Original Article

# Comparison of palatal volume and surface changes between bone-borne and tooth-tissue-borne maxillary expansion on cone beam computed tomography digital cast models

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**ABSTRACT**

**Objectives:** To compare the changes of palatal volume and area in patients treated with tooth-tissue-borne palatal expanders (conventional Haas) and miniscrew-supported palatal expanders (modified Haas).

**Materials and Methods:** The sample included casts of 22 patients treated as part of a clinical study at the Department of Orthodontics, Al-Azhar University, to correct their crossbite malocclusion. Patients were divided equally into two groups upon arrival. The first group, with a mean age of 12 years and 6 months, received the miniscrew-supported palatal expander. The second group, with a mean age of 12 years and 2 months, received the Haas design-palatal expansion appliance. Pre- and post-expansion dental casts were cone beam computed tomography scanned and the slices were constructed into 3D volumes. Fully automated superimposition was done for pre- and post-expansion 3D models. Palatal volume and area were determined, and all measurements were carried out blindly. Paired *t*-test was used to assess the mean differences within each group and Welch's *t*-test was applied to assess the mean changes between the two groups. Shapiro-Wilk test was used to test for the normality of the data.

**Results:** There were no statistical differences in volume changes either within each group or between the groups. Although area changes were statistically significant within each group, the difference between the groups was not significant.

**Conclusions:** Changes that result from the use of either method to expand the upper arch occur primarily in the shape of the palate, but not in its size. (*Angle Orthod.* 2023;93:282–288.)

**KEY WORDS:** Miniscrew-assisted rapid palatal expansion; Palatal volume; Three dimensional-treatment evaluation; 3D models; Digital casts; Rapid maxillary expansion

## INTRODUCTION

Rapid maxillary expansion (RME) is a universally accepted procedure for treating maxillary transverse deficiency and posterior crossbite in adolescents. The two most commonly used types of maxillary expansion appliances are the tooth-borne and bone-borne expanders.[1] Bone-borne expanders consist of a rapid palatal expander supported by four orthodontic miniscrews in the palate.[2,3]

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The forces applied by the tooth-borne expander may result in undesirable effects such as buccal tipping of supporting teeth, root resorption and periodontal-related side effects.[4,5] Additionally, the reported results showed that the suture opening as a result of the use of conventional RME designs was approximately less than or equal to half of the total maxillary expansion.[6] Likewise, bone-borne devices have disadvantages, which should be weighed in terms of the high cost, sensitivity of the technique, and failure rate.[7] Bone-borne expanders were primarily developed to apply forces directly to the palate.[8] Applying the expansion forces directly to the palatal plates of bone would avoid potential dehiscence effects of the buccal bone of the anchored teeth, thereby increasing the expander's orthopedic influence. In adolescent patients with narrow upper jaws, there have been research studies examining the efficacy of hybrid rapid palatal expansion, in which the RME device is anchored on both teeth and mini-implants.[5,9] Others have evaluated bone-borne expanders anchored only with mini-implants.[10] Such studies were designed to determine whether there was any additional orthopedic contribution to maxillary expansion by adding miniscrew anchorage at such young ages. More research is needed to investigate the potential superiority of miniscrew-supported maxillary expanders over Hyrax or Haas expanders in different age groups.[3,11]

Dental and skeletal effects after maxillary expansion have been evaluated using direct measurements on dental casts and x-rays, either posteroanterior or occlusal images. The use of two-dimensional analytical methods to extract evidence of expander efficiency has become less desirable after the development of three-dimensional (3D) digital technology.[8] Digital models have replaced traditional plaster models and are now a practical choice, especially as intraoral scanners have become affordable over time.[12–16]

Scanners have been used by researchers to measure palatal parameters. However, the impossibility of defining the surrounding space and converting mesh surface models into volumetric data similar to cone beam computed tomography (CBCT) has required measurement of palatal volume using either geometry or reverse engineering technology, the accuracy and reproducibility of which has not yet been assessed.[16–20]

Scanning plaster casts using CBCT is a method by which the researcher does not need any other scanning equipment.[21,22] Another advantage of using CBCT over the use of optical and laser scanners is the ability to select the palatal space directly as a volume with zero radio density.[23,24]

Digital models driven from dental casts can provide volumetric information and also can be used to evaluate changes after expansion therapy.[25] A comparison of tooth-borne and bone-borne expanders using a reliable and reproducible digital method may provide an answer to the question of which of the two expansion treatment modalities, tooth-borne or bone-borne, is more efficient.

This study aimed to use pre- and post-expansion digital models to compare changes related to two designs of Haas expanders: tooth-tissue-supported maxillary expanders vs miniscrew-supported maxillary expanders. Changes in the palatal volume and area were evaluated to determine whether either of the two expander designs had an orthopedic effect on the size of the palate.

## MATERIALS AND METHODS

This randomized, parallel-group, prospective clinical study was conducted on 22 adolescent patients, who were treated in the Orthodontic Department, Al-Azhar University, Cairo, Egypt. The sample size of 22 models of the subjects was set to detect an effect size coefficient of 0.8 for both palatal parameters (surface area and volume).[10] The study was approved by the ethical committee of Al-Azhar University, (approval number REC16-032), in addition to the University of Campania, Naples, Italy (approval number 24797/2018).

Study participants included were adolescent patients who sought treatment for a constricted maxilla with either a unilateral or bilateral posterior crossbite. None of the subjects had a previous history of extraction of any permanent teeth, or orthopedic or orthodontic treatment. Cases with any congenital anomaly, history of craniofacial injury, or active periodontal disease were excluded. The sample included eight females and 14 males, ranging in age from 11 years, 5 months to 14 years, 3 months. The sample was evenly randomized. Upon the arrival of an eligible patient at the clinic, they were asked to pick a sealed opaque envelope, which indicated the group allocation. Patients in the first group (group 1) with a mean age of 12 years, 6 months, were treated with bone-borne rapid palatal expansion (Figure 1) in which the expander was supported with four palatal miniscrews (Infinitas mini implant DB10-0004; DB Orthodontics, West Yorkshire, United Kingdom). The second group (group 2), with a mean age of 12 years 2 months, received a Haas appliance that was supported on the teeth and the palatal tissue for expansion (Figure 2). The same expansion screw was used in both groups (Anatomic Palatal Split Screw "S," 13 mm; A7- 1326; Forestadent, St. Louis, MO, USA). The expansion screw was turned a single turn (0.25 mm) daily until the palatal cusps of the maxillary first molars came into contact with the

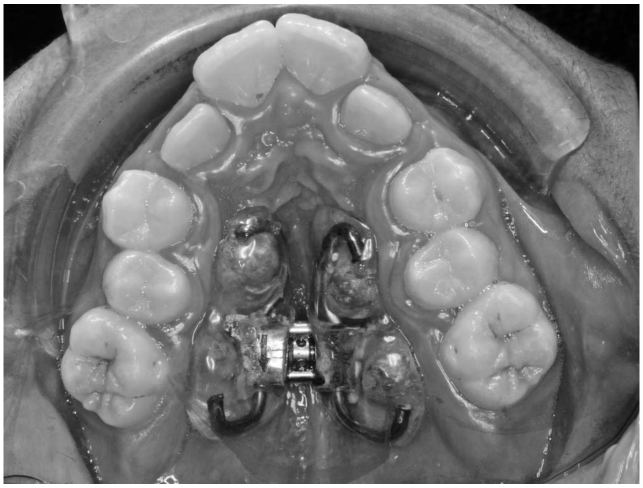

**Figure 1.** Maxillary occlusal view showing the modified Haas supported on four miniscrews.

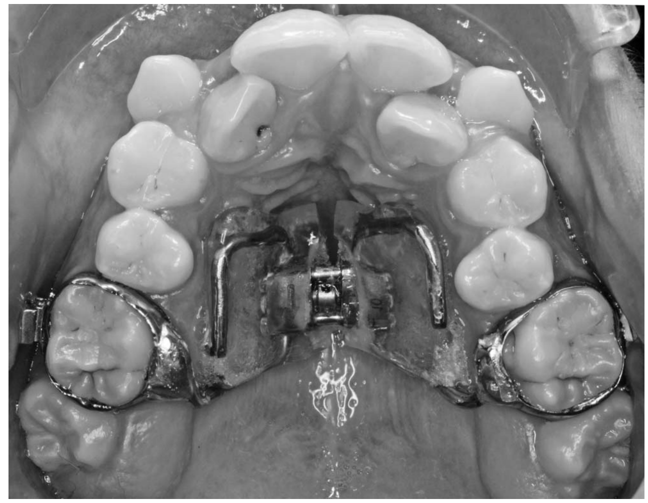

**Figure 2.** Maxillary occlusal view showing the conventional Haas appliance cemented on the first maxillary molars.

buccal cusps of the mandibular first molars. Alginate impressions of the maxillary arch were taken at two timepoints: at the start of treatment (T1), and upon removal of the device after expansion and retention periods (T2) (mean: 29.6 weeks, SD $\pm$ 3 weeks).

SCANORA 3D (Soredex, Tuusula, Finland) was used to scan pre- and post-expansion dental casts. Imaging criteria were 15 mA, 85 kV, and 20 seconds. Scans were saved as Digital Imaging Communication of Medicine (DICOM) with thickness of 0.35 mm, depth of 16 bits, and dimensions of 414 $\times$ 414 mm. Slices were assembled into 3D volume by Viewbox 4.0.1.7 software (DHAL Software, Athens, Greece).

All measurements were carried out blindly. Palatal volume and area were determined using the protocol described by Shahen et al.[25] The volume-extracted surface mesh was the superimposition guide so the pre- and post-expansion digital models were superimposed using the palatal-surface-best fit automation. The most cervical points, where the clinical crowns met the gingival margin of the teeth distal to the lateral incisors, were identified on the pre-expansion model (Table 1).[25]

Palatal pre- and post-expansion volume and area included within the boundaries of the pre-gingival plane, distal plane, and lateral border were measured (Figure 3) and exported to an Excel sheet for statistics. The statistical package used for this study was R statistical package, version 3.5.2 (12-20-2018, Vienna, Austria), Palatal volume and area were described in terms of mean and standard deviation (SD). To test the normality of the data and then select the appropriate comparison tests, the Shapiro-Wilk test for normality was applied. For normally distributed data, the parametric Welch's *t*-test was used to assess the mean differences between the two groups for numerical data (area and volume). Paired *t*-test was used to assess the mean difference within each group. Statistical significance was set at $P \leq .05$.

## RESULTS

The data were normally distributed (Table 2). There were no statistically significant differences found in the palatal volume changes within each group or between the two groups.

Area changes were statistically significant within each group. The area changes were not significantly different between the two groups (Table 3).

**Table 1.** Definitions of Points, Lines, and Planes for 3D Measurements

| Point/Line/Plane/Border | Definition |
|---|---|
| R- L lines | intermediate imaginary lines between the most cervical points of canines, premolars, and molars bilaterally on pre-expansion model |
| R- L canine and molar projections | projections from the gingival margins of the canine and first molar to R- L lines on pre-expansion model |
| Mid-canine | point midway between R- L canine projection points on pre-expansion model |
| Pre-gingival plane | created from three points: mid-canine and R- L molar projection points on pre-expansion model to be used for superimposed pre- and post-expansion cast models |
| Pre- and post-distal plane | perpendicular plane to the gingival plane passing through line connecting the two first molars projections |
| Pre- and post-lateral border | the lateral border defining the volume and area |

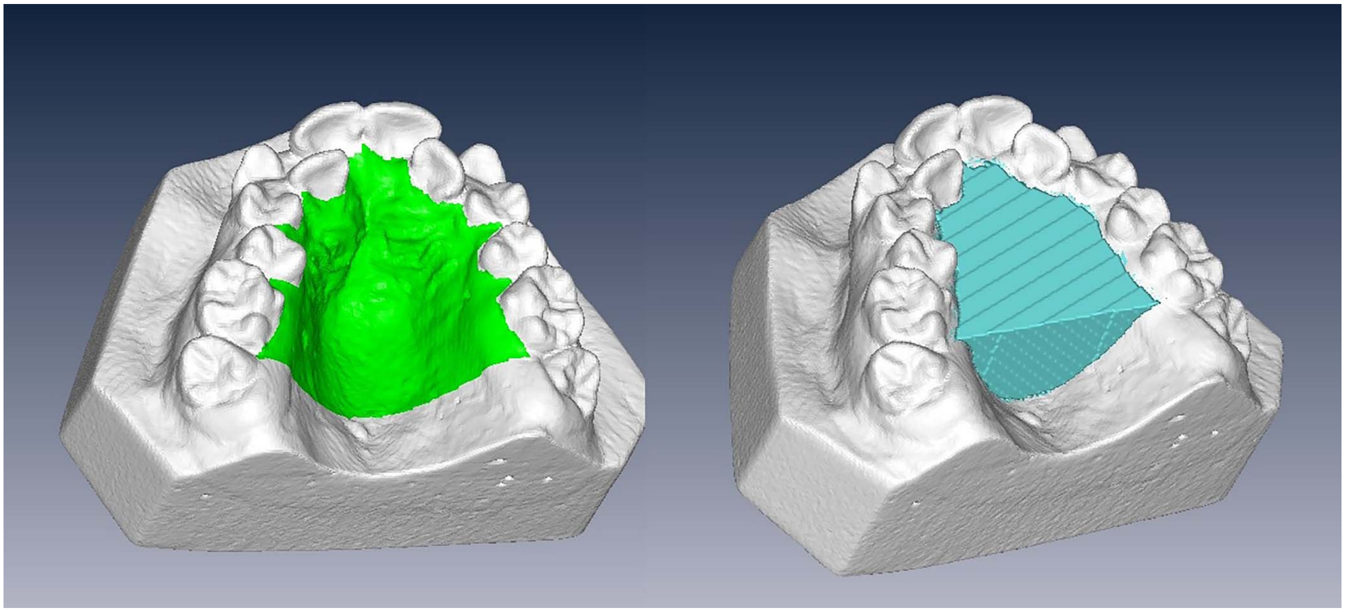

**Figure 3.** Area and volume measurements on CBCT digital cast models. CBCT indicates cone beam computed tomography.

- **Volume:** In group 1 (miniscrew-supported Haas), the mean volume at baseline was 638.2 (±116.19) $mm^3$, which increased to 770.4 (±152) $mm^3$; this change was not statistically significant ($P > .05$). In group 2 (tooth-tissue-supported Haas), the mean volume at baseline was 751 (±26.75) $mm^3$, which increased to 909.5 (±149.64) $mm^3$; this change was not statistically significant ($P > .05$). Comparison between the groups showed that there was no significant difference in volume changes between groups 1 and 2 (Table 3).
- **Area:** In group 1, the mean area at baseline was 938.2 (±102.9) $mm^2$, which increased to 1071.2 (±141.15) $mm^2$; this change was statistically significant ($P < .05$). In group 2, the mean area at baseline was 1010.5 (±45.73) $mm^2$, which increased to 1165.75 (±95.57) $mm^2$; this difference was also statistically significant ($P < .05$). However, there were no significant differences between the magnitudes of the increases observed in the two groups ($P > .05$) (Table 3).

**Table 2.** Shapiro-Wilk Test for Normality of Differences Between Readings Pre- and Post-Expansion in Both Treatment Groups

| | | Shapiro-Wilk Test | |
|---|---|---|---|
| | | *P* Value* | Interpretation |
| Miniscrew-supported | Change in volume | .1191 | Data are normally distributed |
| | Change in area | .9607 | |
| Tooth-supported | Change in volume | .2329 | |
| | Change in area | .3369 | |

* Significance level at $P$ value $\leq .01$.

## DISCUSSION

To investigate the changes of the palate after RME, some studies have included one group of treated subjects[1,3,7,18,19,26,27] in which post-expansion parameters were compared to those at baseline. The data from these studies do not provide enough detailed information for orthodontists to choose among the multiple options of maxillary expansion appliances currently available. Conventional cast models can only provide linear measurements,[7] while digital models allow measurement of area and volume, and evaluation of symmetry[28] There have been some studies that used digital models to assess the effect of RME on the upper arch.[5,21,26,27,29,30] These studies relied either on digital photogrammetric techniques or scanned the models by optical or laser scanners to reproduce 3D models, thus being able to measure palatal area in addition to dental arch-related changes. The reliability of these previously used methods to retrieve quantifiable 3D data was questionable. Reverse-engineering software was used to reconstruct digital 3D models so that a 3D variable such as volume could be measured.

DICOM files, which are derived from CBCT scans as in the current study, enable selection of a radiolucent area directly around the defined boundaries. Conversely, STL files necessarily provided by laser or optical scanners, require indirect measurements that are produced geometrically or by reverse engineering.[17,18]

The ease of processing data provided by CBCT scans of the dental models was another advantage. On the other hand, CBCT scans performed on patients

**Table 3.** Descriptive Analysis of Palatal Volume and Area Within and Between Groups

| | | | | | | | Mean Difference (Change) | | Relative Difference (Percentage Change) | | Within-group Comparison Paired *t*-Test | Between-Groups Comparison |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | Min | Max | Mean | SD | Mean | SD | *P* Value* | *P* Value* |
| Volume | Miniscrew-supported | Pre | 638.2 | 116.19 | 505 | 794 | 132.2 | 130.38 | 21.96 | 24.75 | .086 | .7711 (Mean difference = 26.3, 95% CI: −181.36, 234) |
| | | Post | 770.4 | 152 | 533 | 902 | | | | | | |
| | Tooth-supported | Pre | 751 | 26.75 | 717 | 782 | 158.5 | 128.54 | 20.78 | 16.48 | .0904 | |
| | | Post | 909.5 | 149.64 | 779 | 1066 | | | | | | |
| Area | Miniscrew-supported | Pre | 938.2 | 102.90 | 780 | 1059 | 133 | 73.79 | 14.16 | 7.19 | .0157 | .6957 (Mean difference = 22.25, 95% CI: −110.34, 154.84) |
| | | Post | 1071.2 | 141.15 | 901 | 1286 | | | | | | |
| | Tooth-supported | Pre | 1010.5 | 45.73 | 946 | 1054 | 155.25 | 86.01 | 15.41 | 8.50 | .0365 | |
| | | Post | 1165.75 | 95.57 | 1054 | 1283 | | | | | | |

may be affected by artifacts and distortions due to the fact that the palatal surface has similar Hounsfield units to that of the tongue, soft palate, and muscles. As a result, segmentation of those scans is relatively difficult[25,31] compared to CBCT scans on casts which, in turn, provide excellent soft-tissue reproduction.[22,32,33]

The idea behind the development of the method used in this study was to use the same reference plane to measure changes between the pre- and post-expansion records. This enabled the same operator or even different operators to obtain reproducible and comparable results. Given that dental landmarks change as a result of orthodontic treatment or growth, double identification of a reference plane using dental landmarks on teeth affected by the treatment could be unreliable. Therefore, to minimize that effect, a gingival plane was identified once for the superimposed pre- and post-expansion virtual models.[25,34] Additionally, the assessment of the superimposition of the 3D models has been proven to be as clinically reliable as cephalometric superimposition in cases of RME.[27]

Some authors[18,26] concluded that there was an increase in volume and area after expansion, which may have been caused by identifying the gingival plane reference twice, ie, on models both pre-and post-treatment. However, in the current study, the gingival plane was identified only once on the superimposed models. Therefore, although the volume increased, it did not change significantly, whereas there was a significant increase found upon measuring the changes in palatal area in each group.

The changes that occurred in palatal area could be interpreted as an alteration in the shape of the upper arch due to, most likely, a reduction of the palatal vault height. Geometrically, if there is a sphere with a specific size "volume," any deformation of its shape "area" will result in changing surface area without changing the volume. The effect of reduced height of the palate after expansion could not be detectable without correct 3D analysis. Thus, the method used in the present study helped discern a precise rationale about the changes in the volume "size" and modified shape "area" after palatal expansion. Therefore, it is important to use the same reference for both pre- and post-treatment records to provide a descriptive measure of the palatal volume and how it changed due to treatment.[25,34,35]

## CONCLUSIONS

- There was no statistically significant difference in the changes in volume and area due to expansion between the tooth-tissue-supported Haas-type RME and the miniscrew-supported Haas-type RME.
- Among subjects with each expansion group, significant increases were observed in palatal area due to expansion but increases in volume were not significant.
- Using a reliable method to superimpose and evaluate pre- and post-expansion models, the changes observed resulting from both methods of expansion were mainly in the shape "area" of the palate but not in its size "volume."
- From the results observed after treating constricted maxillae in adolescent patients, there is no significant difference in outcomes observed between using miniscrew-supported Haas expanders compared to conventional Haas appliances in terms of the size increase of the palate.

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