AJO-DO

Is the airway volume being correctly analyzed?

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Introduction: The aim of the study was to determine the most accurate threshold value for airway volume quantification based on specific experimental conditions. **Methods:** Ten scans from the airway prototype were obtained by using cone-beam computed tomography. The volume from each scan was measured with 8 values (25, 50, 70, 71, 72, 73, 74, and 75) of the threshold tool from the Dolphin software (Dolphin Imaging and Management Solutions, Chatsworth, Calif). The gold standard method used was the actual volume of the airway prototype, which was compared with the different threshold values. An intraclass correlation coefficient test was applied to evaluate the intraexaminer calibration and verify differences among the airway volumes measured in all cone-beam computed tomography scans. Analysis of variance with the Tukey post-hoc test was used to compare differences among the measurements with different threshold values with the gold standard. **Results:** The intraexaminer reliability was confirmed by the intraclass correlation coefficient, which was ≥0.99. The intraclass correlation coefficient used to verify the differences among the airway volume measurements in all cone-beam computed tomography scans was ≥0.98, showing that they were comparable. Analysis of variance and the Tukey post-hoc test showed that the volumes measured with the threshold values of the 25 and 50 filters had statistically significant differences from the gold standard. However, volumes measured with the threshold values of the 70, 71, 72, 73, 74, and 75 showed no statistically significant differences from the gold standard and among them. **Conclusions:** In our study for the cone-beam machine and the acquisition parameters used, the threshold value of the 73 used in Dolphin 3D software was the most accurate to measure airway volume, but the threshold values of the 70, 71, 72, 74, and 75 had no statistically significant differences compared with the gold standard, showing they are also reliable. (Am J Orthod Dentofacial Orthop 2012;141:657-61)

Since the introduction of cone-beam computed tomography (CBCT) imaging in dentistry, several studies have evaluated airway volume with different 3-dimensional viewer softwares.[1-12] It was said that the use of CBCT technology for airway evaluation increases the accuracy and the reliability of the measurements.[2] This is because the resulting volumes from the digital data can be manipulated in the 3 axes (sagittal, coronal, and axial), selectively contrasted, emphasized, and reduced to visualize certain anatomic structures such as the airway.

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The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
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Submitted, July 2011; revised and accepted, November 2011.
0889-5406/$36.00

doi:10.1016/j.ajodo.2011.11.019

Yamashina et al[13] used a soft-tissue equivalent phantom to evaluate the reliability and accuracy of CBCT in measuring the density values of air, water, and soft tissues. They concluded that the measurement of the air space surrounded by soft tissues was quite accurate, and that the airway volume acquired from CBCT images is nearly a 1-to-1 representation of the real volume. However, El and Palomo[8] evaluated 3 commercially available softwares and showed that, in the Dolphin 3D Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, Calif), despite its high reliability, the accuracy was poor. That means that the measurements were overestimated or underestimated compared with the actual volumes. Although the Dolphin 3D software gives good control because it allows the user to increase or decrease the threshold value, that can be deceitful. Sometimes filling an empty space in the airway by increasing the threshold can result in overflow of the volume into another region.[8]

Threshold is a Dolphin tool that controls the filling degree of the airway. During airway space analysis, after

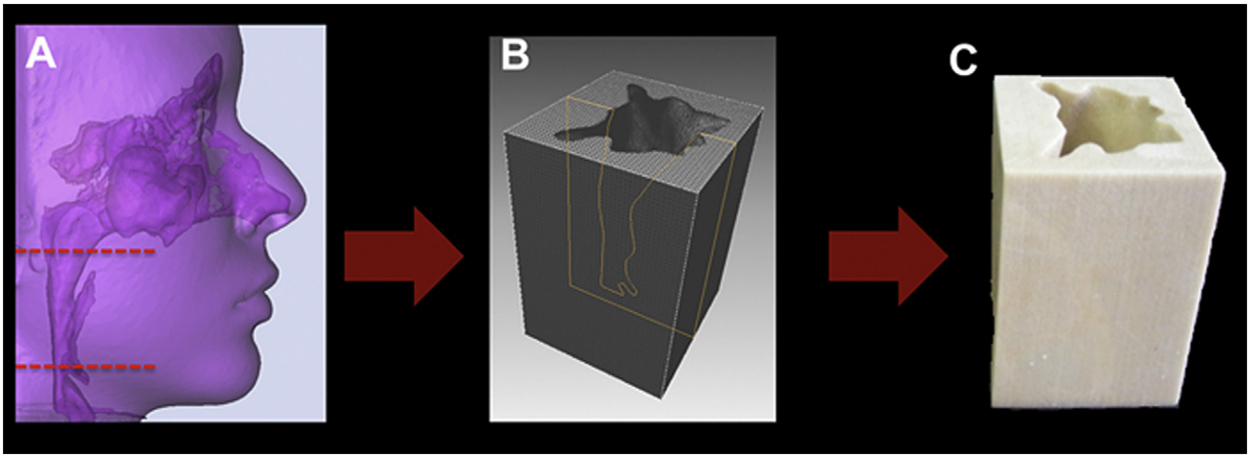

Fig 1. Mimics software images showing the process to create the oropharyngeal airway prototype: **A,** definition of the portion of the airway to be measured; **B,** 3-dimensional model of airway volume; and **C,** the prototype generated through the inverted threshold.

drawing the border around the selected portion, the operator chooses a threshold value, and then the software automatically fills in and displays all the airway space within that border. However, the results of airway volume can vary according to the threshold chosen.[8] Generally, the increase or decrease of the threshold results in a greater or smaller airway volume, respectively.

There is no standardization of the ideal threshold value to achieve the actual volume. Thus, the purpose of this study was to determine the most accurate threshold value for airway volume quantification based on specific experimental conditions.

MATERIAL AND METHODS

This study was revised and approved by the research ethics committee of the Institute of Collective Health Studies of the Federal University of Rio de Janeiro in Brazil.

Initially, to obtain the airway prototype, 1 CBCT scan was randomly selected from the archive at the Department of Orthodontics of Federal University of Rio de Janeiro. The CBCT machine used was the i-CAT (Imaging Sciences International, Hatfield, Pa), and the scanning protocol was 120 kV, 5 mA, 13 × 17 cm field of view, 0.25-mm voxel, and a scanning time of 40 seconds. Data were imported in the digital imaging and communications in medicine (DICOM) format and the 3-dimensional head rendering of each patient was oriented by using Mimics software (version 10.11; (Materialise Medical, Leuven, Belgium) by the same investigator (M.A.).[14,15]

Then the portion of the airway of interest was defined with a specific airway analysis tool from the Mimics software. The superior border was defined from the edge of the hard palate[5,8,12] to the posterior wall of the pharynx (parallel to the Frankfort horizontal), and the inferior border from the tip of the epiglottis to the posterior wall of the pharynx on a plane parallel to the Frankfort horizontal.[4,7,12] After updating the software, the airway volume was obtained. A set of axial images (matrix, 0.25 × 0.25 × 0.25-mm voxel) of the oropharyngeal airway was transformed into a 3-dimensional virtual model with the stereolithography native file extension.[16] A prototype was generated with this software through an inverted threshold, which created a negative airway model (Fig 1).

After that, 10 scans were obtained from the prototype in the same CBCT machine. Data were imported in the DICOM format and handled with Dolphin 3D software (version 11; Dolphin Imaging & Management Solutions). The scans were oriented, and the airway analysis tool of this software was used to obtain the airway volume (Fig 2). The volume from each CBCT image ($n = 10$) was measured with 8 values of the threshold tool from the Dolphin software. The threshold values tested were 25, 50, 70, 71, 72, 73, 74, and 75.

The gold standard method used to obtain the actual volume of the airway prototype was the volume of water necessary to fill the empty space of the prototype measured by high-precision micropipette of 2 to 20 μL (Tedia Pet, Fairfield, Ohio). This procedure was repeated 5 times, and a mean value was computed. This value was compared with the volume measurements obtained with different thresholds.

All measurements were done by the same operator (M.A.). Six CBCT images were randomly selected and remeasured within a 1-week interval. An intraclass correlation coefficient test was applied to evaluate the intraexaminer calibration. Furthermore, the intraclass

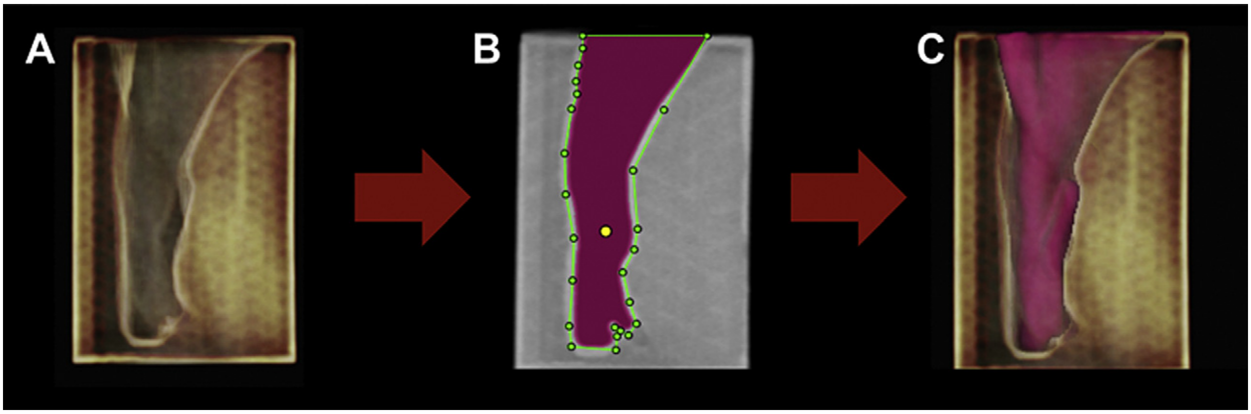

Fig 2. Dolphin 3D software showing: **A,** the prototype scan; **B,** definition of the portion of the airway from the prototype to be measured; and **C,** the airway volume generated.

correlation coefficient test was used to verify differences among the airway volumes measured in all CBCT images to evaluate whether they were comparable. Analysis of variance (ANOVA) with the Tukey post-hoc test was used to compare differences among the measurements with different thresholds and the gold standard, with $P < 0.05$ considered statistically significant.

All statistical analyses were performed by using the SPSS software (version 17.0; SPSS, Chicago, Ill).

RESULTS

The intraexaminer reliability was confirmed by the intraclass correlation coefficient, which was ≥0.99. The intraclass correlation coefficient used to verify the differences among the airway volume measurements in all CBCT images was ≥0.98, showing that they were comparable.

The mean value of the actual volume obtained directly from the prototype was 20514.16 mm^3 (±1.75). This was used as the gold standard value, with which the volumes from the various thresholds in the Dolphin software were compared. The Table shows the means and standard deviations for the volumes measured with each threshold and the gold standard.

The ANOVA and the Tukey post-hoc test results are shown in the Table. Volumes measured with the thresholds of 25 and 50 had statistically significant differences from the gold standard. However, the volumes measured with the thresholds of 70, 71, 72, 73, 74, and 75 showed no statistically significant differences from the gold standard and among them. The volume measured with threshold 73 was the closest to the gold standard, followed by the ones measured with the thresholds of 74, 72, 75, and 71 (Fig 3).

Table. Means and standard deviations for volumes measured with each threshold and for the gold standard (ANOVA and the Tukey post-hoc test were used to compare measurements with different thresholds with the gold standard)

Threshold values	*Mean (SD) (mm^3)*	*Tukey HSD post-hoc test**
25	11880.38 (1034.62)	A
50	18044.02 (154.30)	B
70	20121.10 (121.31)	C
71	20247.56 (115.05)	C
72	20376.24 (107.96)	C
73	20470.96 (112.39)	C
74	20572.52 (124.37)	C
75	20689.48 (123.86)	C
Gold standard	20514.16 (1.75)	C

*Different letters mean a statistically significant difference.

DISCUSSION

CBCT has been applied to evaluate differences in airway morphology and volume between subjects with various facial patterns,[3] oropharyngeal airways in Class III malocclusion children,[5] and differences in pharyngeal airway volumes between healthy children with retrognathic mandibles and those with normal craniofacial growth.[7] Different softwares were used in these studies—eg, InsightSNAP (version 1.4.0; Cognitica, Philadelphia, Pa),[3] INTAGE Volume Editor (KGT, Tokyo, Japan),[5] and InVivoDental (Anatomage, San Jose, Calif).[7] Because the Dolphin software is one of the most used in the United States, the purpose of this study was to determine the most accurate threshold value for airway volume quantification based on specific experimental conditions.

Haskell et al[4] used CBCT images to quantify the relationship between mandibular advancement with the

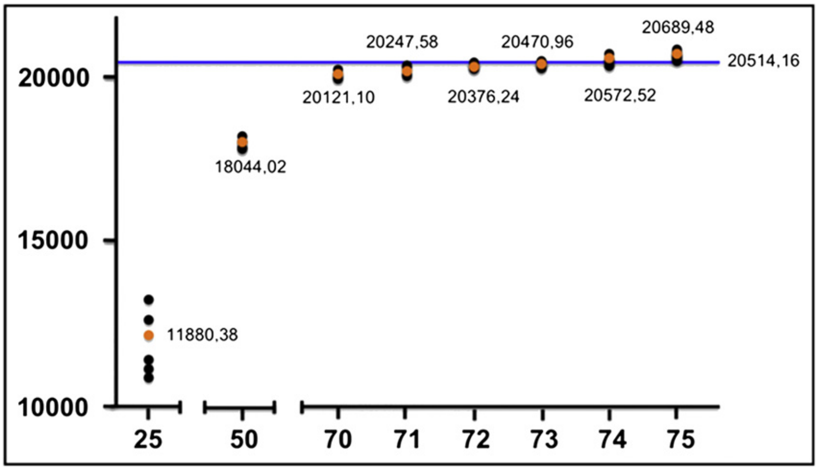

Fig 3. Comparison of the mean values of volumes measured with different thresholds (*orange circles*) to the mean values of volumes measured with the gold standard (*blue line*).

removable Herbst appliance and the resulting upper respiratory airway dimensions and volume, and concluded that oropharyngeal volume increased after using this device. Lohse et al[6] and Zinsly et al[9] showed the clinical applications of CBCT in addition to the diagnosis of possible physical barriers that can affect airway space. Iannetti et al[11] observed, also with CBCT images, an increase in the upper airway volume in patients who had LeFort II advancement. Alves et al[12] evaluated the pharyngeal airway space in nasal-breathing and mouth-breathing children using CBCT and suggested that the pharyngeal airway dimensions are greater in nasal breathers than in mouth breathers. However, although all of these studies used the Dolphin 3D Imaging software, different values of thresholds were used.[4,6,9,11,12]

There is no established protocol for the threshold that must be used when airway volume is measured with the Dolphin 3D software. Some authors who evaluated airway volumes with the Dolphin software used thresholds of 25,[9,12] 51,[8] and 52,[11] and others did not report it.[4,6] The standardization of the threshold value to achieve the airway volume is important because the use of different thresholds can result in different volumes. Since volumes measured with different thresholds might not represent the actual volumes, the comparisons among studies could become worthless if the same threshold was not used.

The automatic segmentation of the airway in the Dolphin 3D software is done by differentiating the densities between the airway and the surrounding soft tissues. Moreover, this automatic segmentation is not realized slice by slice, as in manual segmentation, and thus does not allow delineation of all the tortuous anatomy of the airway. Consequently, an increase of the threshold value can result in an overflow of the volume into the surrounding soft tissues, affecting the accuracy of airway measurements with CBCT. In our study, we preferred to use the prototype because the plastic resin has a different density compared with the soft tissues surrounding the airway. This produces more contrast between air and the resin surface, and therefore increases the accuracy of the measurements.

The threshold values tested in this study were 25, 50, 70, 71, 72, 73, 74, and 75. The choice of the threshold values of 25 and 50 was made because they had already been used in some studies.[8,9,11,12] The other threshold values of 70, 71, 72, 73, 74, and 75 were used in our previous pilot study, in which they had proved to be closer to the gold standard. Among all values simulated in the software, the threshold of 73 was the most accurate in relation to the gold standard. The thresholds of 70, 71, 72, 73, 74, and 75 did not have statistically significant differences to the gold standard (Table; Fig 3). The thresholds of 25 and 50, however, showed statistically significant differences compared with the gold standard and all other thresholds used (Table).

The reliability of all volume measurements was confirmed by the intraclass correlation coefficient of ≥0.99, showing that the operator was calibrated. This showed that any differences in the volume measurements were not attributed to operator error. A second intraclass correlation coefficient test was applied to discard potential differences in the method of obtaining the CBCT images as a confounding factor. The high concordance index (≥0.98) confirmed that the volume measurements of the 10 scans from the prototype were similar when the same threshold was used. To compare the reliability and accuracy of the 3 softwares (Dolphin 3D, InVivo-Dental, and OnDemand3D) in relation to the gold standard

(OrthodSegment software), El and Palomo[8] concluded that they were highly reliable but showed poor accuracy. In their study, the threshold used in the Dolphin 3D software was 51. According to our results, this value does not represent the actual volume and might cause underestimation of the volume, suggesting poor accuracy.

Some authors tested the reliability and accuracy by using a water displacement technique for comparing the CBCT volumes with actual volumes.[17] Because the Dolphin software allows the measurement only of the volume of empty areas, we used an inverted threshold to obtain the prototype, and the actual volume was measured with the aid of a micropipette of 2 to 20 μL. This micropipette allowed high-precision measurement of the actual volume of the prototype.

It seems that the scan protocol (milliamperes, kilovolts) can influence the voxels' gray scale and have an impact on the final volume, since the filling of the airway during the measurement is based on the differences in the gray intensity of the voxels. When the voxels' density is higher, for example, a higher value of sensitivity might also be required if real volume of the airway is desired. In our study, the threshold values obtained are applied to the scan protocol used in the CBCT (120 kV, 5 mA). More studies are required to assess the real effect of the scan protocol in the ideal threshold to be used.

The airway volume is extremely variable because it depends on head posture and breathing stage. However, if a protocol for the threshold value is followed when measuring airway volume, less variation in the results is expected. Our results suggest that accurate prototype airway volume can be obtained with thresholds between 70 and 75 with the Dolphin 3D software.

CONCLUSIONS

According to our results, accurate volume measurements were obtained during the evaluation of the airway prototype with the Dolphin 3D software when a proper threshold value was used. Based on the specific experimental conditions and the CBCT and acquisition parameters used in our study, the threshold of 73 was the most accurate to measure airway volume, but the thresholds of 70, 71, 72, 74, and 75 had no statistically significant differences in relation to the gold standard, showing that they are also reliable.

We thank the 3D modeling laboratory of the National Institute of Technology, Rio de Janeiro, Brazil, for technical support.

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