401 N. Lindbergh Blvd.
St. Louis, MO 63141
Tel.: 314.993.1700, #546
Toll Free: 800.424.2841, #546
Fax: 800.708.1364

Send via email to: jbode@aaortho.org and cyoung@aaortho.org

AAO Foundation Final Report Form
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In an attempt to make things a little easier for the reviewer who will read this report, please consider these two questions before this is sent for review:

- *Is this an example of your very best work, in that it provides sufficient explanation and justification, and is something otherwise worthy of publication? (We do publish the Final Report on our website, so this does need to be complete and polished.)*
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Type of Award, e.g., Orthodontic Faculty Development Fellowship Award

Name(s) of Principal Investigator(s): Mohamed Bazina

Institution: University of Kentucky

Title of Project: Three-dimensional Voxel-based Maxillary Superimposition for Everyday Practice

Period of AAOF Support: (07-01-2019 to 06-30-2021):

Amount of Funding: 20,000$

Summary/Abstract:

Introduction: Cephalometric superimpositions have many uses in orthodontics, including growth evaluation and outcome assessment. However, two dimensional cephalograms can be distorted and yield incomplete two-dimensional data. CBCT imaging provide a three-dimensional, undistorted and more complete patient analysis. CBCT imaging provides many unique advantages to the orthodontic practice and influences how treatment outcomes are assessed. The aim of this study was to investigate the validity of 3D maxillary voxel-based superimpositions compared to the 2D method recommended by the American Board of Orthodontics (ABO). **Methods**: This retrospective study included pre- and post-treatment

CBCT images of 30 adolescent patients. The images were superimposed using the 3D voxel-based tools in Dolphin software. Two different 3D anatomic registration areas (3DA-3DB) were tested for the precision and reproducibility of the 3D maxillary superimpositions as compared to the 2D method using linear and angular measurements looking at the dental changes of the upper right central incisor (U1) and first molar (U6). **Results**: The U1 vertical difference was statistically significant (p=8e-7) for the superimposition method, though the mean differences were clinically insignificant (0.52 mm, 0.76 mm). The U1 angular and U6 vertical difference were not significant for the superimposition method (p=0.3636 & 0.1242, respectively). **Conclusions**: The 3D voxel-based maxillary superimpositions using Dolphin software program showed similar results to conventional 2D superimposition recommended by the American Board of Orthodontics.

Detailed results and inferences:

1. If the work has been published, please attach a pdf of manuscript OR
   We are in the process of submitting this paper to the AJODO for publication.

2. Describe in detail the results of your study. The intent is to share the knowledge you have generated with the AAOF and orthodontic community specifically and other who may benefit from your study. Table, Figures, Statistical Analysis, and interpretation of results should be included.

   Statistical Analysis: The mean differences between the two methods of three-dimensional voxel-based registration was evaluated. The data for each variable (change in maxillary right central incisor angulation, change in the vertical position of the maxillary right central incisor, and the change in the vertical position of the maxillary right first molar) for each of the three superimposition methods was assessed for normality using the Shapiro-Wilk W test ($p<0.05$) for the data for each variable. (Shapiro and Wilk, 1965) The intraclass correlation coefficient (ICC) was determined by independently remeasuring ten subjects for all variables using the two-way mixed-effects model for a single rater (SPSS 27, IBM). All were equal or greater than 0.9, indicating excellent reliability. [8,9] The data was normally distributed for each of the three superimposition types by Shapiro-Wilk test ($p\geq 0.08$).[10] A Mixed Model ANOVA was done to compare the three superimposition types within each subject. (JMP Pro 14.3.0)

   RESULTS
   The U1 vertical difference with all 30 subjects was significant for superimposition type (p=8e-7). The U1 angular difference and the U6 vertical difference were not significant for superimposition type (p=0.3636, p=0.1242 respectively). These results and the mean differences can be found in **Tables I, II, and III,** respectively.

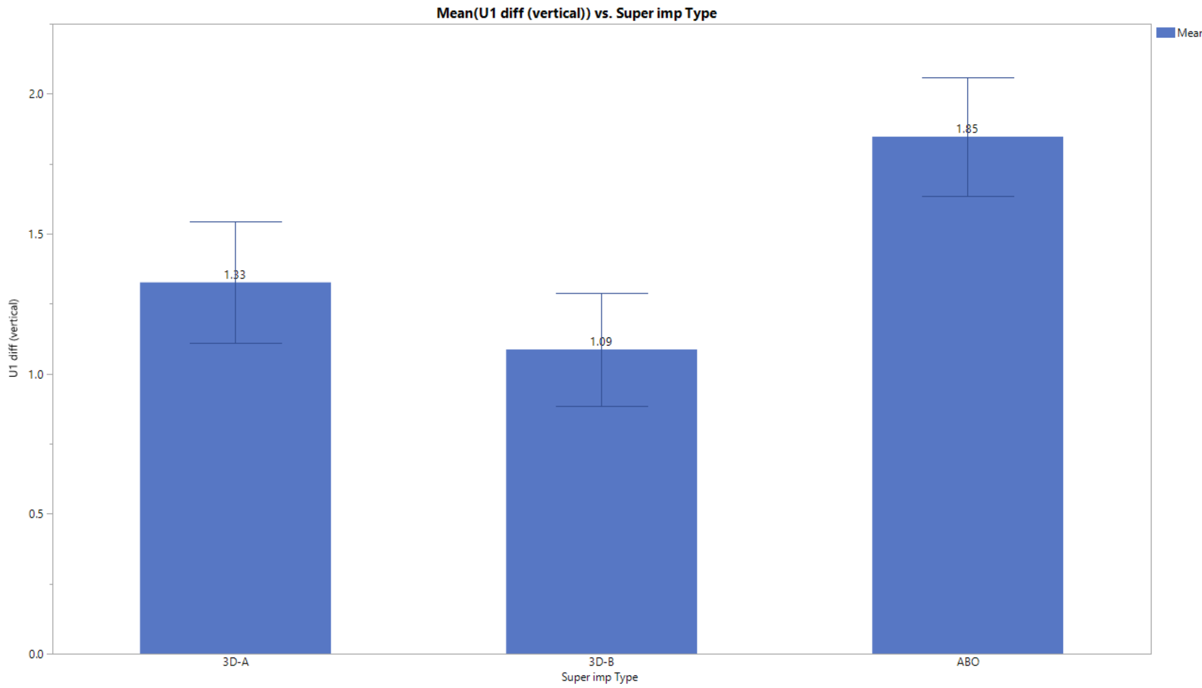

Table-1: Mean vertical differences of the upper right central incisor between the 3 superimposition types

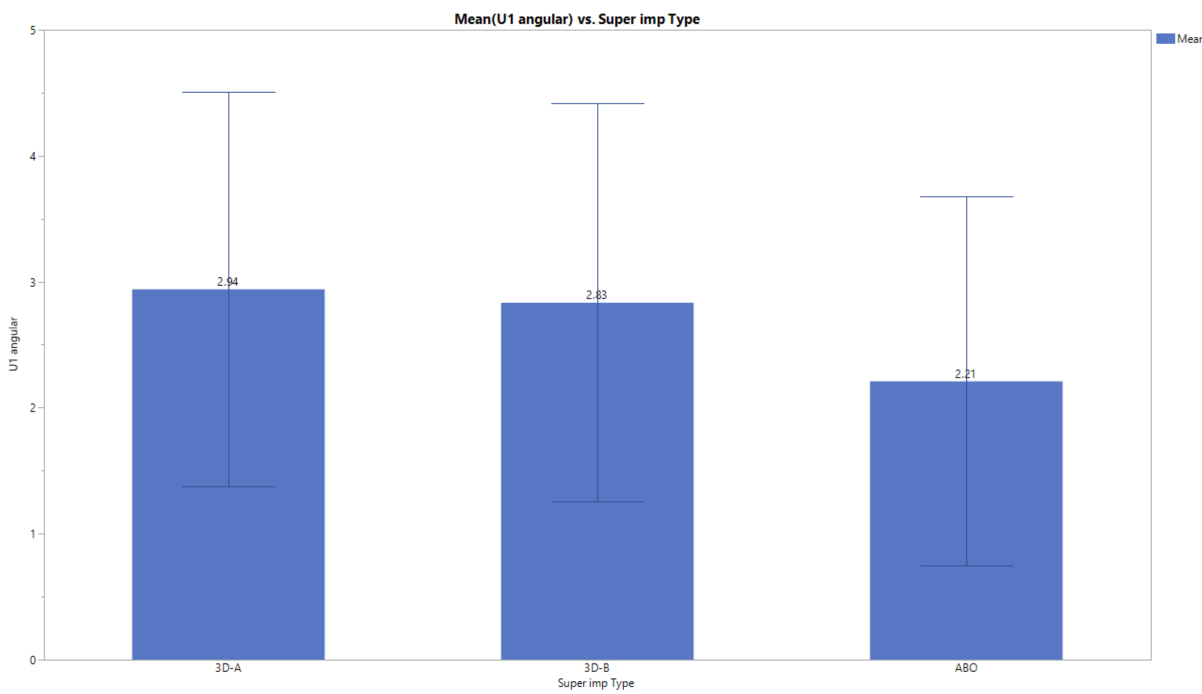

Table-2: Mean angular differences of the upper right central incisor between the 3 superimposition types.

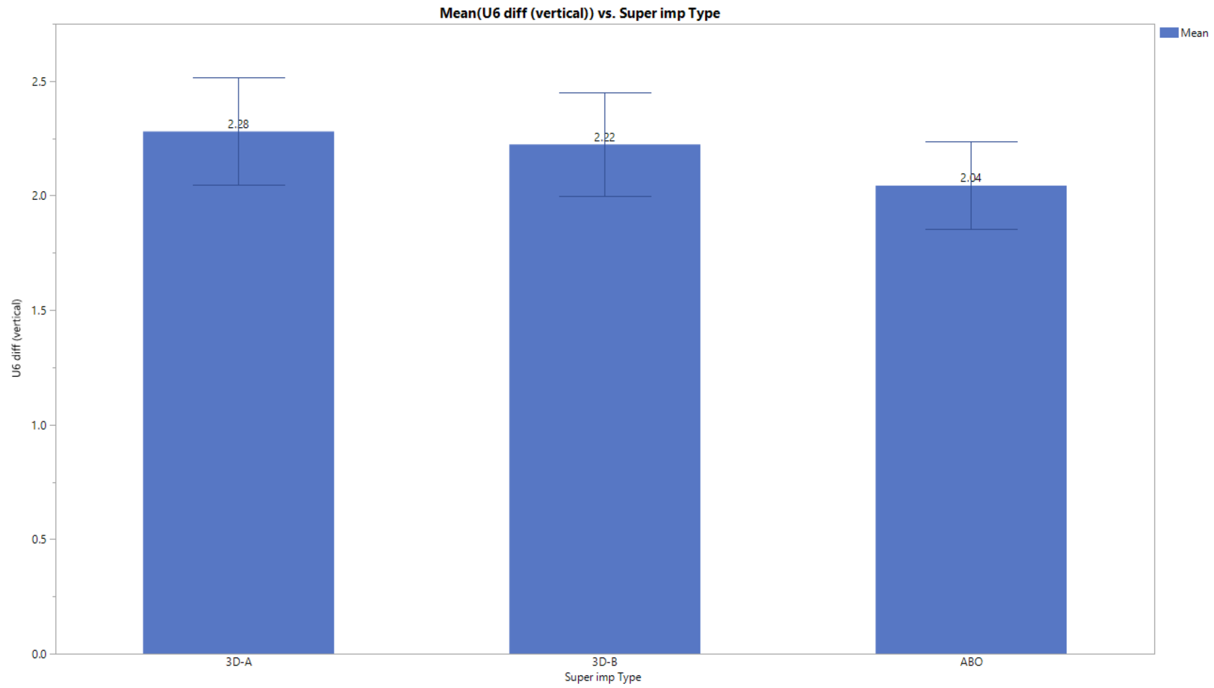

Table-3: Mean vertical differences of the upper right first molar between the 3 superimposition types

<u>Respond to the following questions</u>:

1. Were the original, specific aims of the proposal realized? Yes, the aim of the study was to test a user-friendly software program for precision and reliability of 3D maxillary superimposition, and we believe that our study answered that question.

2. Were the results published? Not yet. We are in the process of submitting the paper to AJODO
   a. If so, cite reference/s for publication/s including titles, dates, author or co-authors, journal, issue and page numbers
   b. Was AAOF support acknowledged? The AAOF support will be acknowledged
   c. If not, are there plans to publish? If not, why not? Yes
3. Have the results of this proposal been presented?
   a. If so, list titles, author or co-authors of these presentation/s, year and locations. Yes, my student presented this paper for the Proffit award this year (2021) and won the second place. I am planning to present it to the Angle Midwest group in the near future.
   b. Was AAOF support acknowledged?
   c. If not, are there plans to do so? If not, why not? The AAOF support will be acknowledged when I present the paper to the Angle group
4. To what extent have you used, or how do you intend to use, AAOF funding to further your career? AAOF fund was and will be very helpful for junior faculty members like myself.

<u>Accounting for Project</u>; (i.e.), any leftover funds, etc. 1091$ is leftover

Comparison of two 3-dimensional user-friendly voxel-based maxillary and 2-dimensional superimposition methods

Shelby Sheeran,[a] James Hartsfield, Jr,[a] Galal Omami,[b] and Mohamed Bazina[a]
Lexington, Ky

Introduction: Cephalometric superimpositions have many uses in orthodontics, including growth evaluation and outcome assessment. However, 2-dimensional (2D) cephalograms can be distorted and yield incomplete 2D data. Cone-beam computed tomography (CBCT) imaging provides a 3-dimensional (3D), undistorted, and more complete patient analysis. CBCT imaging provides many unique advantages to the orthodontic practice and can influence how treatment outcomes are assessed. This study aimed to investigate the validity of 3D maxillary voxel-based superimpositions compared with the 2D method recommended by the American Board of Orthodontists. **Methods:** This retrospective study included pretreatment and posttreatment CBCT images of 30 adolescent patients. The images were superimposed using the 3D voxel-based tools in Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, Calif). Two different 3D anatomic registration areas (3DA-3DB) were tested for the validity and reproducibility of the 3D maxillary superimpositions as compared with the 2D method. Linear and angular measurements were used to evaluate the dental changes of the maxillary right central incisor and first molar. Data distribution was normal by the Shapiro-Wilk W test. A mixed model analysis of variance test was done to compare the 3 superimposition types within each subject, followed by pairwise Tukey-Kramer comparisons when indicated. **Results:** After applying the Benjamini-Hochberg procedure to control the false discovery rate at 0.05 with multiple testing, the U1 vertical difference was statistically significant (P <0.0001) for the superimposition method, though the mean differences were clinically nonsignificant (0.52 mm, 0.76 mm). The U1 angular and U6 vertical differences were not statistically significant for the superimposition method (P = 0.3636 and P = 0.1863, respectively). **Conclusions:** The 3D voxel-based maxillary superimpositions showed similar results to conventional 2D superimpositions recommended by the American Board of Orthodontists. (Am J Orthod Dentofacial Orthop 2023;163:117-25)

Serial cephalometric radiographs have been used to understand facial growth and to determine relatively stable areas that can be used as references to evaluate dental changes because of growth or treatment.[1] Superimposition on stable maxillary structures can be used to evaluate the effects of treatment in the maxillary dentoalveolar complex. Multiple maxillary registration methods have been proposed in the literature. Guy and McNamara[2] proposed using the best fit of the internal palatal structures for maxillary superimposition. However, the metallic implants method, as reported by Björk,[3] remains the gold standard. Based on the findings of Björk,[3] the American Board of Orthodontics (ABO) recommends using the anterior surface of the zygomatic process as a primary anterioposterior (AP) structure and the maxillary zygomaticotemporal sulcus as a secondary AP structure for registration.[4] Vertically, the orbital floor and the nasal floor are recommended. The distance between the 2 floors increases during growth, so the ratio of 3:5 apposition at the floor of the orbit and 2:5 resorption at the floor of the nose should be used to align the 2 tracings in the vertical dimension (Fig 1).[5]

Three-dimensional superimpositions offer many advantages over 2-dimensional images. These advantages include larger volumes or areas of registration (rather than lines or points), which can improve the reliability

[a]Division of Orthodontics, College of Dentistry, University of Kentucky, Lexington, Ky.
[b]Division of Oral Medicine, College of Dentistry, University of Kentucky, Lexington, Ky.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Address correspondence to: Mohamed Bazina, Division of Orthodontics, College of Dentistry, University of Kentucky, 770 Rose St, D408, Lexington, KY 40536; e-mail, bazina018@uky.edu.
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0889-5406/$36.00

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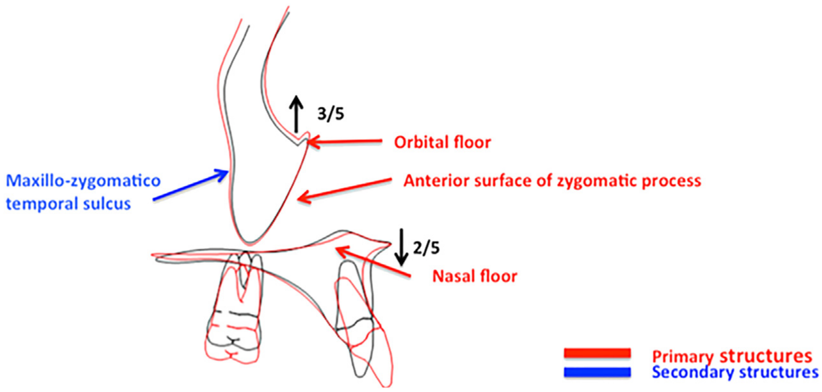

Fig 1. Regional maxillary superimposition as recommended by the ABO.

of the registration. In addition, the lack of distortion and fewer head positioning errors make 3D imaging superior to the traditional methods.[6] Three-dimensional superimposition allows the clinician to evaluate structures previously obstructed on lateral cephalograms and unilateral or asymmetrical changes because of growth or treatment. However, anatomic structures reported to be stable on a lateral cephalogram may not be reliable for 3D analysis, which involves the transverse dimension. Ruellas et al[7] described 2 regions of reference for the 3D voxel-based maxillary registration and found both to be very similar (<0.5 mm) with adequate reproducibility. However, although this method is precise, it is time-consuming and not practical to use in everyday clinical practice.

Recently, commercially available imaging software programs (Dolphin Imaging [Dolphin Imaging and Management Solutions, Chatsworth, Calif], Invivo [Anatomage Inc, San Jose, Calif], and OnDemand [CyberMed, Seoul, South Korea]) developed fast and user-friendly algorithms that allow clinicians to do regional superimpositions to evaluate dental changes (Fig 2). These algorithms need to be tested for validity to ensure their widespread use yields precise and reliable results. Few studies have evaluated the accuracy and reliability of the 3D maxillary superimposition methods, especially in growing patients, and a gap in the literature comparing the 3D maxillary superimposition techniques to the traditional 2D methods. The null hypothesis of this study is that there is no difference between the proposed 3D maxillary superimpositions and the 2D method recommended by the American Board of Orthodontics (ABO) in evaluating the maxillary dental changes that occurred because of growth or treatment.

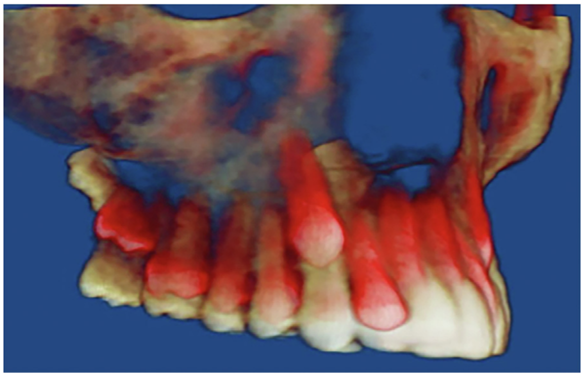

Fig 2. Regional voxel-based maxillary superimposition using Dolphin Imaging software. *Red* is the initial scan, whereas *brown* is the final scan, with the difference between the 2 showing dental changes.

MATERIAL AND METHODS

This project was approved by the Institutional Review Board at the University of Kentucky (approval number 50521). The sample was collected from the Craniofacial Imaging Center at Case Western Reserve University and analyzed at the University of Kentucky. The sample included the initial and final deidentified cone-beam computed tomography (CBCT) images of 30 patients (15 males, 15 females) with a mean age of 12 years (range, 11-13 years at pretreatment [T1]) (Table 1). All scans were taken using the CB MercuRay scanner (Hitachi Medical Systems America Inc, Twinsburg, Ohio) at 100 kV, 2 mA, 12-in field of view, 4096 gray scale, 0.38 mm voxel size, and scan time of 9.5 seconds. Those excluded were patients with posterior crossbites,

Table I. Patient demographics

Demographics	*n*
Gender (n = 30)	
Male	15
Female	15
Total	30
Age at T1 (n = 30), y	
11	9
12	12
13	9
Total	30

patients with craniofacial anomalies, and distorted or incomplete images. All images were analyzed by 1 researcher (S.S) using Dolphin Imaging software, which was chosen because it is the most used software in graduate orthodontic programs (97% of programs) and private practices.

Each of the 30 adolescent patients had T1 and post-treatment (T2) CBCT scans taken by the same machine and exposure parameters. The volumes were oriented using axial, coronal, and sagittal views, as previously described by Ruellas et al.[8] For the 2D superimpositions, lateral cephalometric films were generated from each CBCT scan, using only the right side of the face, and saved into the appropriate time point. The 2 time points were superimposed according to ABO recommendations. These vertical and angular measurements were used to evaluate the dental changes in these patients. Measurements were completed as follows (Fig 3):

1. Maxillary right central incisor (U1) angular change: The angle between the long axes of U1 at T1 and T2 was measured and labeled as U1 angular. If U1 was proclined, a positive value was given, whereas a negative value was given if it was retroclined (Fig 3).
2. U1 vertical change: A horizontal reference line passing through ANS-PNS was constructed. From this horizontal line, a vertical line was dropped at a 90° angle to the incisal edge of each U1 from the 2 time points. The difference between T2 and T1 was calculated and labeled as U1 vertical, with a negative value representing intrusion and a positive value representing extrusion (Fig 3).
3. Maxillary right first molar (U6) vertical change: Similar to U1 vertical change, a vertical line was dropped at a 90° angle from the horizontal reference line to the mesiobuccal cusp of the U6 from the 2 time points. The measurements of these 2 lines were then subtracted and labeled as U6 vertical, with a negative value representing intrusion and a positive value representing extrusion from T1 to T2 (Fig 3).

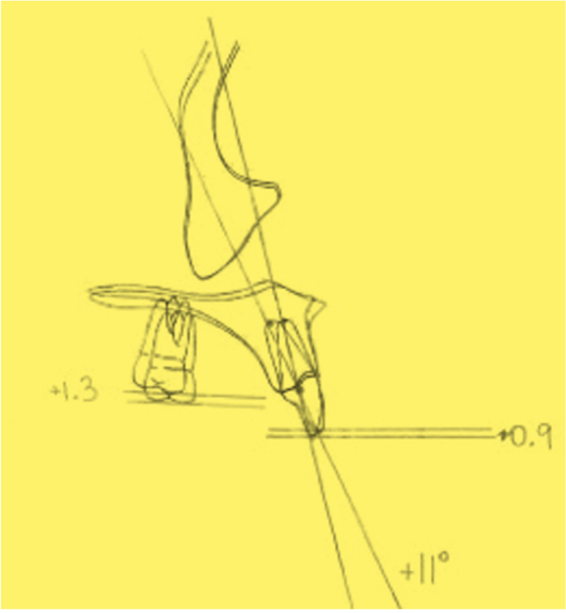

Fig 3. Example of 2D measurements taken to quantify the dental changes in the maxilla.

For the 3D superimpositions, the volumes were segmented, and the T1 and T2 maxillae were saved as separate digital imaging and communications in medicine files (T1 and T2Max). The first was labeled T2AMAX. Because Dolphin software uses a box to define the registration area, a second T2 maxilla (T2Bmax) was constructed by removing the midline structures around the nasal cavity (Fig 4, *A* and *B*). The T2A and T2B maxillae were registered on T1 maxillae using a key ridge (the registration area can be seen in Fig 5). After the superimposition step, the dental changes were evaluated by measuring the angular and linear (vertical) changes in the position of the U1 and linear (vertical) changes in the position of the U6. Each measurement for the 3D superimpositions was completed as follows:

1. U1 angular change: the angle between the long axes of U1 at T1 and T2 was measured and labeled as U1 angular. If the maxillary central incisor was proclined, a positive value was given, and if it was retroclined, a negative value was given (Fig 6, *A*).
2. U1 vertical change: A horizontal reference line passing through ANS-PNS was constructed. From this horizontal line, a vertical line was dropped at a 90° angle to the incisal edge of each U1 from the 2 time points. The difference from T2 to T1 was calculated and labeled as U1 vertical, with a negative value representing intrusion and a positive value representing extrusion (Fig 6, *B*).

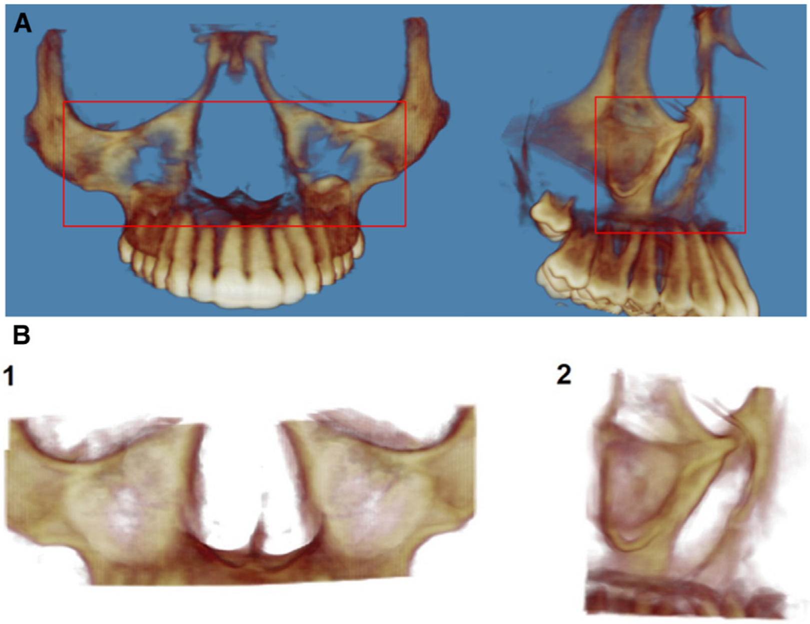

Fig 4. **A,** Shows the anterior and side view of the 3D rendering of the nasomaxillary complex. The *red* bow shows the area used for registration; **B,** Shows the anterior and side views of the segmented area used for registration.

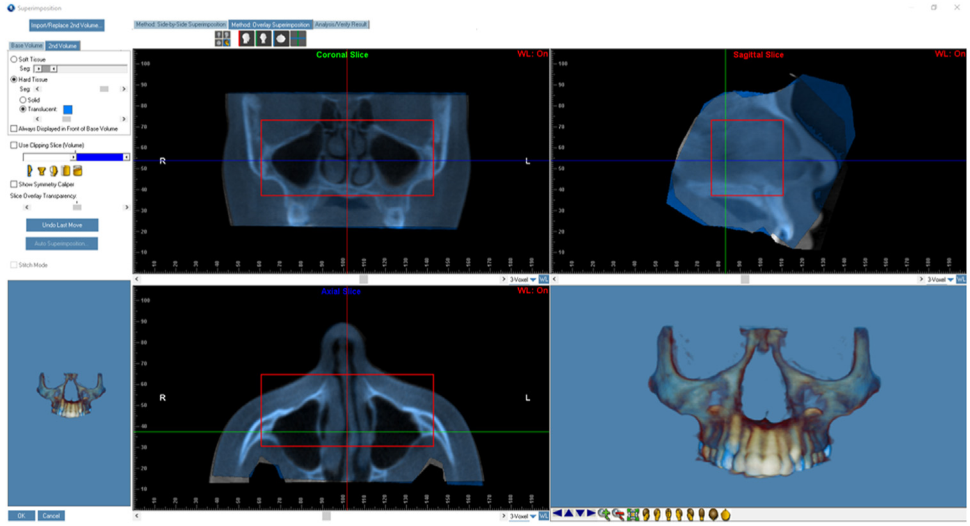

Fig 5. The area of registration is defined within the box (*red*). The superior limit is the infraorbital rim, the inferior limit is the floor of the nasal cavity, the anterior limit is A point, the posterior limit is just distal to the maxillary first permanent molars, and the transverse limits are the key ridges on both sides. In addition, the superimposed models are shown T1, *blue*; T2, *brown*.

3. U6 vertical change: The maxilla was oriented with the axial plane passing through ANS-PNS. From the coronal view, the axial plane was adjusted to ensure its parallel to the palatal plane then the coronal slice was adjusted to show the most accurate view of the mesiobuccal cusp of the U6. A vertical line was dropped at a 90° angle from the palatal plane to the mesiobuccal cusp tip of U6 from the

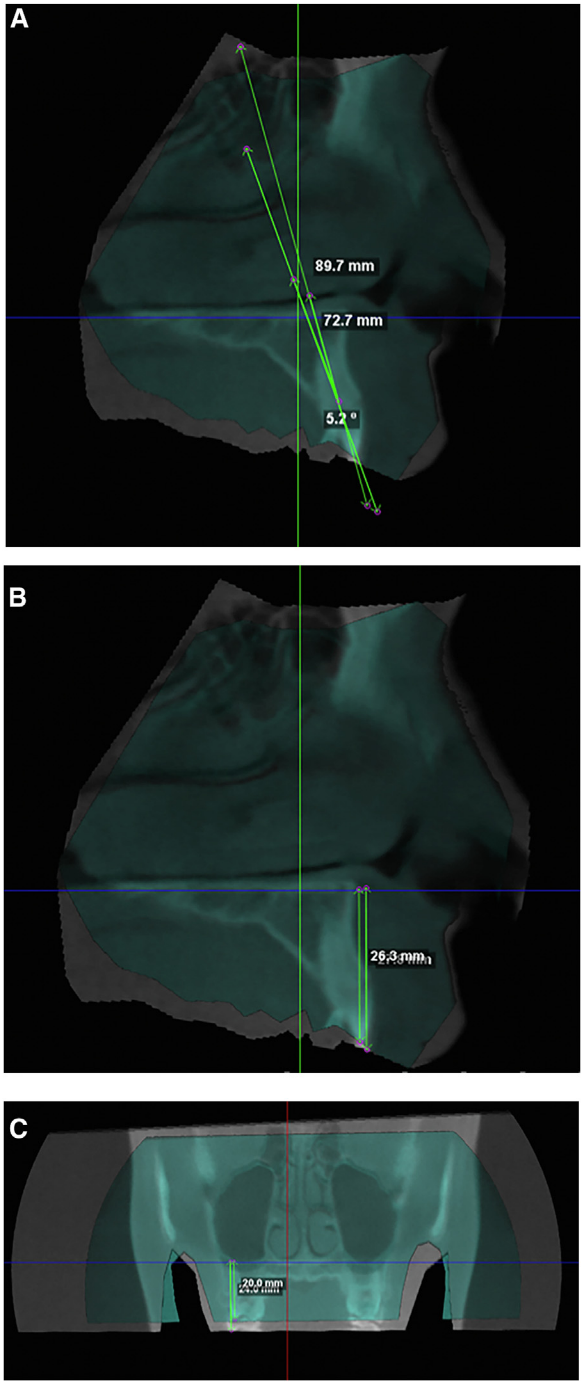

Fig 6. A, Example of 3D measurements taken for an angular change in the UR1; **B,** Example of 3D Measurements taken for a vertical change in the UR1; **C,** Example of 3D measurements taken for a vertical change in the UR6.

2 time points. The measurements of these 2 lines were then subtracted and labeled as U6 vertical, with a negative value representing intrusion and a positive value representing extrusion (Fig 6, *C*).

Statistical analysis

The intraclass correlation coefficient was determined by independently remeasuring 10 subjects for all variables using the 2-way mixed-effects model for a single rater (version 27, SPSS; IBM, Armonk, NY). All were ≥0.9, indicating excellent reliability.[9,10] The data for each variable (change in U1 angulation, change in the vertical position of U1, and the change in the vertical position of the U6) for each of the 3 superimposition methods was assessed for normality using the Shapiro-Wilk W test. The data were normally distributed for each of the 3 superimposition types by the Shapiro-Wilk W test ($P \geq 0.08$).[11] A mixed model analysis of variance was done to compare the 3 superimposition types within each subject, followed by pairwise Tukey-Kramer comparisons when indicated (version 14.3.0, JMP Pro; SAS, Cary, NC). The Benjamini-Hochberg procedure to control the false discovery rate at 0.05 was applied to control the type 1 error rate with multiple testing, and adjusted *P* values were determined and reported. These were compared with a level of significance of $P < 0.05$.

RESULTS

The maximum and minimum values for each of the 3 measurements in the 3 superimposition methods tested (3DA, 3DB, ABO) are listed in Table II. The vertical measurements are in millimeters, and the angular values are in degrees. The U1 vertical difference was significant for the superimposition type ($P < 0.0001$). The U1 angular and the U6 vertical differences were insignificant for superimposition types ($P = 0.3636$ and $P = 0.1863$, respectively). These results and the mean differences can be found in Figures 7, 8 and 9, respectively.

DISCUSSION

The need to investigate the reliability of new technology is an ever-evolving part of the practice of orthodontics. Introduced in the 1980s, CBCT images have proven to be a powerful tool in the diagnosis and treatment planning of orthodontic patients. The ability to view the complex craniofacial structures in the proper 3-dimensions has many benefits in analyzing these

Table II. The maximum and minimum values for each of the 3 measurements in the 3 superimposition methods tested (3DA, 3DB, ABO)

	U1 vertical change		*U1 angular change*		*U6 vertical change*	
Method	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*
3DA	3.2	−0.8	22.7	−11.3	5	0.1
3DB	4	−0.6	25	−12.5	4.7	−0.2
2D	4.1	−0.5	20	−13.9	4.2	0.1

Note. The vertical measurements are in millimeters, and the angular values are in degrees.

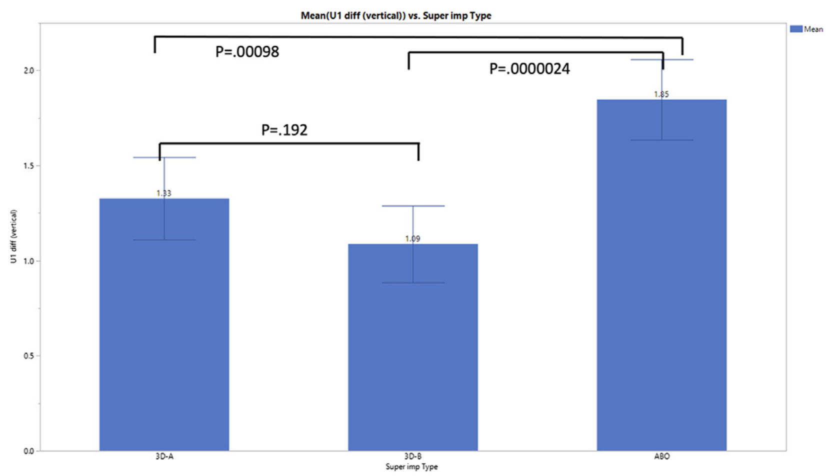

Fig 7. Mean difference between superimposition methods for vertical change in the U1 from T1 to T2.

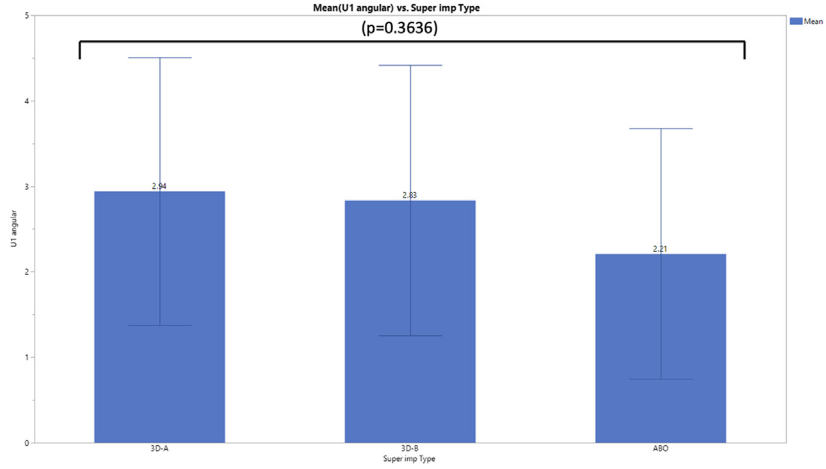

Fig 8. Mean difference between superimposition methods for angular change in the U1 from T1 to T2.

structures. A study done in 2011 revealed that 83% of postgraduate orthodontic programs reported having access to a CBCT machine, 82% used CBCT for specific diagnostic purposes, and 18% used CBCT images for every patient.[12] With many orthodontic practices using CBCT images for diagnosis, treatment planning, and outcome assessments, verification of the reliability of these analysis tools is important to avoid drawing inaccurate conclusions related to patient diagnosis and analysis.

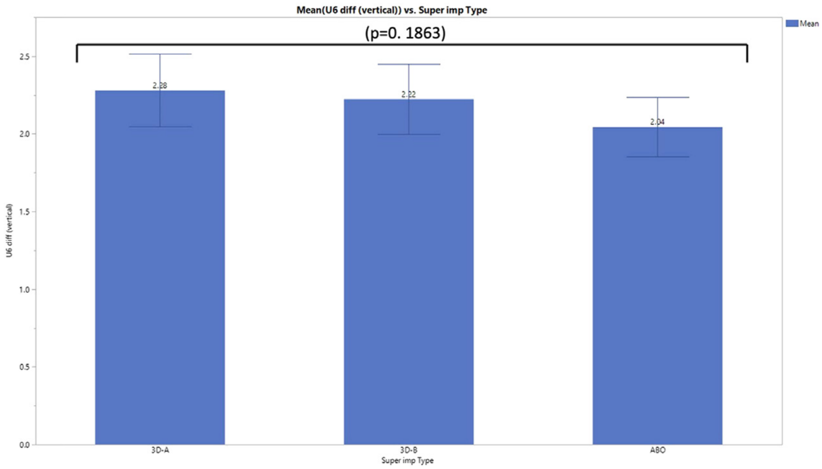

Fig 9. Mean difference between superimposition methods for vertical change in the U6 from T1 to T2.

One of the best ways to evaluate growth and treatment outcomes is by superimposing serial cephalograms. The process of superimposing 3D images is well known to be more reliable when compared with traditional 2D x-rays.[13,14] However, duplicating these studies done in 2D to verify superimposition accuracy in 3D has proven difficult. Previous studies published by Björk and others are nearly impossible to duplicate using CBCT images because of the need to place metallic implants and repeated 3D radiographs for analysis. However, previous studies have found the cranial base superimposition completely reliable when using CBCT images. Cevidanes et al[15,16] published methods for voxel-based superimpositions on the cranial base in both adults and growing patients. These studies found that the voxel-based superimposition method accurately showed growth and treatment effects in these patient populations. Weissheimer et al[17] recently evaluated a fast method of 3D voxel-based superimposition using OnDemand 3D software. He concluded that the mean superimposition error was <0.5 mm in growing and nongrowing patients. Bazina et al[18] evaluated the precision and reliability of the Dolphin 3D voxel-based superimposition compared with Cevidanes' method for cranial base superimposition and found it to be precise and reliable when superimposing nongrowing patients. The mean difference between the 2 methods measured <0.21 mm and was deemed clinically insignificant.

Ghoneima et al[19] studied the accuracy and reliability of landmark-based, surface-based, and voxel-based superimpositions. As with 2D superimpositions, the 3D images can be registered on the basis of stable landmarks (landmark-based superimpositions). The surface-based superimposition matches the surface anatomy of the corresponding 3D surfaces of reference. The voxel-based method is the most recent method of obtaining 3D superimpositions. This method uses the gray values of a region and is suggested to be more accurate because it is fully automated, and no operator error will impact the results. Ghoneima et al[19] found that surface-based and voxel-based superimposition methods using the anterior cranial base as a reference structure were accurate and reliable in detecting growth and treatment changes. Landmark-based superimposition method was reliable but less accurate than the other methods.

Although cranial base superimpositions have been found to be accurate and reliable in 3D, regional superimpositions are equally as important to determine the dental changes during treatment. In 2016, Ruellas et al[7] studied 2 regions of reference for maxillary regional superimpositions using CBCT images and found that both regions showed similar results with adequate reliability. The registration area was defined by semiautomatic segmentation, a time-consuming step that cannot be used in everyday practice. Ruellas et al[7] did not compare their methods to what we already know and have practiced for years, which is the 2D superimposition methods like the one recommended by the ABO. In our study, we used similar registration areas and found that they showed similar results to the 2D superimposition method recommended by the ABO. Because Dolphin Imaging software was used for the 3D superimpositions, a rectangular box was used to define the areas of registration, which led to the inclusion of some midline structures that might not be stable during growth. In our study, we were able to compare 2 different 3D maxillary registrations to evaluate the impact the removal of these midline structures had on

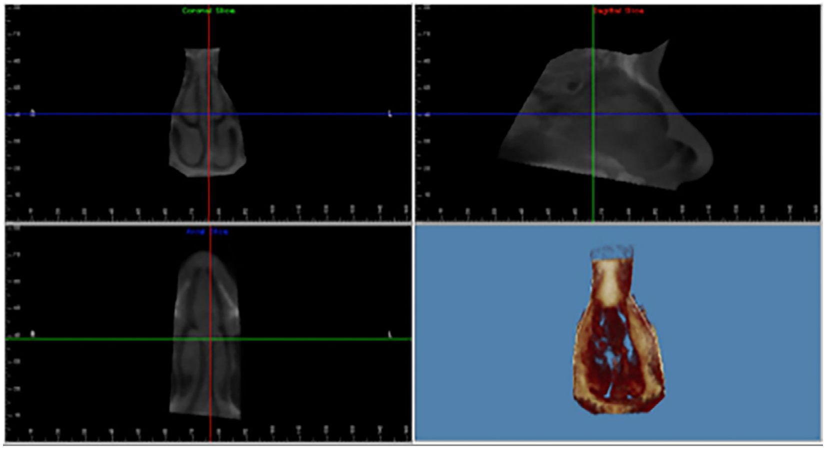

Fig 10. Midline structures removed for T2BMax.

the precision of the maxillary superimposition. The anatomic structures removed include the inferior concha, middle concha, and nasal septum (Fig 10). Based on our findings, there were no differences between the two 3D registration methods used, and removing the midline structures did not affect the precision of the maxillary superimposition.

Among the common disadvantages of 2D superimpositions is the obstruction of important structures needed for cephalometric tracing, leading to difficulty evaluating bilateral structures and not considering the transverse dimension. Excluding patients with posterior crossbites allowed for a more stable 3D reference area in the transverse dimension. It is unknown if the same registration areas can be used in patients with significant skeletal transverse changes because of treatment. The maxillary skeletal expansion has significant width increases on many sutures of the craniofacial complex, including intermaxillary, internasal, maxillonasal, frontomaxillary, and frontonasal sutures.[20] As such, it is possible that in 3 dimensions, these stable areas used for 2D superimpositions could show instability. Future studies are needed to determine if these registration areas can be used in this patient population.

The principal finding in this study was that the mean difference in the measurement for vertical change in the U1 is statistically significant when comparing the 2D vs 3D superimpositions. However, the differences were small ($<$1 mm) and can be considered clinically insignificant. With the average error seen in CBCT varying widely (0.01-0.5 mm),[15,16] average tracing error being around 0.5 mm,[13] and the voxel size in the images used in this study is 0.38 mm, it was decided that anything $<$1 mm to be clinically insignificant. As such, a 0.52 and 0.76-mm difference in the vertical change of the maxillary central incisor can be deemed clinically insignificant.

Although there are many advantages to using 3D images for outcome assessments, it should never be the main reason for exposing the patients to unnecessary radiation. Clinicians are always advised to follow the as low as reasonably achievable principles. There are many advantages to using regional 3D maxillary superimposition to evaluate dental changes because of treatment; for example, in patients with impacted or ectopically erupting teeth, the 3D evaluation of change can be very helpful in designing the biomechanics or evaluating outcomes. These images are accurate, reproducible, and determined in this study to be valid compared with the traditional 2D superimpositions method recommended by the ABO. Using Dolphin Imaging Systems is also a quick, user-friendly approach to superimpositions. A disadvantage to this process could include increased radiation exposure, although radiation doses are gradually decreasing with the continuing development of new technology. A recent study by Koerich et al[21] used a limited field of view CBCT images and superimposed the maxilla and mandible. They found this method to be fast, accurate, and reproducible. This would be a way to limit the amount of radiation exposure in patients when the need is to visualize the dental changes.[21] It must also be considered that human errors in the 2D superimpositions have the potential for inaccurate variations in results.

Our study determined that the basis of superimposition used for centuries in orthodontic practice proves valid even when using 3D voxel-based methods to superimpose the maxilla. These growing patients were found to have clinically nonsignificant variations in the vertical change of the U1, angulation change of the U1, and vertical change of the U6. Although proper operator management of the images is crucial for efficient and accurate results, using Dolphin software for voxel-based superimpositions is user-friendly and fast, allowing practitioners to study treatment outcomes and draw conclusions quickly. Only 3 dental measurements were used in this study to compare the different superimposition methods, which can be considered a weakness. Only 3% of the sample used had extractions, so there were a few variations in the molar AP and angular values. Because we compared the new 3D superimposition methods to the method recommended by the ABO, the transverse dental changes were not evaluated. Future studies should evaluate the method evaluated in this study using an extraction sample to verify our results. Accurate, user-friendly methods for 3D mandibular superimposition in growing patients are also needed.

CONCLUSIONS

Although there is no significant difference among the 3 types of superimpositions when measuring the angular change of the maxillary central incisors or the vertical change of the maxillary first molars, there was for the vertical change in the maxillary central incisors, with the difference between initial and final 3D images being the same for 3DA and 3DB. Both had a significantly smaller change than the ABO superimposition. Although significantly different, the mean differences between the 3DA and ABO and 3DB and ABO were clinically nonsignificant (0.52 mm and 0.76 mm, respectively.) The 3D voxel-based maxillary superimpositions showed similar results to conventional 2D superimpositions.

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