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Evaluation of the accuracy of a simplified hybrid method versus the traditional digital method for measuring palatal volume

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ABSTRACT

Objective: This study aimed to compare a direct conventional 3D digital technique vis a vis a hybrid method in measuring palatal volume.

Materials and methods: Thirty maxillary casts were obtained from the records of patients undergoing orthodontic treatment and pre-conceived boundaries of the palatal vault were marked. Sample was categorised into Group I (Volume estimation using CBCT scan) and Group II (Volume estimation using hybrid method). Estimation of the palatal volume in this study involved filling the volume of interest in the palate with gypsum (Type IV) stone material and carefully carving according to the boundaries and anatomy. This positive reproduction of the palatal space was safely retrieved and then scanned in the NewTom GiANO HR Cone Beam Imaging setup. The obtained scan was analysed in NNT Software Version 3.10 and the volume of the palate was calculated. Two experienced orthodontists carried out the measurements to evaluate the inter and intra-observer reliability. This was compared with the palatal volume calculated by the conventional digital method using CBCT in the NNT Software.

Result: This study showed a consistent and narrow range of the confidence interval for palatal volume. Hence, the sample size was sufficient and had good precision. Considering a 95 % confidence interval, the intra-class correlation coefficient was robust (>0.9) for all measurements calculated by the hybrid method suggesting a high reliability. The mean difference in measurement of palatal volume (Group I vs, Group II) was 1.37 + 0.64 mm3 and the difference was statistically insignificant. Statistical *t*-test conducted between the two methods showed a p-value of 0.34, implying no statistically significant difference between the two methods.

Conclusion: The hybrid method for evaluating the palatal volume is simple, accurate and comparable to the conventional digital method. A major advantage of this simplified method is that the patient is not exposed to any radiation of CBCT. Also, need for a specific skillset for digitally measuring the palatal volume is not a must.

1. Introduction

The palatal volume is adversely affected by maxillary growth aberrations. It is known that breathing pattern, whether nasal, oral or oronasal has a direct influence on the growth of the maxilla and therefore, volume of the palate.[1] The accommodation of the tongue against the palatal vault also determines the volume of the palate, thereby contributing to the balance of the stomatognathic system.[2] Muscular harmony of the tongue, soft palate and other muscles with the skeletal pattern varies according to the positioning of the jaws leading to Class I, Class II and Class III malocclusions. However, accurate three-dimensional (3D) measurement of the palatal morphology in routine clinical practice is challenging without the aid of advanced diagnostic records such as CBCT/CT scans, or 3D intraoral scans.

Various orthodontic treatment modalities such as maxillary expansion, habit correction, and growth modification, are influenced by the anatomic limitations of the oral cavity.[3] Changes in palatal morphology before and after orthodontic or orthognathic treatment also help in the

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evaluation of the chosen modality.

Before the advent of 3D methods of data acquisition, the conventional method of assessing the palatal volume was based on measurements taken on a dental study model such as inter-molar distance, inter-canine distance, palatal height, palatal length, and the palatal surface area.[4,5] Most of these measurements made use of dental landmarks, which are of questionable reliability in cases of malocclusion, missing teeth, edentulous jaws and prosthesis. Moreover, two-dimensional measurements do not reflect the accurate three-dimensional structure of the palatal vault therefore 3D methods were introduced.

Previous studies have reported the use of 3D scanning,[6] volumetric surface scanning,[7] and analysis from radiographs or CBCT/MRI scans[8] for acquiring the volume of the palate, however not all methods were easy to perform in day-to-day practice. Linear measurements on digital models showed the maximum accuracy, although this method was extremely meticulous.

Laser scanning and its subsequent computerized analysis of models were found to be faster and accurate up to 15 μm, and relatively inexpensive as compared to photogrammetric studies.[9] Digital photogrammetric acquisition of a dental cast allows the definition of a 3D model with digital photographic acquisition, followed by optical 3D model creation and graphic rendering. Volume calculation by this method gives a metric accuracy of 0.5 mm concerning the selected fixed points used.[10] On the other hand, optical scanners can be used to scan the dentition or plaster casts to create digital models.[11] After making a 3D surface model of casts, the palatal volume is measured geometrically or by creating a computer-aided design (CAD) model of the volume using reverse engineering technology.[11,12] However, laser and optical scanners can provide only mesh surface models that cannot be converted to volumetric data, whereas CBCT scans can provide volumetric data from which surface models can be derived.

We propose a simplified hybrid method without radiation exposure to measure the palatal volume and test its accuracy against the conventional 3D scanning method.

2. Materials and Methods

A convenience sample of 30 Study models of patients having a complete set of permanent teeth, and excluding those having any craniofacial deformity such as cleft, or any other syndromic condition, were selected.

For volume measurement by conventional digital method, the models were scanned in NewTom GiANO HR Cone Beam Imaging setup which offers 3D model scanning. The desired planes were drawn in the software, and the volume of the palatal vault was calculated by the conventional digital method of reverse engineering (Fig. 1).

Pre-defined boundaries[13] were considered for both conventional and hybrid methods in our study (Fig. 2). The lower limit of the incisive papilla indicated the anterior extent of the upper boundary, whereas the midpoint of the lingual aspect of each maxillary tooth at the level of the gingival margin constituted the extent of the lateral borders. The posterior limit for the palatal volume measurement was considered to be a plane tangent to the distal aspect of the maxillary permanent first molar. It must be also noted that the teeth presenting out of the dental arch either buccally or lingually, were not considered for defining the lateral

Fig. 2. The boundaries for the palatal extent defined prior to measuring the palatal volume by hybrid method.

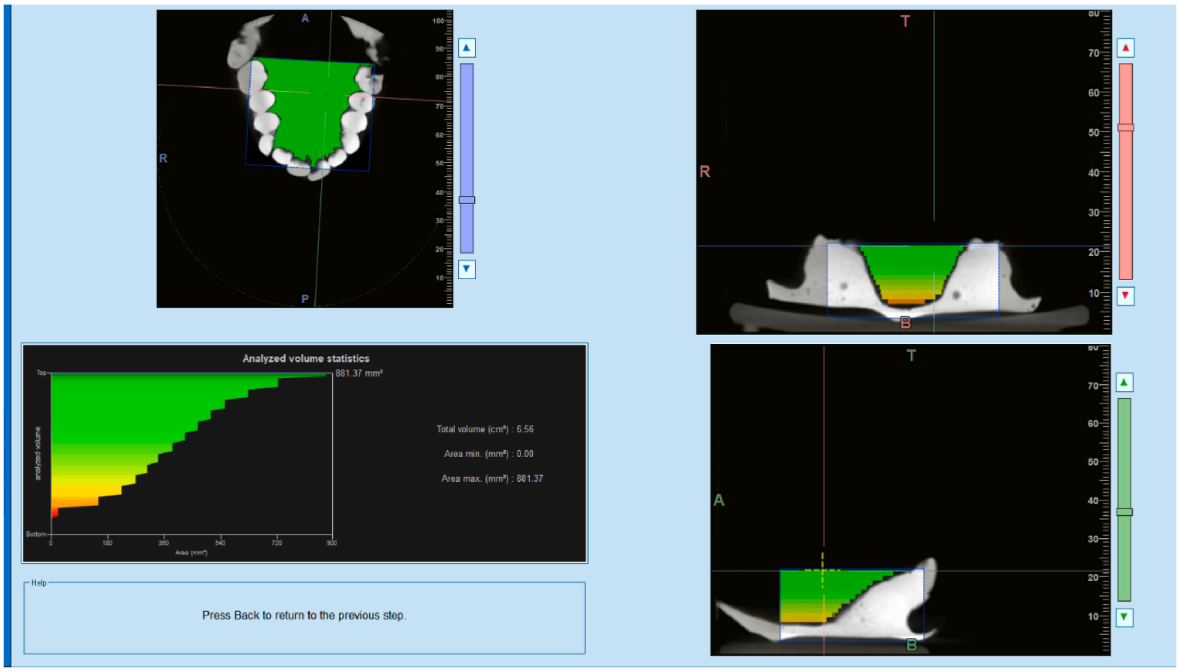

Fig. 1. Measurement of the palatal volume by the conventional method by determining the planes and boundaries on the CBCT scan of the pre-treatment models.

boundaries of the palatal volume measurement.

The estimation of the palatal volume of the same study models was then performed by creating a dental stone replica of the palatal vault. A separating medium was applied to the model to allow safe retrieval. This was followed by filling the palatal vault up to the desired boundaries with dental stone (Kalrock Diestone; Setting Time: 8 min, Setting Expansion: 0.10 %, Compressive Strength: After 1 h 400 kg/cm 2 After 24 h 800 kg/cm 2, Water/Powder Ratio 23 ml/100 g) and allowed to set. (Fig. 3).

After retrieval within 2 h, 3D scanning of the palatal dental stone impression was done in the NewTom GiANO HR Cone Beam Imaging setup. The obtained scan was analysed to measure the volume of the stone replica (Fig. 4). A summary of the workflow has been shown in the flowchart (Fig. 5).

The palatal volume measurement by the hybrid method was done by two experienced orthodontists Observer 1 (O1) and Observer 2 (O2) for all the study models at different times (T1 and T2) 3 weeks apart to evaluate the inter and intra-observer reliability for the hybrid method. The mean and standard deviation (SD) of all readings between the two observers, and the intra-class correlation coefficient (ICC) were used to evaluate the inter-observer and the intra-observer agreement. T-tests for comparison of the two methods were also performed.

3. Results

The palatal volume measured by the conventional digital method by only one observer at one-time point gave a mean value of 9.726 cm^3 with a standard deviation of 2.066 cm^3. The mean of four observations measured by two observers at two-time points by the hybrid method was 9.522 cm^3 with a standard deviation of 1.835 (Table 1). The inter-observer and the intra-observer reliability was excellent with the ICC value above 0.9 (Supplementary Table 1). Statistical t-tests conducted between the hybrid and the conventional digital method showed a p-value of 0.2352 for the two methods. This implies no statistically significant difference between the two methods for a 95 % confidence interval.

The quantitative volume using the hybrid method was computed a total of 4 times for each sample. The average of these four values for each sample was considered as ground truth of the hybrid method. Then difference of the volume from the conventional method was computed for each sample. These quantitative absolute differences in palatal volume are listed in (Supplementary Table 2). The mean and standard deviation of these volume differences were found as 1.37 cm^3 and 0.64 respectively.

Fig. 3. Filling of the palatal vault with dental stone according to the predetermined boundaries prior to the final setting of the stone.

4. Discussion

Previously, growth of and changes in the maxilla were studied on plaster casts by the method of direct measurements of arch width and depth, palatal height or palatal volume.[14,15] Although these methods were reliable, they were very time-consuming, and developments towards easier and faster methods were required.

Earlier, the methods to determine the volume of the whole of the palatal vault used a three-dimensional digitizer.[16] Stone casts mounted on a semi-adjustable articulator were used with an anatomic face bow and a central wax record. The 3D digitizer calculated the palatal height and volume in extraction and non-extraction cases. Later, with the advent of the use of lasers in orthodontics, laser scanning was used for palatal area and volume evaluation initially in cases of maxillary expansion.[17] Another method of palatal volume estimation was attempted in operated unilateral and bilateral cleft lip and palate subjects using digital study models. The 3-matic software was used to calculate the palatal volume delimitated by the predefined gingival plane and the distal planes using the reverse engineering method.[4]

3D digital images of study casts were obtained by using laser scanning to study growth changes in the palatal vault. The diagnostic accuracy of the digital images of study casts was also analysed. However, it was seen that palatal surface area was a more reliable and accurate indicator for the assessment of changes in the palatal vault.[9]

More studies have been conducted using 3D aids, although palatal space selection has always been questionable.[5,18–22] Space selection of the palatal vault is done by predetermining reference planes in all three cardinal directions to set boundaries for the palatal vault. Consecutive records, such as those taken to evaluate pre-treatment and post-treatment changes cannot be relied upon since the reference planes selected for palatal volume were not reproducible after orthodontic treatment changes and growth changes in an individual. Among most of the studies, the palatal surface was detected based on two other planes.[5,18–22] These were the gingival plane and the distal plane. The gingival plane was defined as a plane connecting the midpoints of the dentogingival junctions of the tooth and the distal plane was created through the two distal points of the first molars perpendicular to the gingival plane.[13,19–23] In these studies each dental cast was scanned from 10 or more views then combined and rendered into 3D by using specific software. However, the drawbacks of these methods are that the exact 3D geometrical point could differ each time when combined and rendered into 3D. Another demerit was that the demarcation of the lateral borders was not done. A summary of the existing methods for the measurement of palatal volume and their limitations have been mentioned in Table 2.[10–13,20]

Our study proposed a standardized method to overcome all these problems from previous studies for palatal volume and area assessment, in which the use of digital casts was made which were generated from cone-beam computed tomography scans.

Since the earlier studies were mainly based on 2D measurements on dental casts and cephalometric radiographs, they reflected incomplete information on palatal shape. CBCT scans were then used to reconstruct 3D models, from which the palatal volume could be calculated as the volume of the 3D closed figure of the palate obtained by filling the boundary hole in the 3D scans.[13,26] This method utilized reverse engineering where the gingival plane was produced connecting the following three identified points: one point at the lowest point of the gingival margin of one of the central incisors and two at the lowest points of the gingival margin of the first permanent molars. The distal plane was tangent to the distal surface of the first molars as well as, perpendicular to the gingival plane. However, it is not a true representation of the palatal volume and does not capture the precise upper boundaries of the palate since the upper boundaries cannot be defined using only three points; the extent of the lateral boundary must also be taken into consideration.

The study also compared the pre and post-palatal volumes, however,

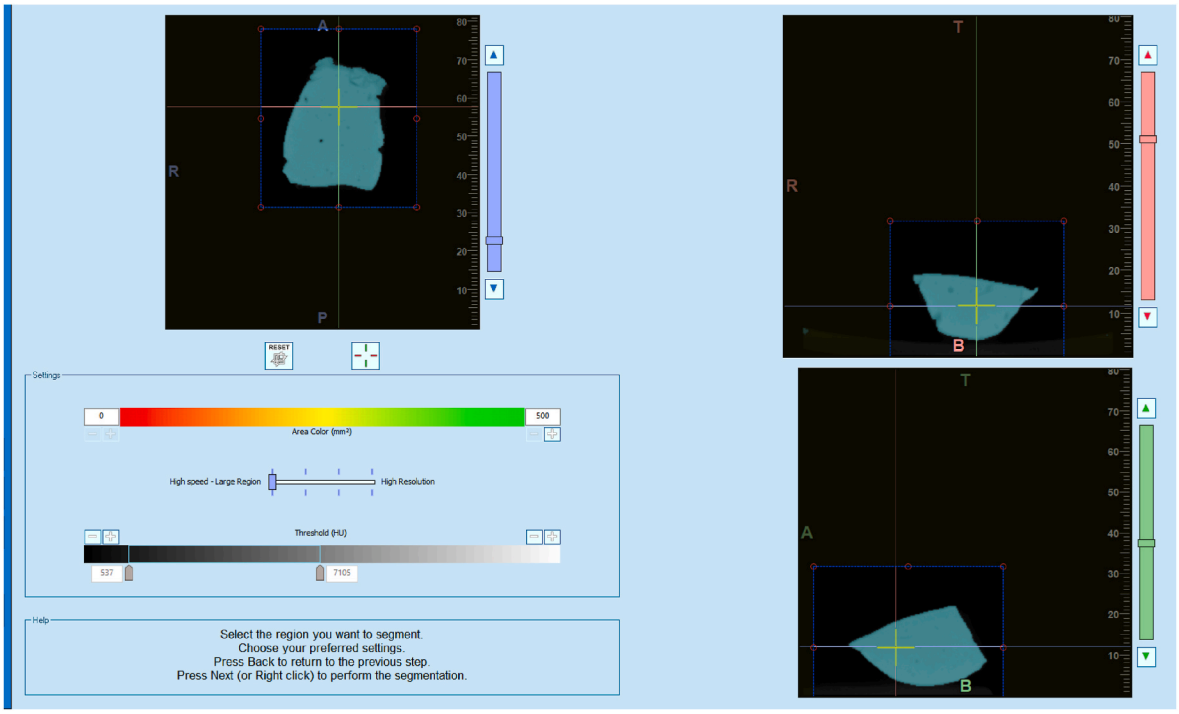

Fig. 4. The volume of the palate was calculated in the NNT software after adjusting appropriate contrast and threshold.

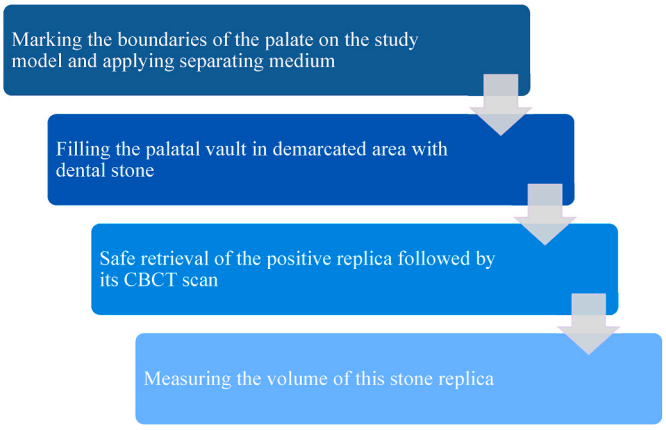

Fig. 5. Flowchart depicting workflow of methodology of the hybrid method.

Table 1
Comparison of palatal volume calculated by the two methods using *t*-test.

	Volume using Conventional method	Volume using Hybrid method	Difference of conventional volume and hybrid volume
Mean	9.726	9.522333	1.370166667
SD	2.066	1.835	0.643736143
p-value	0.2352		

Where.
SD is the standard deviation.
p-value >0.05, it represents that there is no statistically significant difference for 95 % confidence interval.

the cast orientation was not done to obtain the reference planes. Without cast orientation, it is not feasible to use a reference plane to measure palatal volumes or draw comparisons between consecutive records.[30]

Vertically irregularly placed teeth, which are superior or inferior as compared to the remaining teeth in the dental arch would not be recorded in the previous methods or would change the orientation of the gingival plane inappropriately in the reverse engineering method. By using dental stone in the hybrid method, it allowed for better accuracy of the boundaries of the palate. Therefore, our study aimed to calculate the accurate palatal volume by a hybrid method and compare it to the currently used conventional method of calculation.

The importance of analysing the palatal volume is well proven in the field of orthodontics, and so is the requirement of constant record keeping and acquiring of study models from a single patient in the course of his/her treatment. The use of CBCT scans as a routine diagnostic aid for orthodontic patients is still controversial due to the radiation exposure and the need for repetitive records. The hybrid method was developed by making use of the study models which are routinely taken, and analysing it in a CBCT scanner. A laser scanner could be used for palatal volume measurement by hybrid method.

Filling the palatal vault with dental stone initially to create a positive replica allowed carving the stone during its setting phase along the palatal margins of the maxillary teeth, thus improving the accuracy. The same dexterity is difficult to achieve in any software-based reverse engineering method since setting the gingival margins of the palatal vault is extremely technique-sensitive and requires trained personnel to manoeuvre the software features likewise. After safe retrieval of the stone replica, it was scanned three-dimensionally and the volume was calculated by adjusting the contrast threshold of the scan. To compare the accuracy of the hybrid method, it was compared to the conventional digital method of measuring the palatal volume calculated by scanning the maxillary study model of the same individual, and constructing boundary planes in the software, followed by volume calculation of the volume enclosed within these boundary planes.

In another study, Marini and Bonetti used photogrammetry to calculate the degree of volumetric changes in the palate after rapid expansion. The author already states that this technique is very precise in terms of linear measurement of transverse diameters, but was less precise for volumetric measurements.[10]

Our results showed that the observations from the two methods were not significantly different, which indicates that the hybrid method measurements are comparable to those obtained from the conventional

Table 2
Palatal volume measurement methods and their limitations.

S N.	Authors/ Year	Method and software for palatal volume measurement	Limitations
1	Gracco A et al. (2010)[13]	- Using laser scanned digital dental cast and - Measured in opposite software	1. Lateral closing boundary was still missing. 2. 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 post volumes without reorienting the casts.
2	Primozic J et al. (2012)[19]	- Using laser scanned digital dental cast - Software name for measurement of palatal volume not mentioned	1. Each dental cast was scanned from 10 or more views that were then combined and rendered into 3D by using a specific software. These 10 3D points cannot be located geometrically in the same plane. 2. Two planes were used for detecting the third border, such as the palatal surface. 3. From these three boundaries, the palatal volume was calculated, but the palatal space was not selected directly as it is not technically possible on laser scan records. 4. Lateral border were not defined, without a lateral border, it is not clear how the volume boundaries are determined in cleft cases or if some teeth are missing. 5. Laser scanner accuracy was also less (0.22 mm)
3	Primozic J et al. (2013)[23]	Same as Primozic J et al. (2012)[19]	Same as Primozic J et al. (2012)[19]
4	Lione R et al. (2014)[20]	- Scanned using a 3D laser scanner (D800, 3Shape A/S, Copenhagen, Denmark) - Measured in 3-matic software	Same as Primozic J et al. (2012)[19]
5	Lione R et al. (2015)[9]	Same as Lione R et al. (2014)[20]	Same as Primozic J et al. (2012)[19]
6	Ayub PV et al. (2016)[17]	Using laser scanned digital dental cast	It gives the volume in one plane only, but tooth in the arch may be placed different position superior-inferiorly.
7	Kecik D (2017)[21]	Using laser scanned digital dental cast and Measured in 3-matic software	Same as Primozic J et al. (2012)[19]
8	Generali C et al. (2017)[24]	- Using laser scanned digital dental cast (3 Shape R700 laser scanner) - Volume was calculated by reverse engineering using Rapidform™ 2006 (INUS Technology, Tokyo, Japan	1. Lateral closing boundary still missing. 2. The gingival plane was produced from only three points. This may have led to loss of information.
9	Shahen S et al. (2018)[25]	- CBCT machine - Measured using Computer aided design software	1. Need for an available CBCT machine. 2. It takes more time than other available methods.
10	Huang et al. (2020)[26]	CBCT and supporting software used	3. Pre and post cast required for superimposition 1. Trained personnel required for specific landmarking 2. Landmarks on teeth present, so this method cannot be applied in cases of missing teeth.
11	Yassaei S et al. (2022)[27]	CBCT and Mimics ™INK.21.0.software used	1. Trained personnel required for specific landmarking 2. Landmarks on teeth present, so this method cannot be applied in cases of missing teeth.
12	Kinzinger et al. (2023)[28]	Filler quantity measurement method used on digital and plaster models	1. Requires use of morphometric analysis software
13	E. Diah et al. (2007)[29]	- CT scan - Measured using Analyze program	1. CT scan is required. 2. Boundaries defined in coronal slice only

method. To assess the reproducibility and reliability of the method, the volume was calculated twice by two different observers at two given time points.

This method saves the patient's time in the operatory and prevents unnecessary radiation exposure. It can also be taught to the assisting staff or dental technicians which may further reduce the clinician's laboratory time. Multiple calculations of the palatal volume for the same individual are also possible with respect to different phases of the orthodontic treatment, without any financial implications to the patient or the clinician, thus being economically effective.

Consideration regarding the surrounding structures of the palate such as nasal cavity, pharynx on the palatal volume has not been accounted for in this study. These surrounding structures could have a relation with palatal volume, which can be overcome by using 3D CBCT data. This is suggestive of one of the limitations of this study.

5. Conclusion

The newly proposed simplified hybrid method of palatal volume measurement demonstrates ease of acquisition, elaboration and reproduction of the models, and also avoids radiation risk to the patient. This method has also provided us with comparable accurate measurements to the conventional method of palatal volume measurement with CT scans.

Human ethics and consent to participate declarations

Not applicable.

Parents' or guardians' consent

Consent was obtained from every study participant/patient guardian before commencing the study.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobcr.2024.10.011.

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