Original Article

Palatal volume and area assessment on digital casts generated from cone-beam computed tomography scans

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ABSTRACT

Objectives: The objective of this study was to develop a reproducible method to measure the change of palatal volume and area through superimposition using maxillary expansion digital cast models.

Materials and Methods: A total of 10 pre- and 10 postexpansion dental cast models were scanned by the same cone-beam computed tomography machine. Superimposition was performed using a fully automated surface-best fit of the palatal surfaces on the digital cast models. A gingival plane, identified only once on superimposed casts, and a distal plane with the lateral closing border and the palatal surface were used to localize this selection of air. Area and volume were calculated for pre- and postexpansion records. Pre- and postexpansion palatal volume and area were measured by the main investigator and three different observers for inter- and intra-observer reproducibility assessment.

Results: The level of intra- and inter-observer agreement was very strong (intraclass correlation coefficients $\geq$ 0.953; P value $<$ .0001) for all measurements.

Conclusions: Palatal volume and area measurements based on the proposed superimposition are reproducible and can be used reliably. (*Angle Orthod.* 2018;88:397–402.)

KEY WORDS: Digital cast model; Three-dimensional superimposition; Three-dimensional treatment evaluation

INTRODUCTION

Palatal volume and area measurements on dental casts have always been challenging to accomplish even though those measurements can be useful in treatment evaluation because they express a more realistic assessment of clinical palate conditions. Palatal volume and area measurements can help evaluate changes from treatment modalities such as rapid palatal expansion[1] and in the orthopedic treatment of cleft palate cases.[2] Also, they can be used to show the relationship between anomalies in palatal morphology and function such as mouth breathing[3] and posterior crossbite.[4] In addition, they can be used for longitudinal evaluation of palatal vault anatomy.[5] They usually require the use of dental casts, which are an integral part of orthodontic practice and research.[6] Recently, the use of digital models derived from various scanning techniques has become more common. Having digital models allows clinicians to overcome some of the limitations of traditional plaster models as they are not subjected to physical damage and can be easily stored and transferred. Moreover, many studies

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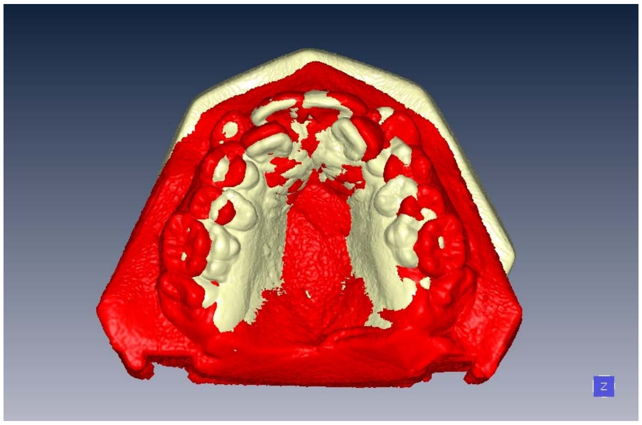

Figure 1. Superimposed pre-and postexpansion digital models based on best fit.

have suggested that measurements derived from three-dimensional (3D) digital models have similar accuracy as those from traditional plaster casts.[7] Optical scanners can be used both in vivo and in vitro to scan the dentition or plaster casts to create digital models.[8]

After making a 3D surface model of casts, the measurement of the palatal volume has been done geometrically or by creating a Computer-aided design model of the volume using reverse engineering technology.[1,9] Alternatively, computed tomography and cone-beam computed tomography (CBCT) machines can provide volume data from which surface models can also be obtained, whereas laser and optical scanners can provide only mesh surface models that cannot be converted to volumetric data. The acquisition of 3D data through the CBCT scanning of dental casts and not directly from craniofacial structures is helpful because several factors complicate the analysis of in vivo scans. With in vivo scanning, there can be artifacts and distortion. Also, the palatal surface border is not easily detected, and the segmentation of the tongue is difficult due to its proximity to tissues such as the suprahyoid muscles and soft palate, which have similar Hounsfield units.[10]

Superimposition procedures can be used to assess treatment changes.[11] Thus, CBCT digital models from casts can be used to provide a 3D superimposition analysis and to evaluate the changes after growth or treatment. Currently, there are no studies using the best-fit superimposition procedure to generate and calculate palatal area/volume changes. Thus, the aim of this study was to develop a reproducible method to measure changes in palatal volume and area after maxillary expansion through superimposition of digital cast models.

MATERIALS AND METHODS

A total of 10 pre- and 10 postexpansion dental cast models of patients from the Orthodontic Department, Faculty of Dentistry, Al Azhar University (Cairo, Egypt) were considered. The casts were randomly selected from consecutive patients, 5 females and 5 males, in the late mixed or early permanent dentition stage, with maxillary constriction associated with the presence of a uni- or bilateral posterior crossbite treated by rapid palatal expansion using a Haas expander appliance. The casts were not damaged and were free of gingival hypertrophy. The study was approved by the ethical committee of the same university (approval number REC16-032) in addition to University of Campania “Luigi Vanvitelli” (Naples, Italy; approval number 13933/17). In this study, the evaluation method was applied on expansion cases but it can be applied in any treatment modality.

Dental cast models were scanned by the same CBCT machine,[12] with the same parameters, X-ray intensity, imaging time, and voxel size. SCANORA®3D (Soredex-Nahkelantie160, Tuusula, Finland) was used at 15 mA, 85 kV, and 20 seconds exposure time. DICOM-formatted images were generated with the same thickness, bit-depth, and dimensions, and then images of 0.35 thickness, 16 bit depth and 414 $\times$ 414 mm were produced. The Digital Imaging and Communications in Medicine (DICOM) files were then reconstructed to volumes to be imported into Computer-aided design software.

Several steps were performed for palatal volume measurement. First, CBCT scans were converted into a triangular mesh only to be used for superimposition.[13–15] A different color was assigned to each time record. Superimposition was performed using a fully automated surface-best fit of the whole area of pre- and postexpansion palatal surfaces after the exclusion of teeth.[1,16,17] The two superimposed CBCT scans of digital models were then recorded as linked files and used as one (Figure 1). After this step, the mesh was no longer used, and all measurements were carried out on the linked superimposed volume data. Second, a gingival plane was constructed only on the pre-expansion record. The most gingival points on the lingual surface of canines, premolars, and the disto-lingual cusp of the first molars were identified. The software drew two imaginary lines intermediate between the canine, premolar, and molar gingival points, one for the right and another for the left side. Then the software made a projection from the canine gingival point and molar gingival point to these two lines. The four points constructed by the projection of the right and left canine and molar points on the two lines are shown in Figure 2. The gingival plane was constructed

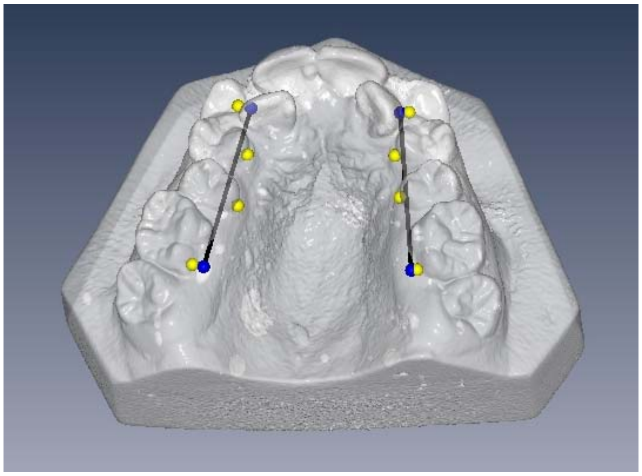

Figure 2. Reference plane construction showing the two constructed imaginary lines.

connecting the mid-canine point (a point midway between canine projections right and left) and the two molar projection points, right and left.

Three borders were constructed to localize the volume selection: gingival plane extended until its contact with the oral structures (Figure 3); distal plane, which was perpendicular to the gingival plane passing through a line connecting the two molar projections; and a lateral border. The remaining border was the palatal surface superior to the gingival plane and anterior to the distal plane. To construct a lateral border defining the volume and area, the digital model was reoriented on the gingival plane, and the gingival contour was traced manually and projected on the gingival plane (Figure 4).

On the superimposed digital models, the distal plane and lateral border were identified twice: once for pre- and once for postexpansion. The gingival plane was identified only once on the pre-expansion record.

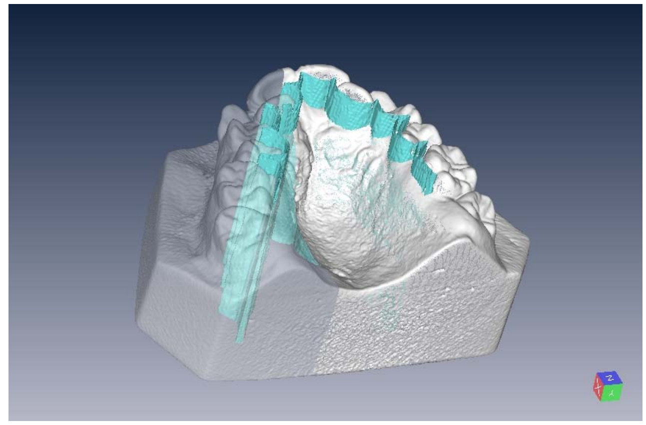

Figure 4. The lateral border to define the volume laterally.

Third, all air space was selected as a zero radio density and the model surface was selected, and then the two border planes, the lateral closing border, and palatal surface localized this selection of air and palatal surface inside only. Volume and area were then calculated for the pre- and postexpansion records.

The previous steps were used to explain to the software developers, but the actual steps performed by the operator were the following:

- Identify gingival points manually.
- Trace gingival borders.
- Select zero radio density with the help of the software.
- Localize volume selection with the help of the border planes.

All other construction was done automatically by the software, without operator intervention.

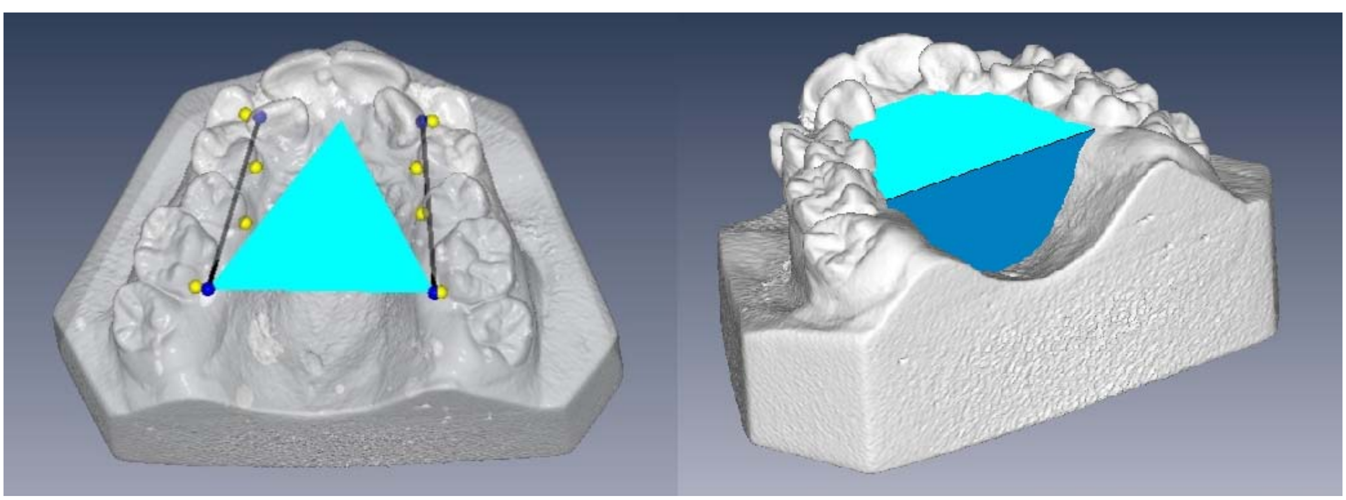

Figure 3. Gingival plane and distal plane forming the occlusal and distal borders.

Table 1. Intraclass Correlation Coefficient for Intraobserver Reproducibility Assessment of the Main Examiner

Measurements	ICC*	95% CI	*P* Value**	Level of Agreement
Pretreatment volume	0.977	0.935–0.994	<.0001	Very strong
Posttreatment volume	0.95	0.849–0.986	<.0001	Very strong
Pretreatment area	0.98	0.945–0.995	<.0001	Very strong
Posttreatment area	0.992	0.979–0.998	<.0001	Very strong

* Intraclass Correlation Coefficient ranges from 0.00 to 0.30 indicates lack of agreement and 0.31 to 0.50 as weak, 0.51 to 0.70 as moderate, 0.71 to 0.90 as strong, 0.91–0.100 as very strong agreement.
** Statistical significance at *P*-value $\leq$ 0.05.

Reproducibility of Volume and Area Measurements

Pre- and postexpansion palatal volume and area were measured by the main investigator three times at weekly intervals and by three different observers once to evaluate inter and intraobserver reproducibility. The results were exported to an Excel spreadsheet. Means, standard deviations, coefficients of variation, and intraclass correlation coefficients for inter- and intraobserver reproducibility were evaluated.

RESULTS

Good precision of the method was evidenced by the narrow confidence interval. In addition, the sample size was adequate as demonstrated by the consistent range of the confident interval. The level of intra- and interobserver agreement was very strong (intraclass correlation coefficients $\geq$ 0.953; $P < .0001$) for all measurements (Tables 1 and 2). The coefficient of variation, which gives a measure of the variability of results regardless of the means, did not exceed 4.42% and was not correlated to palate size variation. It showed low variability (0.47–4.42%) across the range of the mean as demonstrated in Table 3.

DISCUSSION

Previously, to evaluate palatal area and volume, laser-scanned records have been used.[1,9,18] All of the previously reported methods claimed accuracy and reproducibility of the border delimitation of the palatal space.[2,19]

In one method, the palatal space selection was based on delimited surfaces.[3–5,18,20] A gingival plane was defined connecting the midpoints of the dentogingival junctions. A distal plane was created through the two distal points of the second molars perpendicular to the gingival plane. These two planes were used for detecting the third border, such as the palatal surface. From these three boundaries, the palatal volume was calculated,[3–5,18,20] but the palatal space was not selected directly as it is not technically possible on laser scan records. Furthermore, 10 3D points cannot be located geometrically in the same plane. Also, without a lateral border, it is not clear how the volume boundaries are determined in cleft cases or if some teeth are missing.

With another method, the selected volume was calculated by reverse engineering.[1] The horizontal plane was produced connecting the following three identified points: one at the lowest point of the gingival margin of one central incisor and two at the lowest points of the gingival margin of the first permanent molars. The posterior limiting plane was tangent to the distal surface of the first molars and perpendicular to the horizontal plane. Palatal volume, visualized as a solid volume,[1] was defined as the volume between the reference surfaces and the palatal surface. However, a lateral closing boundary was still missing. The gingival plane was produced from only three points. This may have led to loss of information. Moreover, it may not be comparable between consecutive records because two reference planes have been selected to measure pre- and postvolumes without reorienting the casts.[21–23]

One additional method was based on geometric measurements performed by tracing and dividing the palatal space into small sections with regular shapes used to calculate area and volume geometrically.[9] However, it followed straight lines and not the irregular surface, generating geometric shapes and lines that

Table 2. Intraclass Correlation Coefficients for Interobserver Reproducibility Assessment

Measurements	ICC*	95% CI	*P* Value**	Level of Agreement
Pretreatment volume	0.973	0.924–0.993	<.0001	Very strong
Posttreatment volume	0.954	0.873–0.987	<.0001	Very strong
Pretreatment area	0.953	0.869–0.987	<.0001	Very strong
Posttreatment area	0.988	0.967–0.997	<.0001	Very strong

* Intraclass Correlation Coefficient ranges from 0.00 to 0.30 indicates lack of agreement and 0.31 to 0.50 as weak, 0.51 to 0.70 as moderate, 0.71 to 0.90 as strong, 0.91–0.100 as very strong agreement.
** Statistical significance at *P*-value $\leq$ 0.05.

Table 3. Standard Deviation and Coefficient of Variation for Intra- and Interobserver Measures

Case	Volume & Area	Main Observer SD	Main Observer CV	Observer 1, 2, 3 SD	Observer 1, 2, 3 CV
1	Volume pre	12.66	2.33	16	2.94
	Volume post	39.53	4.42	38.07	4.26
	Area pre	17.39	1.88	17.09	1.85
	Area post	26.69	2.41	35.51	3.19
2	Volume pre	7	1.04	9.5	1.42
	Volume post	6.11	0.76	6.66	0.83
	Area pre	6.11	0.58	7.57	0.72
	Area post	11.79	0.92	13.61	1.06
3	Volume pre	5	0.74	10.07	1.48
	Volume post	10.97	1.52	12.5	1.73
	Area pre	11.02	1.18	13.01	1.4
	Area post	16.46	1.59	16.52	1.59
4	Volume pre	18.77	2.4	18.72	2.4
	Volume post	39.46	3.7	37.65	3.45
	Area pre	11.93	1.13	13.75	1.3
	Area post	6.66	0.52	7.57	0.59
5	Volume pre	18.88	2.38	17.09	2.14
	Volume post	14.47	1.6	36.91	4.29
	Area pre	12.01	1.21	10.54	1.06
	Area post	10.12	0.99	10.82	1.05
6	Volume pre	2.08	0.33	5.51	0.87
	Volume post	18.61	2.31	32.88	4.05
	Area pre	7.09	0.73	12.29	1.26
	Area post	9.54	0.83	10.69	0.94
7	Volume pre	13.43	1.87	15.5	2.16
	Volume post	12.29	1.57	12.66	1.62
	Area pre	10.54	1	7.09	0.68
	Area post	6.03	0.59	6.56	0.64
8	Volume pre	10.5	2.08	12.58	2.48
	Volume post	2.52	0.47	4.51	0.85
	Area pre	28.54	3.17	27.5	3.05
	Area post	10.21	1.31	13.89	1.79
9	Volume pre	26.39	3.49	26	3.52
	Volume post	17.35	1.72	18.23	1.81
	Area pre	6.08	0.64	5.57	0.59
	Area post	11.55	1.01	13.43	1.18
10	Volume pre	19.52	2.61	20.21	2.71
	Volume post	15.5	1.99	16.5	2.12
	Area pre	5.03	0.49	7.55	0.74
	Area post	6.43	0.54	8.19	0.69

may not represent exactly the actual structural anatomy of the palate.

To overcome the limitations described, in this study a standardized method was used for the detection of a reference plane that was derived from three points constructed based on eight points. Using two imaginary lines instead of a best-fit plane may reduce the impact if there is an odd occlusal or gingival point, which may affect the whole plane. According to this reference plane, the digital cast was reoriented, allowing a reproducible gingival contour tracing to create a lateral border having good intra- and interclass correlations.

A scanned palatal surface does not have stable structure to be used for superimposition. Although palatal rugae have been suggested[1] as relatively stable structures to use for superimposition, they have been shown to be hardly reliable as a reference.[24] Consequently, the automated process of best-fit superimposition seems to have the least possible error.[17,23]

Moreover, using the same gingival plane for both pre- and postrecords can give more comparable results. Nevertheless, volume measurements calculated based on the superimposition of pre- and postdigital casts using the same reference plane has never been proposed. In this study, the gingival plane for superimposition was identified only once on the prerecord. The main advantage of this procedure is that the same operator or multiple operators can have reproducible and comparable results as shown by statistical analysis demonstrating no clinically significant method error. In addition, to avoid the influence of dental landmark changes resulting from orthodontic treatment such as tooth-supported expanders, unified border planes were created for both superimposed records to localize volume selection.

Other authors have assessed the reproducibility of palate volume measurement[20] with a high variation of results, with standard deviations ranging between 34% and 40% of the mean and errors associated with palate size. In this study, the standard deviation did not exceed 9.7% of the mean and was nearly constant and not associated with palate size. The method in this study allowed good data reproducibility for both volume and area measurements in different patients. There was a low possibility of error in the identification of structures because the digital models were reoriented uniformly. Moreover, using the same gingival plane enabled easier comparison between pre-and posttreatment.

The data derived from CBCT exams can produce both volume and surface models, whereas that from laser scans can only be used to obtain surface models.[17] Therefore, volume assessment does not require indirect calculations such as those produced geometrically or by reverse engineering.[25] Instead, it simply follows from the direct selection of space inside the borders that have been selected. Higher resolution computed tomography machines can be used if better quality is needed.

This method has some limitations, such as the need for an available CBCT machine, although it could also be applied on a laser scan if suitable software tools were developed. It might take more time than other available methods, but it is reproducible. In the future, new software advances may decrease the time required.

CONCLUSIONS

- Palatal volume and area measurements based on this proposed superimposition method were reproducible.

- This novel approach represents a valid alternative to the other methods currently used to evaluate palatal volume and area.

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