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A comparative study of the accuracy between two computer-aided surgical simulation methods in virtual surgical planning

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A comparative study of the accuracy between two computer-aided surgical simulation methods in virtual surgical planning

Abstract

Objective: The aim of this retrospective and observational study was to compare the accuracy of two different virtual surgical planning (VSP) protocols, namely, the CASS method and the modified CASS method.

Materials and methods: The patients underwent bimaxillary orthognathic surgery, planned using either the CASS method or the modified CASS method. Linear and angular discrepancies between the VSP outcome and postoperative outcome for both groups were compared for maxilla, mandible, and chin segments. Aside from the comparison between both groups, additional criteria were used to determine the accuracy of the protocol based on a linear and angular difference between planned and actual outcomes of less than 2 mm and 4°, respectively. The intergroup comparisons were performed by one-way ANOVA, with the level of significance set at 5%.

Results: A total of 21 patients, of both genders, were assigned into group I (n = 11), planned with the CASS method, and group II (n = 10), planned with the modified CASS method. Both the CASS and modified CASS methods presented similar accuracy with regard to linear differences for the maxilla, mandible, and chin segments, except for ΔX for the mandibular segment, where the modified CASS method showed slightly better accuracy. However, there was a statistically significant difference with regard to angular differences in the chin segment, with the CASS method shown to be the more accurate. Aside from $\Delta pitch$ for the chin segment, no linear or angular differences exceeded 2 mm or 4°.

Conclusion: Although statistically significant differences were found with regard to angular measurements in the chin segment, the accuracy of the modified CASS method for virtual planning can be considered as clinically equivalent, with a performance comparable to that of the CASS method.

Keywords: computer-aided surgery; orthognathic surgery; virtual surgical planning; computed tomography; osteotomy

Introduction

Combined orthodontic–orthognathic treatment is a valuable choice for the correction of Angle Class II and III dentofacial deformities, which not only rehabilitates the jaw's function, but also improves facial aesthetics (Dantas et al., 2015). Although dentofacial surgical approaches are case-specific (Park and Baik, 2001), Le Fort I osteotomy is considered to be the most frequent procedure (Shin et al., 2015), and is often associated with bilateral sagittal split osteotomy (Iwai et al., 2017). Surgical techniques play an important role with regard to outcome; however, their success also depends on detailed surgical planning (Xia et al., 2015; Zhang et al., 2016; De Riu et al., 2017; Ritto et al., 2018).

For many years, surgical planning has been performed in a traditional way by means of cephalometric predictive tracings and dental models mounted on a semi-adjustable articulator. Eventually, the surgical plan is transferred to the patient via acrylic surgical splints and two-dimensional (2D) images (Xia et al., 2005; Swennen et al., 2007; Gateno et al., 2017). In order to overcome the 2D limitations, three-dimensional (3D) virtual surgical planning (VSP) emerged as a useful tool, leading to more accurate and predictable hard- and soft-tissue changes (Stokbro et al., 2014; Stokbro et al., 2016; Ritto et al., 2018), and a simpler laboratory stage (Ritto et al., 2018).

On this basis, the computer-aided surgical simulation (CASS) method was developed (Xia et al., 2009), which allows oral surgeons to perform virtual surgical movements, resulting in predictable 3D changes (Xia et al., 2011). Some modifications to the CASS method have been proposed by Tonin et al. (2020), in order to simplify the demand for equipment without losing accuracy. Due to the constant evolution of computed tomography scanning equipment, surgical planning software, and surgical navigation systems, there is a need to investigate the accuracy and reliability of new methods for VSP in relation to postoperative outcome.

Therefore, our study proposed a modified CASS method that is more practical and simple than current techniques, whilst maintaining accuracy. Thus, the aim of the investigation was to assess the accuracy of CASS and the modified CASS method, by comparing the angular and linear differences between the planned and actual postoperative outcomes of each method.

Materials and methods

Sample

This retrospective and observational study was approved by two Permanent Ethics Committees on Experiments in Humans (CAAE: 8116.5.917.0.0000.5374 – Faculdade São Leopoldo Mandic, Campinas), and in accordance with the STROBE initiative statements (*Strengthening the Reporting of Observational Studies in Epidemiology*) (Von Elm et al., 2008).

For the sample size estimation, a preliminary pilot study was conducted with 10 patients. Data obtained from this study showed that most of the linear and angular differences between the planned and actual outcomes presented standard deviation values that corresponded to 80% of the mean values. Thus, the sample size was calculated to have an effect size of 1 mm or 1°, with a standard deviation of 0.8 mm or 0.8°, by assuming 80% of power and 5% of level of significance. Based upon these assumptions, a sample of 11 individuals was suggested for each group. The literature suggests a linear difference of less than 2 mm (Tng et al., 1994; Donatsky et al., 1997; Padwa et al., 1997) and an angular difference of less than 4° (Tng et al., 1994; Donatsky et al., 1997; Padwa et al., 1997) between planned and actual outcomes as criteria to determine accuracy of the method.

The inclusion criteria were as follows: 1) patients who were scheduled to undergo double-jaw orthognathic surgery; 2) patients who were scheduled to undergo a computed tomography scan as a part of their treatment; 3) patients who agreed to use the CASS protocol for their treatment planning; 4) only cases planned by the same surgeon for either CASS or modified CASS methods. Patients with craniofacial anomalies, such as cleft lip and syndromes, and those who had already undergone any craniofacial surgery were excluded.

CASS method

In group I, the CASS surgical planning protocol was used (Gateno et al., 2003a; Gateno et al., 2003b; Gateno et al., 2007; Xia et al., 2007; Xia et al., 2011). First, CT data for the skull model were obtained by placing a rigid bite jig (LuxaBite, DMG America, Englewood, NJ) between the maxillary and mandibular teeth in a centric relationship (CR). The bite jig was attached using a facebow with fiducial markers assembly (Medical Modeling Inc., Golden, CO). Thereafter, CT data for dental models were obtained by scanning the set of plaster dental models and facebow with fiducial markers assembly. Eventually, a composite skull model was created. For this, the teeth of the CT skull model were removed, leaving the fiducial markers in place. The upper and lower digital dental models, with their corresponding fiducial markers, were then imported into the CT skull model. After the fiducial markers were aligned, the digital dental models were merged into the 3D skull model using 3D modeling software (Figure 1).

Once the composite skull model had been aligned, the fiducial markers were hidden, and the model was oriented into a natural head position (NHP) based upon clinical data provided by the gyroscope, which defined the roll, yaw, and pitch (3DM; MicroStrain Inc, Williston, VA). Roll was defined as the rotation around the *y*-axis (anteroposterior direction), yaw as rotation around the z-axis (inferosuperior direction), and pitch as rotation around the *x*-axis (mediolateral direction) (Hsu et al., 2013; Tonin et al., 2020) (Figure 2).

Modified CASS method

In group II, a modified CASS surgical planning protocol was used, which proceeded as follows: standardization of NHP, standardized photographic record protocol, occlusion registering in CR, pre- and postoperative CT scanning, and pre- and postoperative intraoral teeth scanning.

The patients were instructed to be in a relaxed standing position, with their feet a comfortable distance apart and slightly diverging. They were then asked to tilt their heads forward and backward with decreasing amplitude until they came to a comfortable and relaxed position. Where necessary, the oral surgeon may have adjusted the head position slightly in order to make the facial deformity more evident. Once they were comfortable, the patients were asked to look directly into their own eyes in a mirror, which was mounted in front of them at a distance of 2 meters, and finalize their head position (Ferraz et al., 2019).

Extraoral photographs were recorded by means of a digital camera (Canon 60D) with an ultrasonic 100 mm macro lens. A built-in gyroscope was adjusted to an orthogonal position, parallel to the floor, to make sure that the full set of equipment was in a true vertical position (Cassi et al., 2016). The digital data obtained by photography were transferred into 3D images in order to reproduce the NHP in the virtual model (Figure 3). A CR wax bite was created using wax number 7 (NewWax, Technew®) (Bobek et al., 2015). The patient was instructed to bite the wax until primary contact between any teeth was attained. In order to avoid distortion, the wax bite was kept in a refrigerated environment and the CT was performed on the same day.

By the same team, maxillary and mandibular dental arches were scanned in occlusion separately, using a high-resolution intraoral scanner (3Shape Trios 3®; 3Shape, Copenhagen, Denmark). These images were used as a guide to obtain the final occlusion during VSP in the 3D virtual environment. The digital dental models were saved and exported as standard triangulation language (STL) files and incorporated into the 3D CT to substitute the teeth, using the software 3D Studio Max (Autodesk Inc., California, USA) (Figure 4). This resulted in a composite skull model that displayed an accurate rendition of bones, soft tissues, and teeth. Table 1 summarizes the differences between both methods.

Virtual planning and orthognathic surgery

VSP was performed with Dolphin Imaging® 3D version 11.95 (Dolphin Imaging and Management Solutions®, Chatsworth, CA, USA) for both groups I and II. Using the composite skull model, simple or segmented Le Fort I osteotomy, bilateral sagittal split ramus osteotomy, and mentoplasty were simulated by the same experienced and trained surgeon. Eventually, these simulations were actually executed in a hospital environment.

Postoperative CT

For surgical outcome evaluation, CT data were obtained 30 days after surgery for all patients of both groups I and II (Hsu et al., 2013). For this, the patients were asked to bite an acrylic device, so that the same intermaxillary space created by the wax bite during preoperative CT scanning could be reproduced (Bobek et al., 2015; Yamashita et al., 2017; Souza-Pinto et al., 2019; Tonin et al., 2020).

Outcome evaluation

Outcome evaluation was achieved through the superimposition of VSP and postoperative CT for both CASS and modified CASS methods. The outcome evaluation was performed by a single maxillofacial surgeon, with significant expertise. In order to minimize the confounding factors, all postoperative CT models were oriented based upon superimposition with preoperative CT. The models were superimposed by the voxel-based method in Dolphin 3D software (Haas-Junior et al., 2019; Tonin et al., 2020). Anatomical structures not affected by the surgery, such as cranial base, sella turcica, frontal nasal, and frontal zygomatic sutures, were selected as areas of reference for superimposition (Tonin et al., 2020). A tool in Dolphin 3D software version 11.95 allowed refined adjustments in order to check the spatial reconstruction (axial, coronal, and sagittal). Using this technique, the voxels in the defined area were matched, and the images were automatically superimposed (Ghoneima et al., 2017).

The postoperative CT was segmented into two parts — the cranium at the midface and the mandible — and the images were transferred into 3D Studio Max software in STL format (Figure 5). Next, four different time points (T) along a timeline were chosen. T0 was the moment at which an overall superimposition was performed between VSP and actual surgical outcomes. T1 was when superimposition of the maxilla was achieved, based on three landmarks: (a) the midline between the maxillary central incisors; (b) the tip of the mesiobuccal cusp of the maxillary right first molar; (c) the tip of the mesiobuccal cusp of the maxillary left first molar. T2 was the moment when superimposition of the mandible was achieved, based on three analog landmarks located in the mandible (a, b, and c). Finally, T3 was the moment when superimposition of the chin was achieved, based on three landmarks: one in the central region and two points on the sides. To avoid cofounding factors at all three superimposition time points (T1, T2, and T3), landmarks were identified and recorded both in the VSP and postoperative models.

To measure the differences between the planned and postoperative positions, measurements were made in relation to T0. Thus, the landmarks were on the same surface to allow linear and angular measurements between different moments in relation to T0 — that is, T0–T1 for the maxilla, T0–T2 for the mandible, and T0–T3 for the chin.

A triangle mesh was created to measure the linear differences between the VSP and postoperative surgical outcomes. The centroid of the triangle for each object (maxilla, mandible, and chin) was calculated. The centroid coordinates (X_C, Y_C, Z_C)

were computed using the following equations: $X_C = (X1 + X2 + X3)/3$; $Y_C = (Y1 + Y2 + Y3)/3$; and $Z_C = (Z1 + Z2 + Z3)/3$.

With these equations, C1 was used to represent the centroid of the VSP model, while C2 represented the centroid of the postoperative surgical model. Differences in linear distances for the centroid of the maxilla, mandible, and chin were calculated using the following equations: $\Delta X = X_{C1} - X_{C2}$ (mediolateral), $\Delta Y = Y_{C1} - Y_{C2}$ (anteroposterior), and $\Delta Z = Z_{C1} - Z_{C2}$ (superoinferior).

For angular differences, angular coordinates between the triangles of both VSP and postoperative surgical models were calculated. Specific algorithms were calculated using Matlab software version 2015a (MarthWorks, Inc., USA), which resulted in the final angular differences in roll, yaw, and pitch (Figure 6).

Statistical analysis

Linear and angular differences (Δ) between the VSP and postoperative models for both CASS and modified CASS groups were computed and submitted to statistical analysis by SPSS software, version 24.0 (IBM Corp., Armonk, NY), with a significance level of 5% ($p < 0.05$). All data underwent the Shapiro–Wilks normality test and test for homogeneity. Since the data presented both normal distribution and homogeneity, one-way ANOVA was applied. Whenever the difference between the methods was not statistically significant, the 95% confidence interval for the difference between the means was evaluated for equivalency. The thresholds, d, for linear and angular measurements were 2.0 mm and 4°, respectively.

Results

A total of 21 patients of both genders, aged from 18 to 65 years old, were included and divided into two groups. Group I ($n = 11$) was planned using the CASS method and Group II ($n = 10$) was planned using the modified CASS method.

Linear and angular differences between the planned and postoperative surgical outcomes for maxilla, mandible, and chin segments are presented, respectively, in Tables 2, 3, and 4.

No statistically significant differences were found for all linear measurements, except ΔX for the mandible segment. The mean values of these differences were found to be less than 2 mm for both CASS and modified CASS groups. For the mandible segment, the mean difference, ΔX, for the modified CASS group showed less variation in comparison with the CASS method ($\Delta X = 0.37 \pm 0.24$, $p < 0.05$).

No statistically significant differences were shown for angular measurements for both the maxilla and mandible segments ($p > 0.05$). However, the CASS group showed less significant variation for the chin segment in comparison with the modified CASS group (Table 4).

For data without statistically significant differences, the differences between the means and 95% confidence intervals, for both the linear and angular measurements, showed that the means were equivalent within the threshold *d*. The differences between the linear measurement means were less than –1.0 or 1.0, and the 95% confidence intervals were within the prespecified threshold of 2.0 mm. The differences between the angular measurement means were less than –2.0° or 2.0°, and the 95% confidence intervals were within the prespecified threshold of 4.0° (Tables 2, 3, and 4).

Discussion

Virtual surgical planning (VSP) is a valuable tool in orthosurgical cases. Nevetheless, the accuracy of this technique needs to be verified as new methods are proposed and developed. Several VSP methods are available in the literature; however, the CASS method proposed by Gateno (2003a; 2003b; 2007; 2015) and Xia (2000; 2005; 2007; 2009; 2011; 2015) represents one of the most accurate for this purpose. The proposed modification to the CASS technique used in our study aims to eliminate the need for an external digital orientation sensor attached to the facebow (Hsu, et al., 2013), since the weight of the digital sensor may influence the head position in such a way that the requirement of a relaxed head posture might not be achieved. In the modified CASS method, extraoral photographs taken in the NHP with the help of the camera's built-in gyroscope were supposed to attain the same accuracy achieved using the CASS method. For our study, it was assumed that the averages of the linear and angular discrepancies between the virtually planned outcome and the actual postoperative outcome should not exceed 2.0 mm or 4°, respectively, which are values that have been considered as clinically acceptable by previous studies (Xia et al., 2007; Hsu et al., 2013; Ritto et al., 2018).

During surgery, the CR can be influenced by the bite jig (Hsu et al., 2013). For our modified method, the rigid acrylic bite jig was substituted with a wax bite (Souza-

Pinto et al., 2019; Tonin et al., 2020), as proposed in the Charlotte protocol. With this approach, only discrete bite opening during CT was needed to allow the CR to be reproduced (Bobek et al., 2015). Moreover, neither artifacts nor soft-tissue distortion that could affect the VSP were observed in CT images when the wax bite was used, in contrast with the CASS method (Xia et al., 2009).

In place of the physical plaster models adopted in traditional workflow approaches (Nadjmi et al., 2010; Zhang et al., 2016b), intraoral scanning was utilized in our study to obtain the virtual dental model. According to Zhang et al. (2016), intraoral scanning is a valid choice in terms of accuracy; moreover, it is better accepted by patients in comparison with the experience of undergoing alginate impressions. Furthermore, intraoral scanning is less time consuming in comparison with the traditional impressions and plaster method, and is just as accurate. The fusion of digital scanning of the dental surfaces with CT images is considered to be a valid and safe method (Baan et al., 2020).

With regard to the superimposition, three methods can be found in the literature — landmark based, surface based, and voxel based (Ghoneima et al., 2017). For our study, a voxel-based method that involved matching gray values was chosen for its accuracy, reproducibility, and practicability (Bazina et al., 2018; Tonin et al., 2020; Bin et al., 2020). Although algorithmic values formed the basis of this method, the skill of the surgeon was still required. Since a correct VSP is critical for the success of the surgery, precise manipulation of the images by the surgeon was imperative. It should be emphasized that quantitative analysis of the accuracy was not possible using the Dolphin software; therefore, the superimposed images were transferred in STL format into the 3D Studio Max software for linear and angular measurements. This allowed the discrepancies between 3D VSP and surgical outcomes to be quantified (Hsu et al., 2013; Stokbro et al., 2016; Tonin et al., 2020).

The accuracy of VSP in relation to surgical outcomes has previously been reported for the maxilla (Xia et al., 2009; Tucker et al., 2010; Hsu et al., 2013; Stokbro et al., 2016; Heufelder et al., 2017; Ritto et al., 2018; Tonin et al., 2020), mandible (Tucker et al., 2010; Hsu et al., 2013; Stokbro et al., 2016), and chin (Tucker et al., 2010; Hsu et al., 2013; Stokbro et al., 2016). Similar methods were adopted in our study, in which the assessment of accuracy was based upon differences in linear measurements (De Riu et al., 2017; Tonin et al., 2020) and in angular measurements (Xia et al., 2007;

Hsu et al., 2013; Heufelder et al., 2017; Ritto et al., 2018). Regarding the linear measurement discrepancies, only Δ*X* for the mandible showed statistically significant differences, with a lower mean difference presented by the modified CASS method. However, these slight differences can be considered as clinically acceptable. It should be noted that negative or positive values for delta variation (Δ) during VSP do not influence in the result Since most data for the maxilla and mandible failed to reject the null hypothesis with regard to difference, further analysis based upon the difference between the means and 95% confidence intervals were performed. In general, the modified CASS method showed clinical accuracy equivalent to that of the CASS method.

Intragroup differences were not compared in our study; therefore, accuracy differences in all three dimensions — if they exist — could be evaluated in future studies. With regard to angular measurement discrepancies when using the modified CASS method, both the maxilla and mandible measurements showed similar accuracy to the CASS method. Only the angular measurement discrepancies for the chin showed significant differences in comparison with the CASS method. These apparent discrepancies probably can be attributed to the fact that, for the mentoplasty, no surgical splint was used in either the CASS method or the modified CASS method, allowing the surgeon to have autonomy in terms of chin positioning, based on their own expertise. The relevance of these apparent differences could be addressed in future studies. In the present study, it was evident that all mean differences, except for Δ*Pitch* for the chin, were less than 2 mm and 4° for linear and angular measurements, respectively. These results are not only in agreement with the literature (Tng et al., 1994; Donatsky et al., 1997; Padwa et al., 1997), but are also able to offer clinical assurance to those considering the modified CASS as an accurate method for virtual planning.

Based upon the results and the limitations of this study, the accuracy of both the CASS and modified CASS methods for virtual planning can be considered as clinically equivalent, giving comparable performances. The proposed modified method is shown to be accurate and reliable for virtual planning, and represents an alternative option.

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Figure legends

Figure 1. A. 3D reconstruction of the composite skull using the CASS method, showing the fiducial markers (yellow) and dental surfaces with fiducial markers (red). B. Superimposition of the fiducial markers for dental surface replacement. C. Orientation of the composite skull by the digital sensor (red); D. Final composite skull.

Figure 2. Representations of angular orientations (roll, yaw, and pitch). Pitch was defined as rotation around the *x*-axis (mediolateral direction), roll as rotation around the *y*-axis (anteroposterior direction), and yaw as rotation around the *z*-axis (inferosuperior direction).

Figure 3. Photographic records: A. lateral view; B. 3D reconstructed lateral view, showing the transfer of values generated by the photograph in the lateral view; C. lower view photograph of the patient; D. 3D reconstructed inferior view, showing the transfer of values generated by the photograph in the inferior view.

Figure 4. A. Intraorally scanned dental surfaces. B. Composite skull with replacement of the dental surfaces.

Figure 5. Superimposition between VSP (green) and surgical outcome (blue). These images were acquired using the computer graphic software 3D Studio Max® (Autodesk

Inc., USA). Linear measurements (green) in the four perspectives of view: A. left side; B. superior view; C. right side; D. frontal view.

Figure 6. A and B. Schematic illustration of the triangle mesh (pink) and the centroid (yellow). Angular measurements: C. roll (green arrow); D. yaw (blue arrow); and E. pitch (red arrow).

Legends

Figure 1. 3D reconstruction for the creation of the composite skull by CASS method. A. 3D reconstruction of the composite skull with the fiducial marker (yellow) and dental surfaces with the fiducial markers (red); B. Superimposition of the fiducial markers for dental surface replacement; C. Orientation of the composite skull by the digital sensor (in red); D. Final composite skull.

Figure 2. Representations of angular orientations (roll, yaw, and pitch). The pitch was defined as the rotation around the x axis (mediolateral direction), roll as the rotation around the y axis (anteroposterior direction), and yaw as the rotation around the z axis (inferosuperior direction).

Figure 3. Photographic records. A. Lateral view; B. 3D reconstructed lateral view, showing the transfer of values generated by the photograph in the lateral view; C. lower view photography of the patient; D. 3D reconstructed inferior view showing the transfer of values generated by the photograph in the inferior view.

Figure 4. A. Intraorally scanned dental surfaces; B. composite skull with the replacement of the dental surfaces.

Figure 5. Superimposition between VSP (green) and surgical outcomes (blue), these images were acquired on computer graphic software 3D Studio Max® (Autodesk Inc., USA). Linear measurements (green) in the four perspectives of view: A. left side; B. superior view; C. right side; D. frontal view.

Figure 6. A, B. Schematic illustration of the triangle mesh (pink) and the centroid (yellow). Angular measurements: C. roll (green arrow); D. yaw (blue arrow); and E. pitch (red arrow).

Table 1. Summary of the main differences between the CASS and modified CASS methods

	CASS	**Modified CASS**
Natural head position (NHP)	Gyroscope	Standardized photographic record protocol
Occlusion registering with centric relationship	Rigid bite jig	Wax bite (wax number 7)
Teeth replacement	CT data of dental models	Intraoral scanner
Final occlusion	Guided by scanned models in final occlusion	Digitally obtained through color-coded map

Table 2. Means and standard deviations of linear and angular differences for the maxilla between VSP and surgical outcomes, using both CASS and modified CASS methods

	CASS method (n = 11)		**Modified CASS method (n = 10)**		**Difference in means**		**95% confidence interval for difference in means**		***p*-value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Lower limit**	**Upper limit**	
Linear measurements (mm)									
ΔX	0.56	0.61	0.66	0.75	0.09	0.30	–0.53	0.72	0.757
ΔY	1.33	0.60	1.60	1.15	0.27	0.39	–0.55	1.10	0.500
ΔZ	1.06	0.84	1.31	1.06	0.25	0.42	–0.62	1.12	0.555
Angular measurements (°)									
Δ*Roll*	0.98	0.78	0.62	0.60	0.21	0.38	–0.60	1.01	0.103
Δ*Yaw*	0.80	0.74	1.00	1.01	0.39	0.64	–0.95	1.72	0.253
Δ*Pitch*	1.24	1.03	2.24	1.61	–1.14	1.04	–3.31	1.03	0.598

Table 3. Means and standard deviations of linear and angular differences for the mandible between VSP and surgical outcomes, using both CASS and modified CASS methods

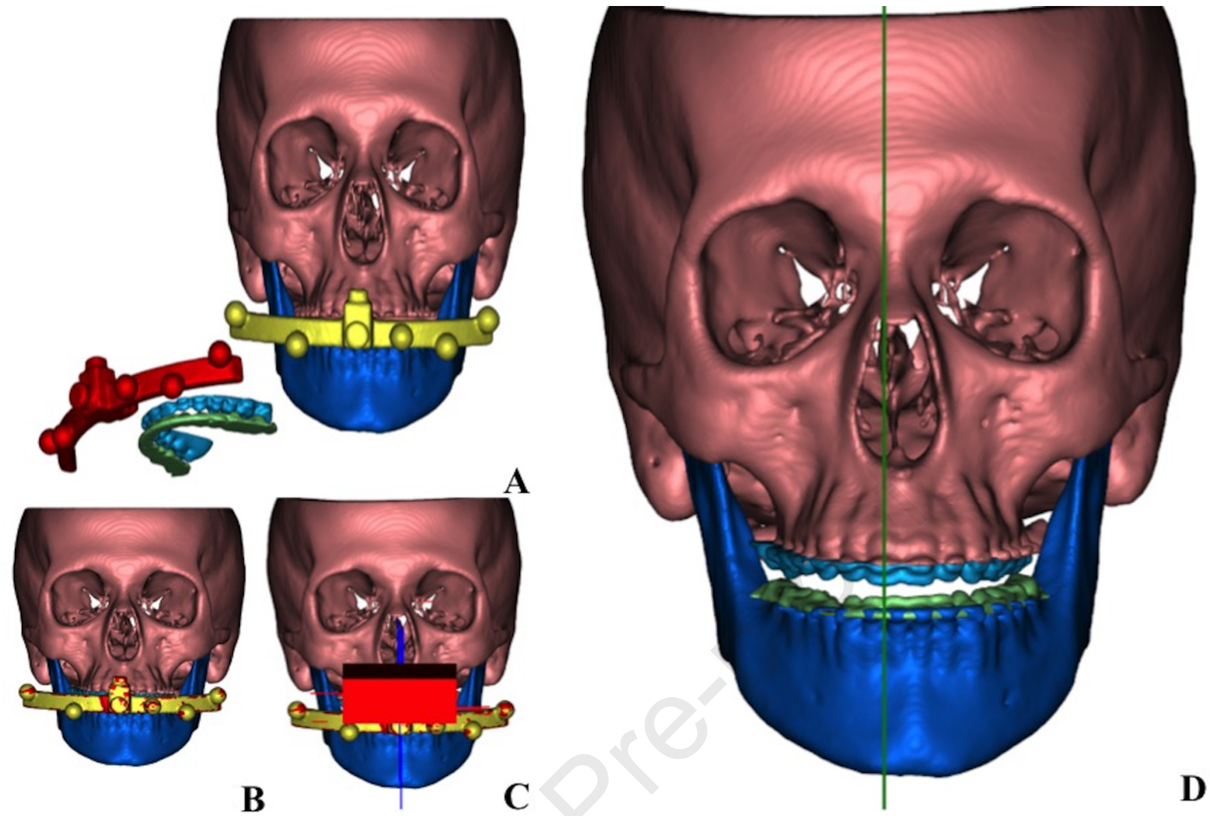
	CASS method (n = 11)		Modified CASS method (n = 10)		Difference in means		95% confidence interval for difference in means		p-value
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Lower limit**	**Upper limit**	
Linear measurements (mm)									
ΔX	1.19	1.20	0.37	0.24	–0.81	0.39	–1.62	0.00	0.049*
ΔY	1.17	1.16	1.46	1.00	0.29	0.47	–0.70	1.29	0.543
ΔZ	1.07	0.80	1.28	1.33	0.21	0.48	–0.79	1.21	0.664
Angular measurements (°)									
Δ*Roll*	2.66	3.07	1.52	1.19	0.39	0.64	–0.95	1.72	0.552
Δ*Yaw*	1.32	0.77	1.76	0.97	–1.14	1.04	–3.31	1.03	0.285
Δ*Pitch*	1.44	1.39	1.83	1.53	0.44	0.38	–0.36	1.23	0.265

*Statistically significant difference at 5%

Table 4. Means and standard deviations of linear and angular differences for the chin between VSP and surgical outcomes, using both CASS and modified CASS methods

	CASS method (n = 11)		**Modified CASS method (n = 10)**		**Difference in means**		**95% confidence interval for difference in means**		***p*-value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Lower limit**	**Upper limit**	
Linear measurements									
ΔX	0.57	0.69	0.69	1.10	0.12	0.39	-0.70	0.95	0.760
ΔY	0.78	0.83	0.91	1.06	0.13	0.41	-0.73	1.00	0.751
ΔZ	0.66	0.96	1.00	1.20	0.34	0.47	-0.65	1.33	0.482
Angular measurements (°)									
$\Delta Roll$	0.70	0.89	3.07	1.53	3.15	0.89	1.28	5.02	0.002**
ΔYaw	0.53	0.69	2.40	1.88	2.37	0.56	1.20	3.55	0.001**
$\Delta Pitch$	0.88	1.39	4.03	2.46	1.86	0.61	0.57	3.16	0.007**

**Statistically significant difference at 1%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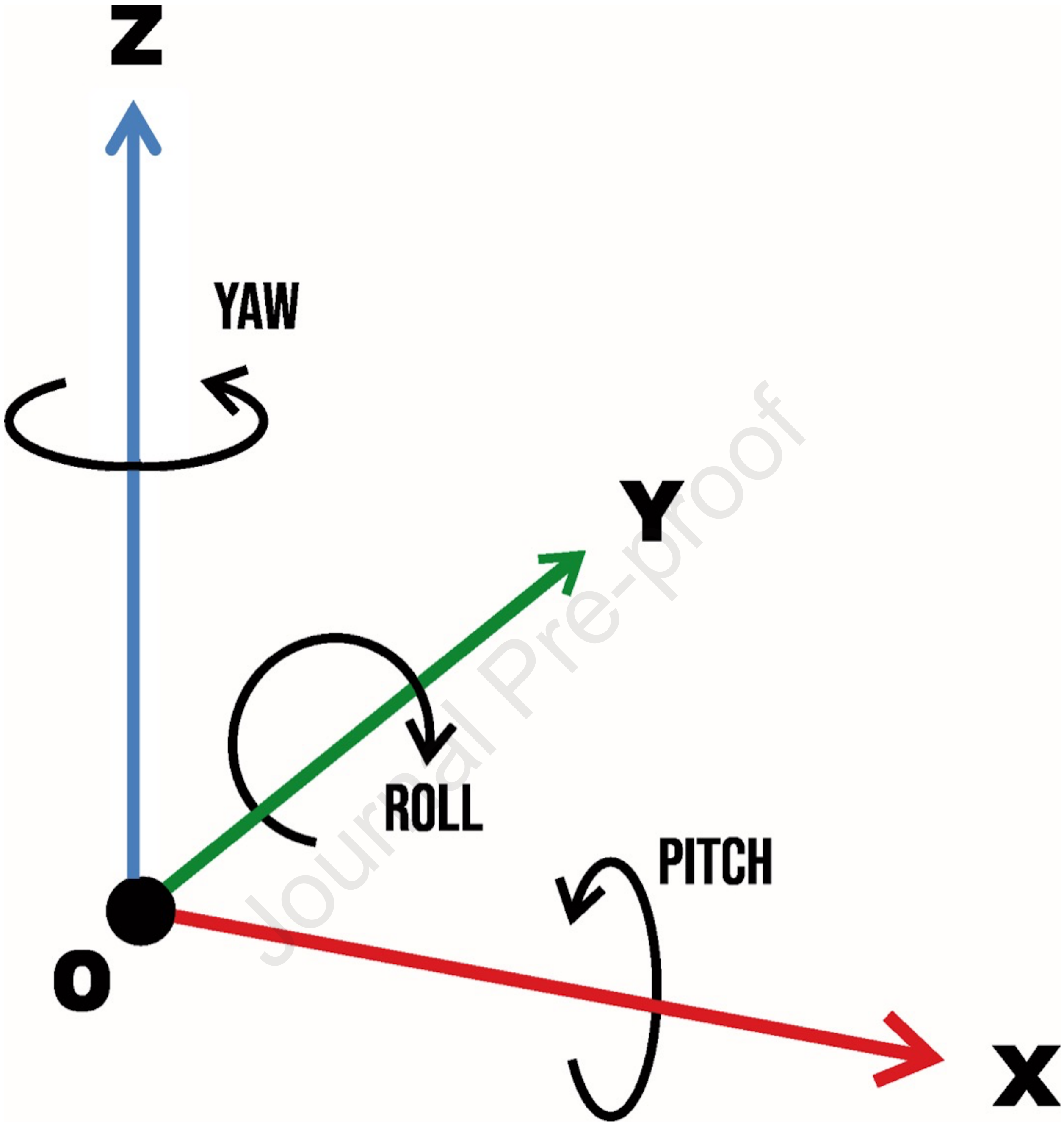
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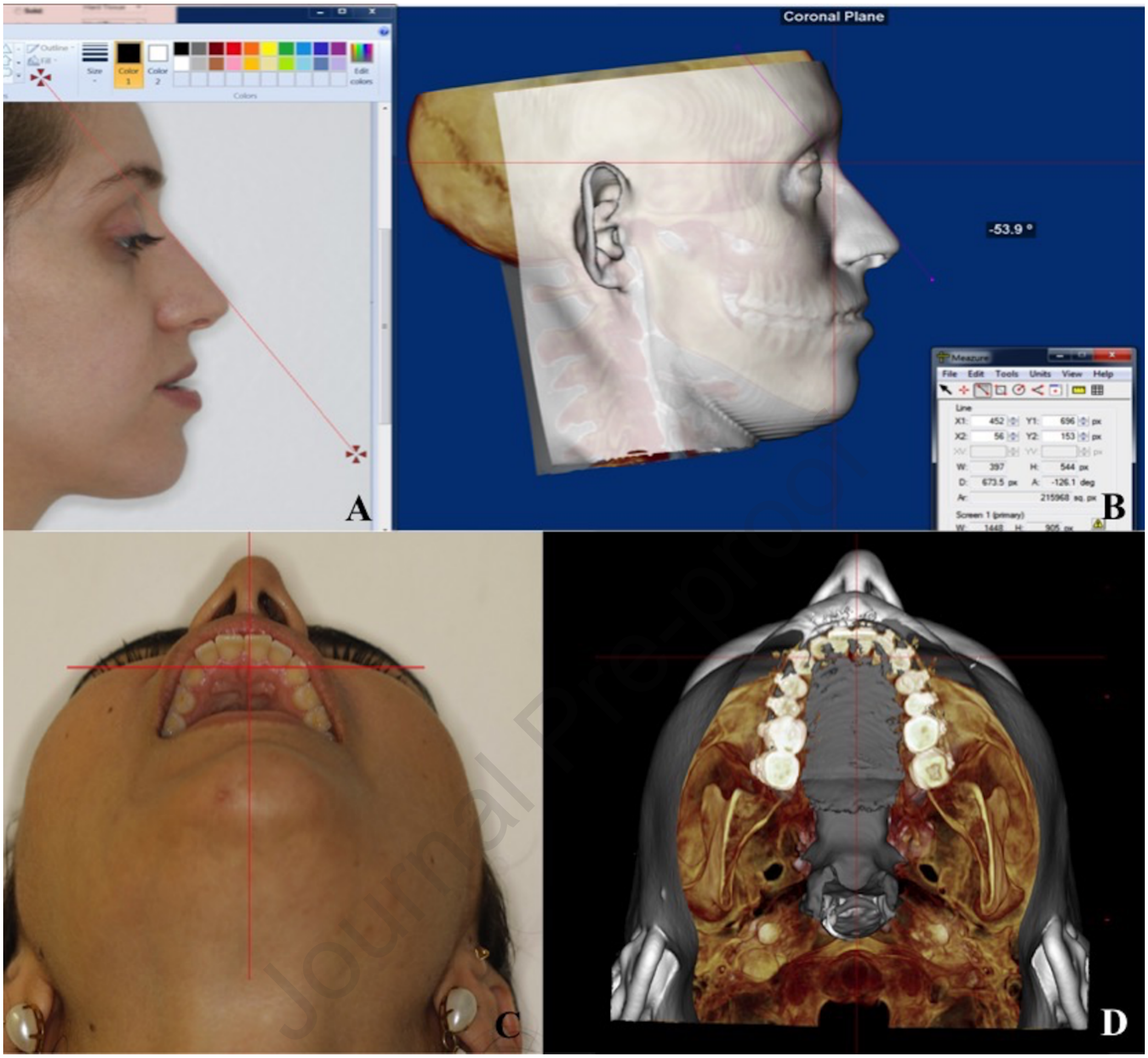
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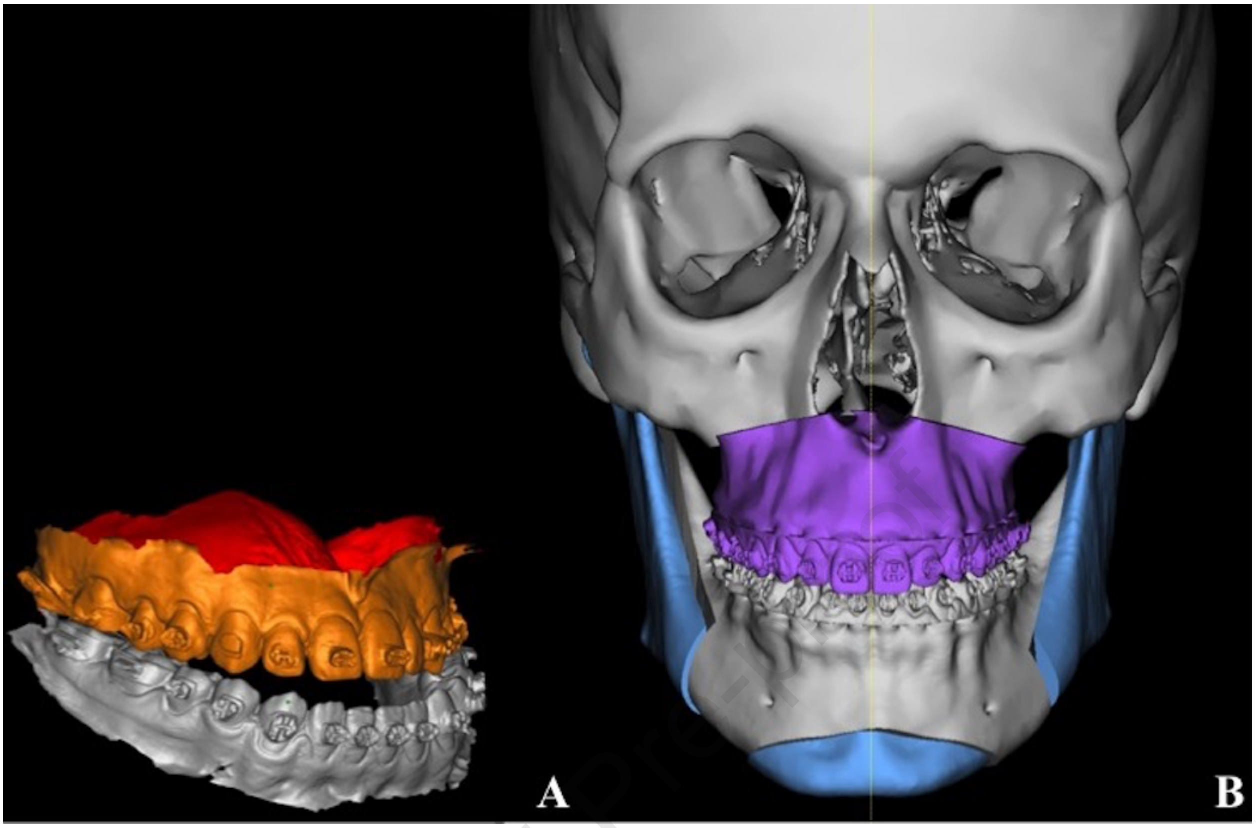
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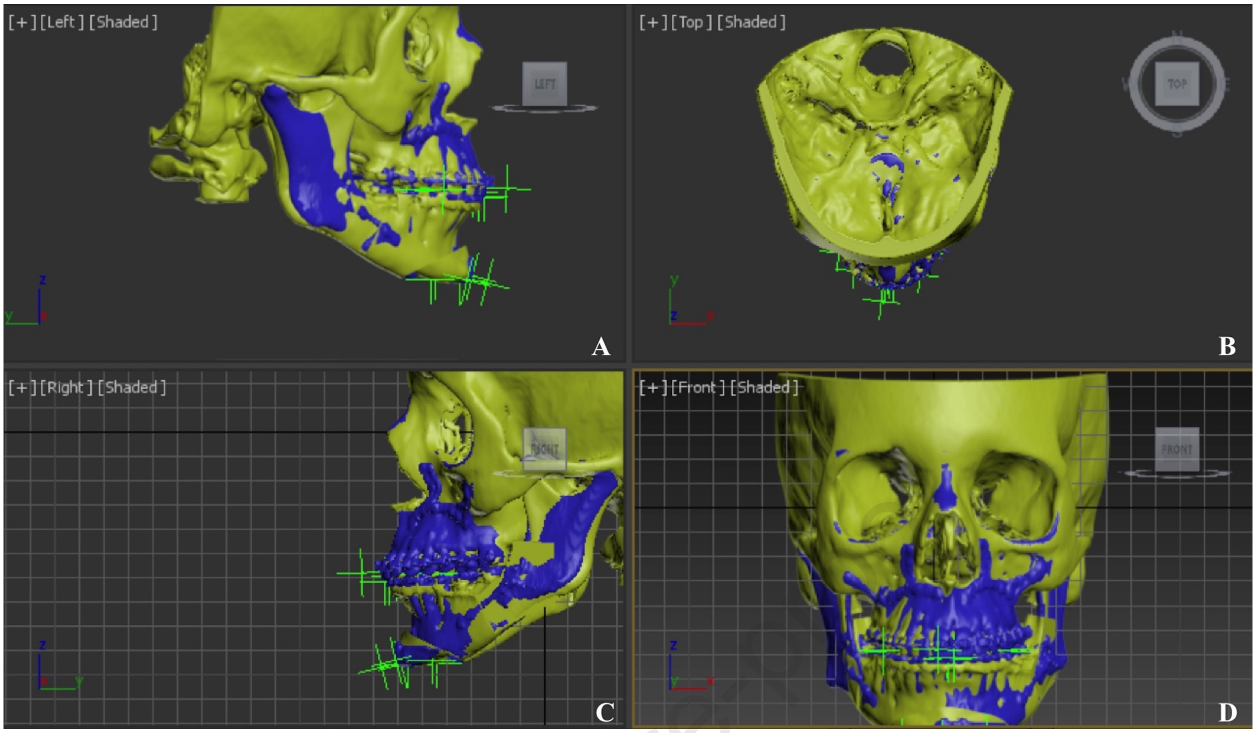
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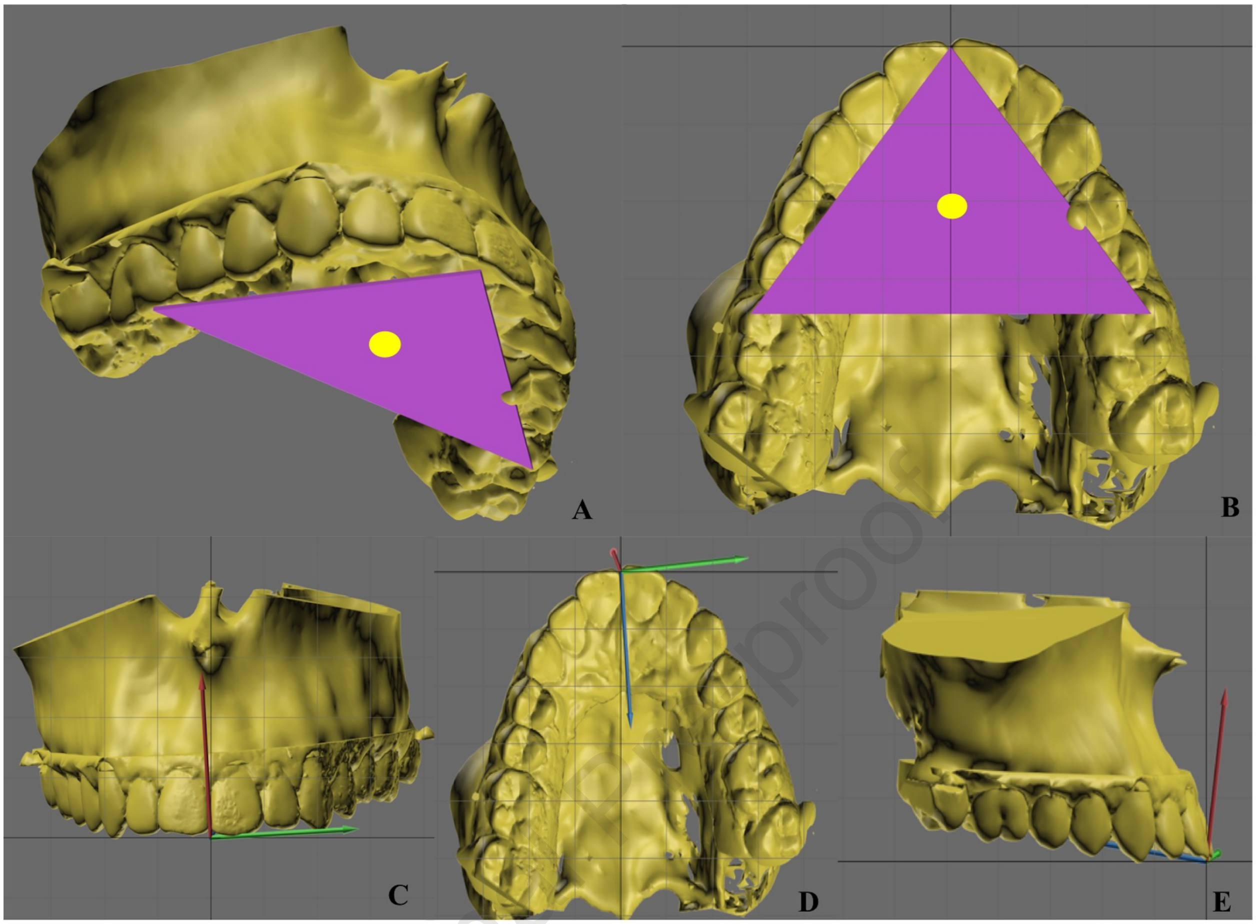
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