SE**	**Minimum**	**Maximum**
0	2	30	244 **A** 1	9941 0	126127	43
0	25	29	567 **A** 1	6121 0	294327	34
0	4	27	528 **B** 1	1585 0	193126	31

Different letters in same column indicate statistical difference tested under ANOVA and Bonferroni Test (*P* < 0.05)

Table 2: Comparison of chosen thresholds among the voxels protocols analyzed in this study.

	0.2 voxel size	**0.25 voxel size**	**0.4 voxel size**
Mean and range for 25 threshold	19602.8 (7444.3 –59056.30) **A**	21698.90 (11768.40 –34867.20) **A**	22845.98 (12491.70 –42969.70) **A**
Mean and range for chosen threshold	20637.65 (7990.70 –60105.10) **B**	22626.31(12097.80 –36032.00) **B**	23396.33 (13042.70 –43994.00) **B**

Different letters in same column indicate statistical difference tested under Paired Samples t Test (*P* < 0.05).

Table 3: Upper airway volume and range (mm^3) in each voxel size group for preset (25) and chosen threshold.

Voxel size	**Mean of differences**		**Minimum of differences**	**Maximum differences**	**SD**
0.2	1034.84 **A**		109.4	4059	564.48
0.25	927.41	A	226.3	2734.1	516.72
0.4	550.35	B	127.9	2119	359.10

Different letters in same column indicate statistical difference tested under Welch complemented by Bonferroni test (*P* < 0.000).

Table 4: Upper airway volume (mm^3) and standard deviation (SD) in each voxel size group for preset (25) and chosen threshold.

Chatsworth, Calif), InVivoDental (Anatomage, San Jose, Calif), and OnDemand3D (CyberMed, Seoul, Korea) and showed that the Dolphin 3D presented high reliability, but poor accuracy. The authors also noted that the software exhibited inconsistencies within themselves. Since the gray values on CBCT images do not correspond to the Hounsfield units from multi-slice CT, it is not possible to perform image estimation according to each tissue. Therefore, to adjust soft tissue boundaries all voxels are put together and its gray values are used to render the surface disclosure [19].

Yamashina et al. [10], using VGStudio MAX1.2.1 software evaluated the reliability and accuracy of CBCT using a phantom to measure the air, water, and soft tissues density and concluded that the measurement of the airway volume was accurate. In our study, all images were analyzed using Dolphin software, which is widely used and provides a specific airway tool for area and volume estimations. To access the airway analysis, a semiautomatic segmentation is presented, in which the user should establish the soft tissue borders and then locate the seed points into the airway space. A threshold tool is available, so the examiner can change the airway space filling degree according to visual inspection. Since there is no standard protocol for these instruments and measurements [8,14,20-22], the calibrated observer calculated with the preset (25) and the best value that visually could fill the airway borders.

Alves Junior et al. [8], aimed to determine the most accurate threshold value for airway volume quantification based on an airway prototype. The authors evaluated different threshold values and suggested that the volumes measured with the threshold of 25 and 50 had statistically significant differences from the gold standard, and volumes measured with values from 70 to 75 showed no statistical differences from the gold standard and among them. The best thresholds values of this research ranged between 26 and 43 - median of 30, 29 and 27 for 0.2mm, 0.25mm and 0.4mm voxel sizes respectively – diverging from the former study. In this research, a threshold of 70 or more clearly trespassed the soft tissues boundaries and consequently the measurements were discarded. Our results showed statistical differences between the volume using the minimum value of threshold (25) and the observer chosen value, thus suggesting that maintenance of the preset threshold may underestimate the airway size. Also, increasing the threshold resulted in an increased airway volume measured. This study has a limitation that there isn't a gold standard to determine the ideal threshold number for each voxel protocol, but on the other hand, the authors examined a huge number of patient's complementary exams in contrast to a phantom.

The benefits and risks when requesting a CBCT scan should always be considered [5,14]. Evidence-based guidelines for radiation protection outline rules for justification and optimization of CBCT exposures suggest individual protocols for different clinical situations. For orthodontics, the committee states "research is needed to define robust guidance on clinical selection for large volume CBCT in orthodontics, based upon quantification of benefit to patient outcome" [13]. In this sense, the voxel size determines the image resolution and should be selected according to the diagnostic task. Some protocols have a higher resolution (smaller voxel sizes), but also result in higher radiation exposure for the patient [13,20]. It is prudent that the least needed resolution should be used to reduce patient exposure to radiation. This study compared the airway volume acquired with three voxel resolutions – 0.2 mm, 0.25 mm, and 0.4 mm.

When the mean differences of preset and chosen values of thresholds were assessed, the differences decreased with the increase in voxel size suggesting that the threshold choice varies on the voxel size, and both play a role in the airway volume measurement.

In conclusion, for airway assessment when using Dolphin Software, the thresholds values near to 30 showed better filling to the airway space. Using the preset threshold is not recommended since it might underestimate the airway values. Moreover, the acquisition protocol, specifically the voxel size, influenced the threshold choice and volume assessment. In vitro studies, trying to simulate the airway borders in phantoms should be executed to define the protocols, and consequently, the airway tools parameters to evaluate the volume in CBCT.

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