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# Assessing the validity of ITK-SNAP software package in measuring the volume of upper airway spaces secondary to rapid maxillary expansion

Mohammed Almuzian, Hind Mohammed Al Ghatam<sup>1</sup> and Lubna Al-Muzian<sup>2</sup>

## Abstract:

**INTRODUCTION:** The purpose of this study is to evaluate the validity of a free-access software package (ITK-SNAP) in segmenting and measuring the volume of upper airway spaces secondary to rapid maxillary expansion (RME).

**MATERIALS AND METHODS:** Sixteen participants who required RME were recruited for this study. Preoperative (T1) and 6-month postoperative (T2) cone-beam computed tomographic scans of all participants were analyzed. OnDemand3D software packages was used for superimposition and orientation of the images, while ITK-SNAP software was used to measure the volume of airway spaces. At week one (W1), all volumetric measurements were carried out by one examiner and repeated after 1 week (W2). Paired *t*-test, the interclass correlation coefficient, and Dahlberg coefficients of reliability were used to assess the reproducibility.

**RESULTS:** Student's *t*-test showed no significant difference between the W1 and W2 set of measurements ( $P > 0.05$ ). Coefficients of reliability were above 95% and intraclass correlation coefficient ranged from 0.99 to 1.000, which altogether confirmed the satisfactory reproducibility of the measurements.

**CONCLUSIONS:** ITK-SNAP software package is a reliable and cost-effective method to segment and measure upper airway changes subsequent to RME.

## Keywords:

Airway volume, ITK-SNAP software, maxillary expansion

## Introduction

The effect of rapid maxillary expansion (RME) on the upper airway spaces was first described by Brown,<sup>[1]</sup> and has subsequently been reported by Haas.<sup>[2]</sup> These effects can be gauged using nonradiographical objective tests such as Rhinomanometry and Acoustic Rhinometry (AR). The former represents a functional technique that provides a reading of airflow versus differential pressure in order to

assess the patency of the nasal cavity.<sup>[3]</sup> The hindrances of Rhinomanometry are that it necessitates wearing of a mask, while the measurements are being acquired,<sup>[4,5]</sup> inability to localize the site of the obstruction within the nasal passage<sup>[3]</sup> as well as unreliability in detecting small changes in nasal patency.<sup>[6]</sup> On the contrary, AR is based on the concept that changes in the acoustic impedance or the reflection of sound waves within the nasal cavity are proportionate to changes in a cross-sectional area.<sup>[3]</sup> Potential error might be developed if AR being

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Honorary Lecturer in Orthodontics, Department of Orthodontics, University of Sydney, Sydney, Australia,<sup>1</sup>Dental and Maxillofacial Centre, Royal Medical Services, Bahrain Defense Force, Wadi Alsail, Kingdom of Bahrain, <sup>2</sup>Department of Pediatric Dentistry, University of Edinburgh, Edinburgh, UK

## Address for correspondence:

Dr. Mohammed Almuzian,  
Edinburgh, UK.  
E-mail: dr\_muzian@hotmail.com

executed in an environment with a nonstandardized temperature and humidity because sound velocity increases with increase of these variables.

Some reported the use of magnetic resonance imaging (MRI) to quantify the volumetric changes of airway spaces,<sup>[7]</sup> yet its weaknesses include a longer examination time and motion artifacts from breathing, carotid pulsations, and swallowing,<sup>[7]</sup> as well as low accuracy and sensitivity.<sup>[8]</sup> Another method to assess volumetric airway changes is the two-dimensional (2D) radiographical technique using lateral and posterior–anterior cephalometry.<sup>[9]</sup> The drawbacks of 2D cephalometry are distortion and magnification with poor reproducibility of landmark identification.<sup>[10-13]</sup> In order to avoid the inherent hitches of the 2D methods, 3D imaging based on computed tomography (CT) and cone-beam computed tomographic (CBCT) data were advocated;<sup>[14-21]</sup> however, there are certain limitations such as high cost, radiation dose, and artifacts created by metal objects.<sup>[22,23]</sup>

Numerous software packages are available to analyze the 3D data acquired from CT or CBCT scan, as part of volumetric measurement process, but all impose a pricey license to operate. Additionally, most of them lack the capability to subdivide the 3D virtual model of airway space, which is a crucial step because each airway segment is associated anatomically and physiologically to a different function and/or disorder. The ultimate aim of the study is to assess the validity of free-access ITK-SNAP software in segmenting and measuring the volumetric changes of upper airways spaces secondary to RME using data derived from CBCT scan.

## Materials and Methods

The sample size indicated that 14 participants were required to yield a confidence level of 95% and a Beta error level of 20%.<sup>[24]</sup> Therefore, it was decided to recruit 17 patients to overcome the potential exclusion of some cases. An ethical approval was granted by NHS/Greater Glasgow/09-S0709/40 and Victoria Hospital/Fife/09-062.

A cast-cap appliance with a Hyrax screw (Forestadent, Germany) was used for maxillary expansion. The appliances were activated immediately after capturing the pretreatment CBCT scans (T1). Then, at the end of active phase, a posttreatment scan (T2) was acquired. Both CBCT scans (T1 and T2) were taken using an iCAT scanner (Imaging Sciences International, Hatfield, PA, USA) in natural head position.<sup>[25]</sup> The data files for the CBCT images have been saved and stored as DICOM files and subsequently analyzed using two different types of analyzing software, namely

OnDemand3D (Cybermed, Seoul, Republic of Korea) and ITK-SNAP version 2.2.0 ([www.itksnap.org](http://www.itksnap.org)). ITK-SNAP is an open-access popular library image analysis algorithm funded by the US National Library of Medicine.<sup>[26]</sup>

OnDemand3D software package used to superimpose T1 images on their corresponding T2 scans using the anterior cranial bases as stable structures; later, the orientated images were saved as new T1 image (NT1) [Figure 1]. These strategies in orientation permitted a homogeneous segmentation as it excluded potential errors that might be resulted from variable head position.

Using NT1 and T2 scans, the airway boundaries were defined, segmented, and volumetrically measured using the ITK-SNAP software package [Tables 1-3; Figures 2-4]. C2sp/V plane subdivides the retropalatal space into two distinct spaces: the upper retropalatal (URP) and lower retropalatal (LRP) spaces taking into consideration that if the C2od locates superior to C2sp/V plane, then the whole segment would be considered as LRP space.<sup>[12,24,27]</sup>

Before commencing the volumetric measurements, a test of the threshold was accomplished through quantifying a volume of a hollow polymer-rubber phantom. The



Figure 1: Superimposition of T1 over T2 images, on the cranial base structure, to produce NT1 image

Table 1: Points and landmarks

Point	Definition
ANS	The tip of the bony anterior nasal spine at the inferior margin of the piriform aperture, in the midsagittal plane and often is used to define the anterior end of the palatal plane
C2sp (or C2od)	It is the most superior–posterior extremity of the odontoid process of the second cervical vertebrae (C2)
LOR	The lowest point of the left inferior orbital floor
PNS	The most posterior point of the bony hard palate
Spip	The most inferior–posterior point of the soft palate

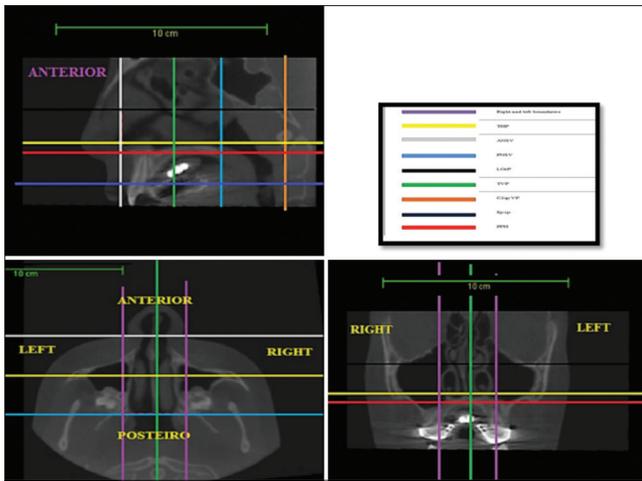


Figure 2: Volumes of interest and their boundaries



Figure 3: Segmentation procedure using ITK-SNAP

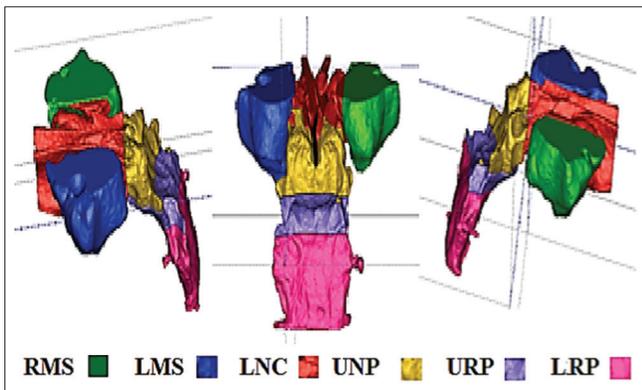


Figure 4: Three-dimensional virtual visualization of nasopharyngeal spaces

phantom was fully filled with controlled amount of water and the physical volume (PV) was calculated by converting ml to mm<sup>3</sup> (in the ratio 1:1). Afterward, the i-Cat machine scanned the phantom; data imported and examined by ITK-SNAP software wherein the threshold was fine-tuned until the virtual volume match the PV. Accordingly, a threshold of -450 gray levels appeared to be ideal.

Table 2: Lines and planes

Line and plane	Definition
ANSV plane	A true vertical plane (TV) plane passing through point ANS, as shown from the lateral view. If the mid-palatine split extends to involve the ANS, then the most posterior ANS is considered
C2sp/V plane	Defined by the frontal plane perpendicular to FH passing through C2sp
LORh plane	A true horizontal (TH) plane tangent to LOR
PNSH plane	TH plane passing through PNS and extended to the posterior wall of the pharynx
PNSV plane	TV plane passing through PNS. If the mid-palatine split extends to involve the PNS, then the most posterior end of the palate is considered
Spip/FH plane	A plane parallel to the FH plane passing through the Spip
SPPTV plane	A sagittal plane parallel to TV passing through the most lateral point of the maxillary sinus
True horizontal (TH) plane	A reference line constructed horizontal to the floor
True vertical line (TV) plane	A reference line constructed perpendicular to the floor

All volumetric measurements were carried out by one examiner and repeated after 1 week, and the data were exported to a separate datasheet for statistical analysis.

### Statistical analysis

Statistical Package for the Social Sciences (version 13; SPSS, Chicago, IL, USA) was used to conduct the statistical analysis. The sample was found to be normally distributed for most parameters using the Kolmogorov–Smirnov test; hence, paired *t*-tests and intra-class correlation coefficient were used to assess error in the study, while the degree of reproducibility was evaluated using Dahlberg coefficients of reliability.

### Results

Data of one subject were excluded due to positioning error during CBCT capturing, hence, records of the remaining 16 subjects (8 females and 8 males) were analyzed; mean age was 12.4 and 12.8 years for males and females, respectively [Table 4]. The results of the reproducibility are presented in Tables 5 and 6.

Table 5, which demonstrates the reproducibility of pretreatment volumetric measurements, shows that there is no statistically significant difference between measurements taken at first week (W1) and the subsequent week (W2) ( $P > 0.05$ ). The coefficients of reliability are all above 95%, the intra-class correlation coefficient ranged from 0.99 to 1.000. Close examination of the data reveals similarities of the repeated measurement of the volume of left maxillary sinus (LMS) and LRP, with mean difference of 6 and 8 mm<sup>3</sup>, respectively. The mean difference of repetitive measurements of the right

**Table 3: Volumes of interest and their boundaries**

Volume of interest	Boundaries					
	Anteriorly	Posteriorly	Superiorly	Inferiorly	Medially	Laterally
LNC	ANSV plane	PNSV plane	LORh plane	Inferior nasal wall	Nasal septum	Lateral nasal wall
UNP	PNSV plane	C2sp/V plane	LORh plane	PNSH plane	N/A	SPPTV
Retropalatal	PNSV plane	C2sp/V plane	PNSH plane	Spip/FH plane	N/A	SPPTV
RMS and LMS	The whole of the sinus cavities were included to the level of LORh plane superiorly and their minimum constricted opening with the adjacent paranasal cavities					

**Table 4: Gender distribution**

Gender	Number (n)	Mean age (years)	Range (years)
Male	8	12.4	10.5-14.08
Female	8	12.8	10-16.25

**Table 5: Reproducibility of pretreatment volumetric measurements at W1 and W2**

Volume	T1W1		T1W2		T1W1:T1W2			
	Mean	SD	Mean	SD	MD	DET	t-test	ICC
LMS	6934	4190	6940	4207	-6	7.53	0.59	1
RMS	6893	3695	6855	3681	38	17.98	0.16	1
LNC	4695	2108	4785	2195	-91	41.73	0.14	0.99
UNP	2761	1409	2736	1395	25	13.72	0.22	1
URP	553	836	527	827	27	5.88	0.48	1
LRP	3296	2246	3305	2265	-8	6.41	0.37	1

T1W1: Pretreatment measurements on the first occasion, T1W2: Pretreatment measurements on the second occasion, MD: Mean difference, SD: Standard deviation, DET: Dahlberg error test, ICC: Interclass correlation

**Table 6: Reproducibility of posttreatment volumetric measurements at W1 and W2**

Volume	T1W1		T1W2		MD	T1W1:T1W2		
	Mean	SD	Mean	SD		DET	t-test	ICC
LMS	6849	3723	6855	3729	-7	11.4	0.72	1
RMS	7096	3347	7155	3348	31	7.61	0.12	1
LNC	5517	3371	5600	3374	-83	3.98	0.62	1
UNP	3079	1391	3101	1373	-23	10.19	0.84	1
URP	402	692	432	731	-30	1.4	0.38	1
LRP	3158	2060	3153	2151	-5	62.25	0.38	0.99

T2W1: Posttreatment measurements on the first occasion, T2W2: Posttreatment measurements on the second occasion, MD: Mean difference, SD: Standard deviation, DET: Dahlberg error test, ICC: Interclass correlation

maxillary sinus (RMS) is nearly six times more than that of LMS, while that for upper nasopharynx (UNP) and URP spaces show a negligible difference, a fluctuation of <1%. The highest dissimilarity is recorded at lower nasal cavity (LNC), 91 mm<sup>3</sup> of an average variation of the mean, though the difference was statistically not significant. Overall, the findings of the repeated posttreatment volumetric measurements at 2 weeks interval shows an almost parallel findings to the repeated pretreatment measurements.

## Discussion

A key feature of ITK-SNAP is the existing facilities to segment and navigate through the volumetric data set

in three planes of space with a linked cursor system that allows tracking of a single voxel. The automatic segmentation process allows construction of the main 3D virtual surface, while the semi-automatic segmentation allows fine-tuned segmentation to identify the most appropriate border between neighboring structures,<sup>[28,29]</sup> in turn these allow an accurate measurement of the volume of interest. ITK-SNAP software allows subdivision of airway space that, generally, permitted the exclusion of potential masking changes of the adjacent or remote airway spaces. Furthermore, the chosen intensity region filter was set with a reliable threshold value of -450 gray levels. A fixed threshold was adopted rather than interactive one to eliminate operator subjectivity in boundary selection, thus eliminate operator’s visual discrimination.<sup>[30]</sup>

The most acceptable rationalization for high mean difference of the repeated measurements at level of LNC is the semi-automatic segmentation, in particular at area of maxillary sinus’s hiatus, which might induce some random errors. Interestingly, it is obvious that volume of interest that is bounded by soft tissue’s constructed planes such as UNP and URP exhibited an uppermost degree of difference in the repeated measurements. Nevertheless, all differences were statistically not significant and the reproducibility of the measurements was assessed as being satisfactory.<sup>[24]</sup> An open-minded criticism of this study is the impossibility of absolute control of the tongue position during radiographic scanning,<sup>[31]</sup> though the subjects were given special instructions for breathing and swallowing during the 20-second scan of the CBCT capture as recommended by Chang *et al.*<sup>[24]</sup>

Outcomes of this study confirm that CBCT scanning is a valuable imaging modality to gauge the effect of RME on nasopharyngeal dimensions and ITK-SNAP software is a friendly-use, cost-effective, and reliable package for measuring nasopharyngeal volumes. A second prospective implication of this software package is to measure the dimension of bony defect of patient with cleft palate before alveolar bone grafting. This would assist in quantifying the amount of the required bone to fill the cleft defect and reduce unnecessary morbidity of the donor site as a result of unnecessary over harvesting. A proposal for forthcoming studies includes the usage of

a color mapping methodology for detailed appraisal of changes at different parts of the nasopharyngeal space, as shape's alterations of the airway space is as vital as volumetric changes.

## Conclusions

ITK-SNAP software package is a reliable and cost-effective method to segment and measure airway changes subsequent to RME. A single fixed threshold value (-450 gray) is an accurate value for intensity region filtering.

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Nil.

## Conflicts of interest

There are no conflicts of interest.

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