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# A new way of analyzing tooth movement using universal coordinate system geometry single point superposition in a 3D model

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## ABSTRACT

**Introduction:** Superposing 3D models is an imminent need. However, current methods rely on marking multiple points on the maxilla and mandible, which could increase point marking and overlapping errors. **Objective:** This study aimed at developing a method for superimposing 3D models of the maxillary and mandibular arches with Autodesk Inventor® engineering software, using a single universal coordinate system (UCS) point superposition. **Methods:** A total of 104 STL (stereolithography) models of the maxillary and mandibular arches exported from My iTero® platform were retrospectively selected, in which T0 and T1 were the initial and refinement periods, respectively (n=26 per group). The X, Y, and Z coordinates associated with a single point in each arch were inserted into the models with SlicerCMF® software for model orientation. The arch models with UCS registration were transferred to Autodesk Inventor® for superimposition and to measure tooth movements performed during Invisalign® treatment. Arch expansion, intrusion and rotation were analyzed by two examiners. The statistics were performed using intraclass correlation coefficients (ICC), Dahlberg's formula, and t-test ($p<0.05$). **Results:** A reliable method of superimposing 3D digital models using a single UCS point in the maxilla and mandible was developed. ICC showed excellent intra- and inter-examiner correlation (ICC>0.90). A systematic error was not found concerning linear and angular measurements (<1mm and <1.5°, respectively). Digital dental movements could be analyzed, including arch expansion, dental intrusion, and tooth rotation. **Conclusions:** The developed method was proven reliable and reproducible for superimposing 3D models of the maxillary and mandibular arches by using UCS system.


**Keywords:** Digital models. 3-dimensional diagnosis and treatment planning. Reproducibility of results.

## RESUMO

**Introdução:** A sobreposição de modelos 3D é uma necessidade iminente. No entanto, os métodos atuais dependem da marcação de múltiplos pontos na maxila e na mandíbula, o que pode aumentar a incorporação de erros no processo de sobreposição. **Objetivo:** O objetivo desse estudo foi desenvolver um método para sobrepor modelos 3D das arcadas superior e inferior utilizando o *software* de engenharia Autodesk Inventor®, por meio da marcação de um único ponto em cada arcada, usando o sistema de coordenadas universal (UCS). **Métodos:** No total, 104 modelos STL das arcadas superior e inferior exportados da plataforma My iTero® foram selecionados retrospectivamente, onde T0 foi o período inicial e T1, o de refinamento (n=26 por grupo). As coordenadas X, Y e Z associadas a um único ponto em cada arcada foram inseridas nos modelos usando o *software* Slicer-CMF®. Os modelos com os pontos UCS demarcados foram transferidos para o *software* Autodesk Inventor® para realizar a sobreposição e medir os movimentos dentários realizados durante o tratamento com Invisalign®. Os movimentos de expansão, intrusão e rotação foram analisados por dois examinadores. A análise estatística foi realizada usando os coeficientes de correlação intra-classe (ICC), fórmula de Dahlberg e teste *t* ($p<0{,}05$). **Resultados:** Foi desenvolvido um método confiável de sobreposição de modelos digitais 3D usando um único ponto UCS na maxila e mandíbula. O ICC apresentou excelente correlação intra e inter-avaliadores (ICC>0,90). Não foi encontrado erro sistemático nas medidas lineares e angulares (<1mm e <1,5°, respectivamente). Os movimentos dentários puderam ser analisados por meio do método proposto, incluindo expansão da arcada, intrusão e rotação dentária. **Conclusão:** O método desenvolvido provou ser confiável e reprodutível para sobreposição de modelos 3D das arcadas superior e inferior usando o sistema UCS com marcação de ponto único.


**Palavras-chave:** Modelos digitais. Diagnóstico e plano de tratamento 3D. Reprodutibilidade de resultados.

## INTRODUCTION

Digital model superimposition is mainly used for observation of occlusal changes caused by craniofacial growth,[1,2] analysis of accuracy and predictability of orthodontic treatment with aligners,[3,4] and evaluation of orthodontic tooth movement.[5-8] The use of three-dimensional (3D) digital models for orthodontic outcome analysis has advantages over other methods, such as less exposure to radiation, quality of image visualization and lower cost.[7]

Several methods seek reliability for overlapping 3D models by demarcating points in the maxilla and mandible that are stable and do not move during orthodontic treatment.[6,9-11] Studies that looked for superimposition points in the maxilla observed that the most stable is situated in the posterior part of the incisor papilla and the palatal rugae.[10,12,13] Regarding the mandible, solid points that can be used for superimposition in 3D models are scarce.[7,11] Thus, there is a need for studies to establish a stable point for better accuracy in mandibular superimposition.[14]

Dental software programs have been developed to assist orthodontists in treatment planning, but all have shown limitations and difficulties when used in research.[15-17] Autodesk Inventor® is an engineering software program that uses the Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system to build products and items, and to help understand how a product or body behaves under certain conditions. It uses the Universal Coordinate System (UCS) that defines the orientation of the Cartesian axes X, Y, and Z in three-dimensional space, associated with a single point mark on the part/model with high accuracy. Autodesk Inventor® was used to evaluate implant accuracy.[18] Due to its advantages, the use of Autodesk Inventor® in the superimposition of 3D models in Dentistry might bring reliability and agility to the studies of three-dimensional movements in the maxillary and mandibular arches.[18]

Understanding the step-by-step of superposition is mandatory for analyzing 3D models.[19] However, it is known that this is not simple and that the researcher or clinician can face many difficulties. In this sense, to overcome these obstacles and make 3D analyses simpler, more effective and cheaper, this study aimed to provide a step-by-step protocol of 3D models superimposition of the maxillary and mandibular arches, by marking a single point using the UCS geometry with SlicerCMF® and Autodesk Inventor® software.

## MATERIAL AND METHODS

This retrospective observational study was approved by the Ethics and Research Committee of the Federal University of Minas Gerais (CAAE: 48546321.4.0000.5149) and the Brazilian Clinical Trials Registry (ReBEC, # RBR-7df547h). Sample size calculation (Supp. Table 1) and inclusion and exclusion criteria were determined (Suppl. Table 2). The sample was composed of 104 STL (Stereo-lithographic or Standard Triangle Language) models from 27 participants, treated with the Invisalign® system (Align Technology, Santa Clara, CA, USA) and exported from my iTero® platform (https://clincheck.invisalign.com Align Technology, Santa Clara, CA, USA) (Fig 1). One participant carried out a restorative treatment and lost the follow-up in the refinement phase, thus a total of 26 participants were included in the study (Fig 1).

The maxillary and mandibular arches were scanned using an iTero® scanner (model Element, S/N: RTC2018 W06A228) by two operators, under the same conditions, at two time-points: T0 (start of treatment) and T1 (refinement phase). Models superimposition and analysis were performed using SlicerCMF® (version 4.11; http://slicer.org) and Autodesk Inventor® software. The first step was to determine the maxillary or mandibular landmarks in the 3D SlicerCMF® software, to generate the UCS coordinate system numbers in T0 and T1 models. In the maxilla, the reference point was created with a vertical line

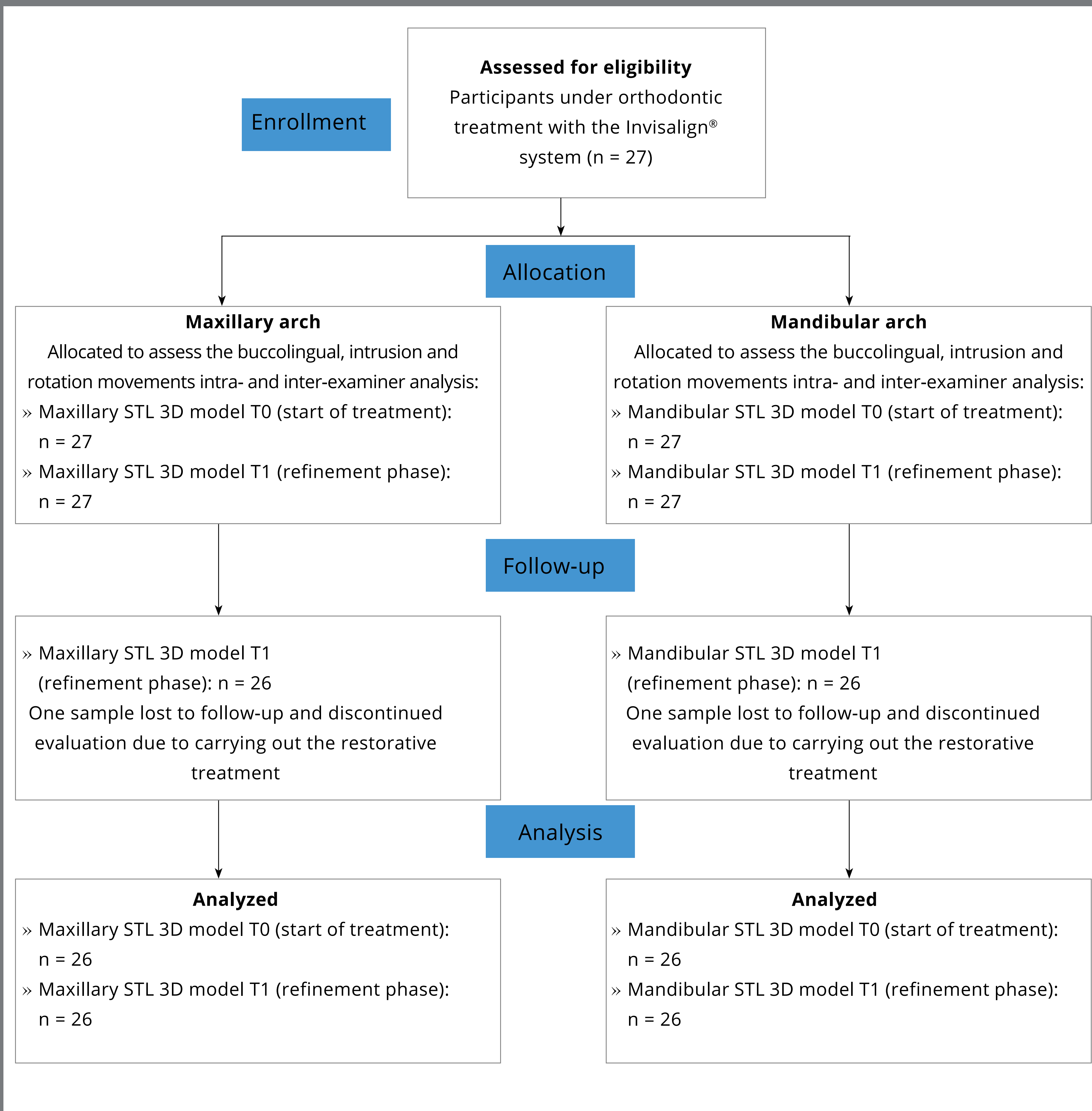


**Figure 1:** CONSORT flow diagram.

passing through the medial region of the palate suture and a horizontal line passing through the upper region of the second palate rugae. The intersection between these lines was considered the region of interest and a landmark was created (Fig 2). To standardize the superposition process in the mandible, a vertical line passing through the midline region was developed with a horizontal line passing through the mucogingival junction (Fig 2). The intersection between these lines was considered the region of interest and a landmark was developed. The X, Y, and Z coordinates were then set from these maxillary and mandibular landmarks, establishing stable references in

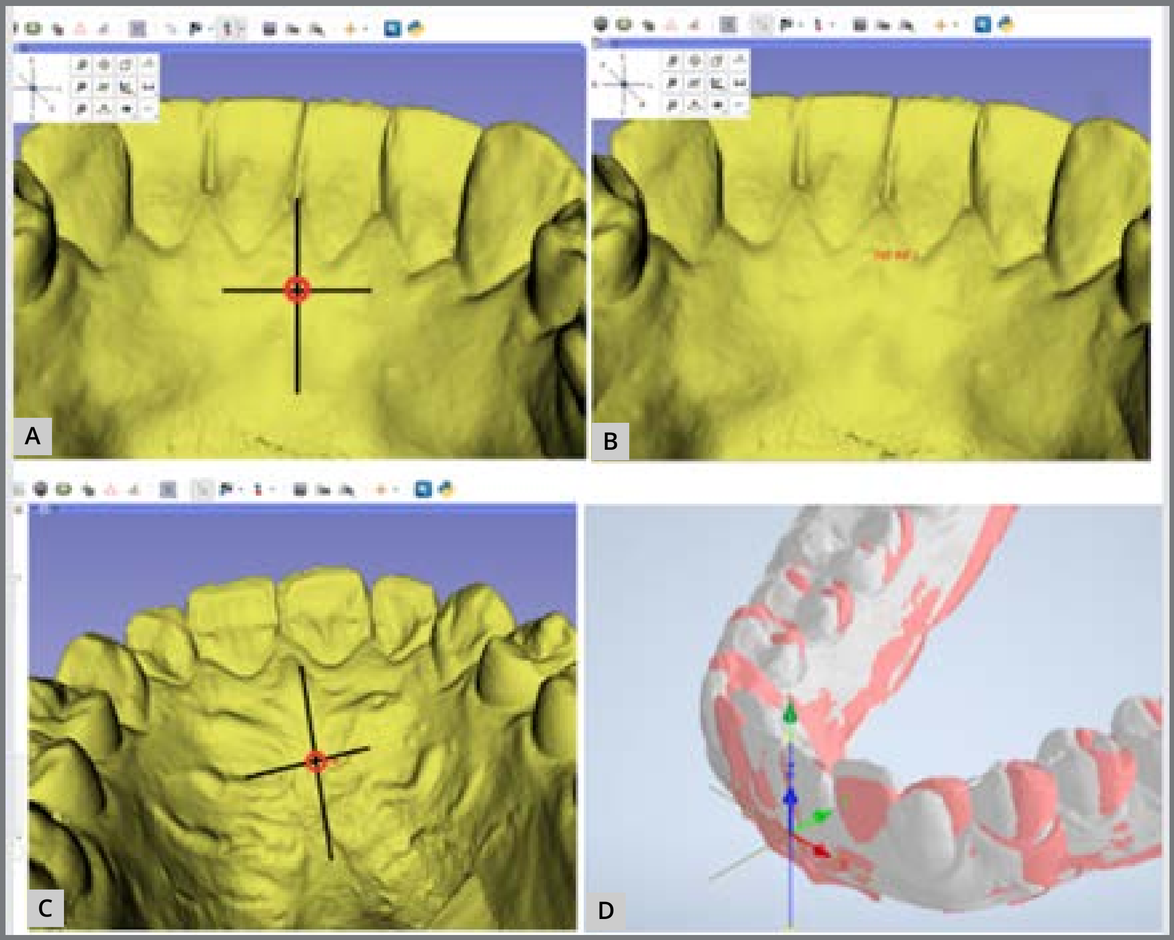


**Figure 2:** Mandibular and maxillary landmark position using vertical and horizontal lines to define the point of interest position. **A)** Mandibular landmark position; **B)** geometric coordinates generated after marking the point; **C)** maxillary landmark position; **D)** mandibular superposed models.

space in T0 and T1 models. Afterward, the X, Y, and Z coordinates were copied and used in Autodesk Inventor® (Fig 3) to promote an overlap between the geometric points in T0 and T1 models. After superimposing models, tooth movement was

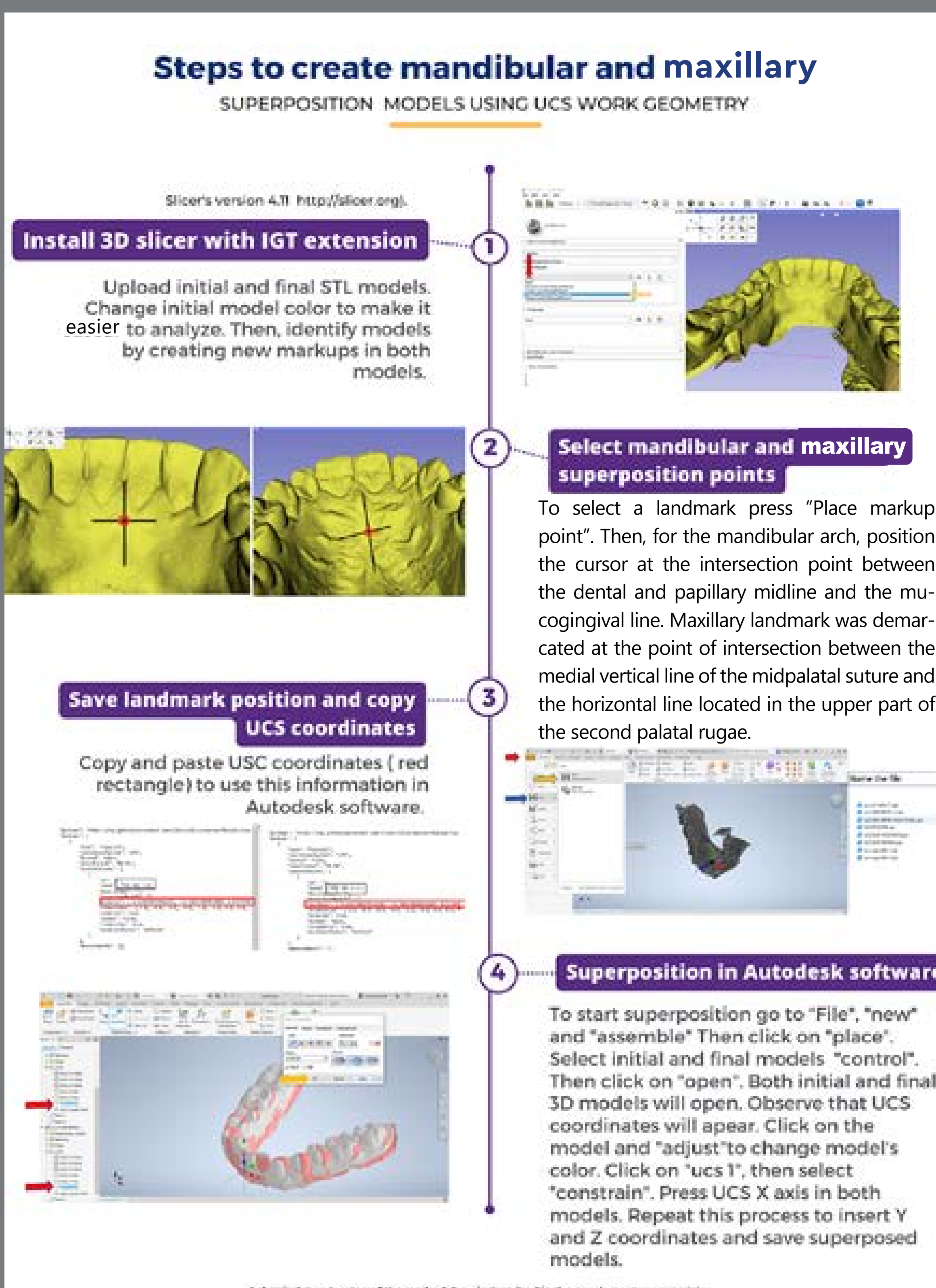


**Figure 3:** Flowchart indicating a summary of the step-by-step procedure for marking points on the maxilla and mandible using Slicer 3D® software and superimposing models in Autodesk Inventor® software.

measured in Autodesk Inventor® (Fig 4). The 3D movements of buccolingual translation of maxillary and mandibular canines, premolars and molars were analyzed, and the intrusion and rotation movements of the mandibular incisors and canines

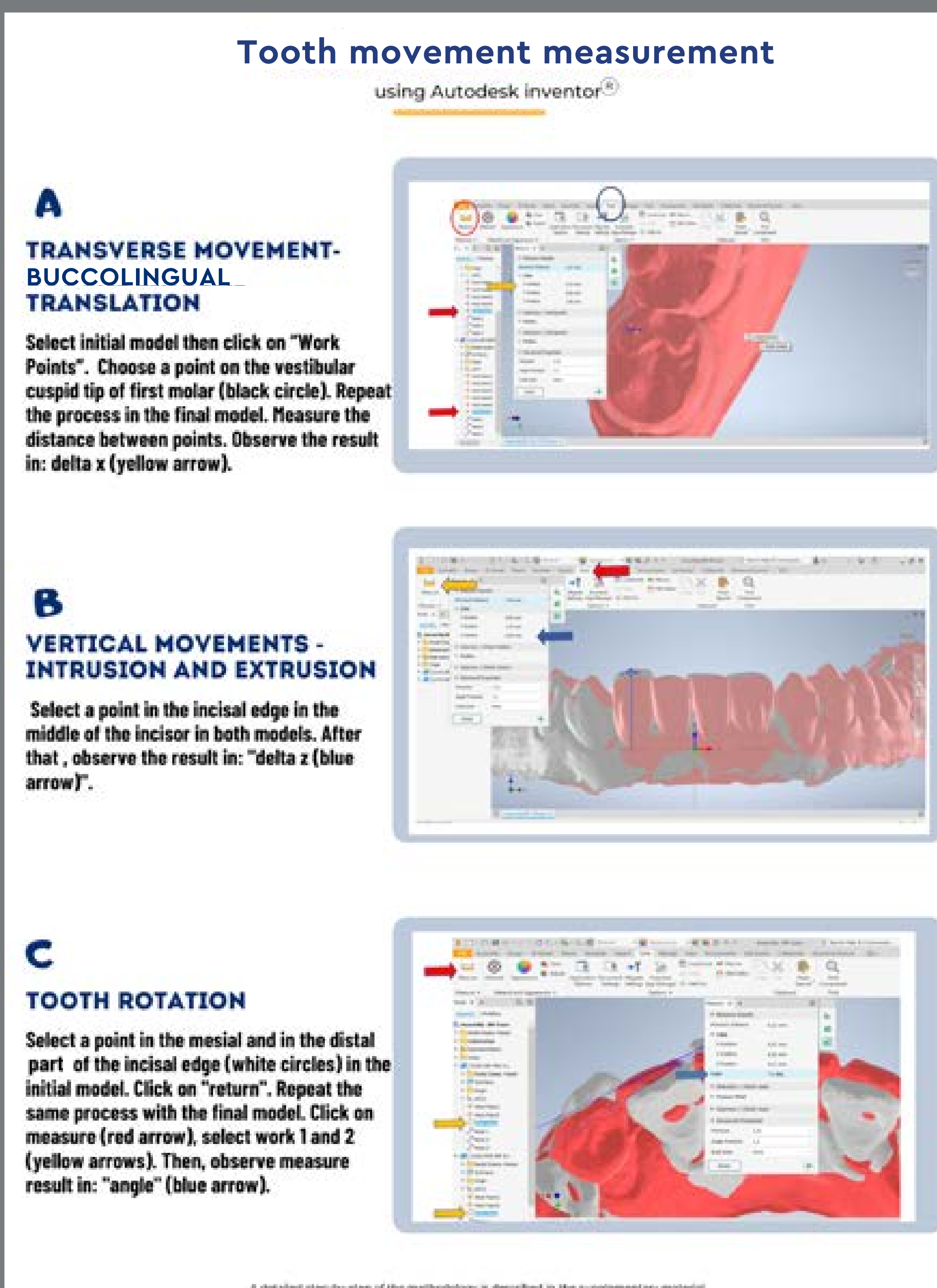


**Figure 4:** The image represents tooth movements measurement: **A)** Buccolingual translation; **B)** Vertical movements (intrusion and extrusion**)**; **C)** Rotation movements.

were measured. The intra- and inter-examiner calibration was performed. Examiner 1 (RS) repeated the measurements twice with a 15-day interval (intra-examiner) and Examiner 2 (JP) performed these measurements once (inter-examiner). A detailed description of the methodology was prepared and can be seen in the supplementary material (Suppl. Table 3).

## STATISTICAL ANALYSIS

The results were expressed as mean ± standard deviation. Intra- and inter-examiner agreements were calculated using an intraclass correlation coefficient (2-way random, single measurement, absolute agreement) and Bland-Altman plot,[1] using the SPSS (IBM SPSS Statistics version 19.0, Inc., New Armonk, NJ, EUA) and GraphPad Prism softwares (version 8.0 for Mac, La Jolla, California, USA), respectively. For the assessment of systematic error, the Dahlberg formula was used. For systematic error evaluation, linear measurements should not exceed 1 mm and angular measurements should not exceed 1.5°.[20] The steps for model analysis were performed by two examiners (RS and JP, inter-examiner). The first examiner performed the steps twice, with a 15-day interval between examinations (intra-examiner). ICC values of 0.9 to 1 were considered excellent, 0.6 to 0.7 were good, 0.4 to 0.5 were considered reasonable, and less than 0.4 were categorized as poor.[20] Student's t-test was used to analyze the differences between the groups, and $p < 0.05$ was considered statistically significant. Statistical analysis was performed using the program GraphPad Prism (version 8.0 for Mac, La Jolla, California, USA).

# RESULTS

## SUPERPOSITION OF THE 3D MODEL WAS REACHED BY STANDARDIZING LANDMARK LOCATION IN THE MAXILLA AND MANDIBLE AND USING UCS GEOMETRY

The study generated a step-by-step guide that can be accessed in the supplementary material (Suppl. Table 3) and a video to help researchers perform the superimposition of STL models. The first step is the download of SlicerCMF® and Autodesk Inventor® softwares. Both softwares are freely available for students. Afterward, the step-by-step and the video should be followed to help the analysis. The superposition process in the maxilla and mandible was standardized using UCS geometry, single point in 3D STL models. The 3D buccolingual translation and intrusion movements were measured in millimeters and rotation movement in degrees. The buccolingual translation movement was measured as the distance between the buccal cusps of canines, and mesiobuccal cusps of premolars and molars on the X-axis in millimeters (mm). The vertical movement of the mandibular canines and incisors was measured from the tip of the canine cusps to the middle of the incisal edges. Displacements in the gingiva direction (intrusion movement) were considered with a positive sign (+); Displacements in the incisal occlusal direction (extrusion movement) were considered with a negative sign (-). The amount of vertical movement was observed in the Z-axis in millimeters (Suppl. Table 3 and Fig. 5).

**Figure 5:** “Step-by-step” video.

The “Step-by-step” video can be watched through the QR code above (Fig 5).

## INTER- AND INTRA-EXAMINER MEASURES SHOWED A HIGH DEGREE OF AGREEMENT

Intra- and inter-examiner measures showed a high degree of agreement, analyzed by ICC and Bland-Altman statistical tests, indicating that the methodology of 3D models superposition was effective (Tables 1 and 2).

**Table 1:** Results of the intra-examiner agreement in the buccolingual translation, intrusion and rotation movements.

| Tooth | n | Measure 1 (RS) | | Measure 2 (RS) | | Type of movement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | ICC | 95% CI | D | P | BA |
| | | | | | | Buccolingual translation (mm) | | | | |
| Maxillary right canine | 26 | 0.250 | 0.225 | 0.254 | 0.233 | 0.993 | 0.962-0.992 | 0.038 | 0.952 | -0.003 |
| Maxillary right first premolar | 26 | 0.412 | 0.363 | 0.394 | 0.329 | 0.885 | 0.743-0.948 | 0.155 | 0.857 | 0.017 |
| Maxillary right second premolar | 26 | 0.446 | 0.413 | 0.468 | 0.396 | 0.916 | 0.813-0.962 | 0.158 | 0.849 | -0.039 |
| Maxillary right first molar | 26 | 0.329 | 0.227 | 0.341 | 0.249 | 0.887 | 0.747-0.949 | 0.105 | 0.853 | -0.012 |
| Maxillary right second molar | 26 | 0.365 | 0.257 | 0.371 | 0.267 | 0.955 | 0.900-0.980 | 0.075 | 0.937 | -0.005 |
| Maxillary left canine | 26 | 0.259 | 0.187 | 0.268 | 0.213 | 0.882 | 0.736-0.947 | 0.091 | 0.863 | -0.009 |
| Maxillary left first premolar | 26 | 0.434 | 0.460 | 0.535 | 0.608 | 0.853 | 0.671-0.934 | 0.277 | 0.503 | -0.100 |
| Maxillary left second premolar | 26 | 0.539 | 0.557 | 0.483 | 0.418 | 0.878 | 0.728-0.945 | 0.228 | 0.682 | 0.056 |
| Maxillary left first molar | 26 | 0.356 | 0.271 | 0.379 | 0.251 | 0.840 | 0.643-0.928 | 0.135 | 0.756 | -0.022 |
| Maxillary left second molar | 26 | 0.237 | 0.160 | 0.294 | 0.211 | 0.823 | 0.599-0.922 | 0.108 | 0.283 | -0.057 |
| Mandibular right canine | 26 | 0.270 | 0.200 | 0.328 | 0.291 | 0.816 | 0.583-0.919 | 0.151 | 0.410 | -0.062 |
| Mandibular right first premolar | 26 | 0.323 | 0.308 | 0.290 | 0.269 | 0.990 | 0.978-0.996 | 0.041 | 0.678 | 0.033 |
| Mandibular right second premolar | 26 | 0.448 | 0.532 | 0.424 | 0.525 | 0.990 | 0.978-0.996 | 0.064 | 0.869 | 0.024 |
| Mandibular right first molar | 26 | 0.372 | 0.353 | 0.359 | 0.379 | 0.977 | 0.950-0.990 | 0.305 | 0.900 | -0.001 |
| Mandibular right second molar | 26 | 0.269 | 0.199 | 0.267 | 0.199 | 0.979 | 0.951-0.991 | 0.032 | 0.966 | 0.002 |
| Mandibular left canine | 26 | 0.317 | 0.303 | 0.305 | 0.306 | 0.971 | 0.936-0.987 | 0.262 | 0.888 | -0.003 |
| Mandibular left first premolar | 26 | 0.298 | 0.330 | 0.250 | 0.269 | 0.983 | 0.962-0.992 | 0.281 | 0.562 | 0.038 |
| Mandibular left second premolar | 26 | 0.341 | 0.435 | 0.292 | 0.319 | 0.969 | 0.931-0.986 | 0.331 | 0.642 | 0.048 |
| Mandibular left first molar | 26 | 0.377 | 0.345 | 0.304 | 0.279 | 0.978 | 0.950-0.990 | 0.289 | 0.404 | 0.060 |
| Mandibular left second molar | 26 | 0.236 | 0.197 | 0.178 | 0.150 | 0.948 | 0.885-0.977 | 0.064 | 0.239 | 0.050 |
| | | | | | | Rotation (degrees) | | | | |
| Mandibular right central incisor | 26 | 6.920 | 5.485 | 6.347 | 4.999 | 0.961 | 0.911-0.983 | 1.418 | 0.697 | 0.319 |
| Mandibular right lateral incisor | 26 | 6.414 | 6.234 | 6.258 | 7.248 | 0.979 | 0.953-0.991 | 1.342 | 0.934 | -0.093 |
| Mandibular right canine | 26 | 8.654 | 8.487 | 8.307 | 8.529 | 0.987 | 0.969-0.994 | 1.376 | 0.883 | -0.318 |
| Mandibular left central incisor | 26 | 7.043 | 5.512 | 6.322 | 5.211 | 0.969 | 0.932-0.986 | 1.316 | 0.626 | 0.478 |
| Mandibular left lateral incisor | 26 | 5.466 | 4.847 | 5.258 | 5.020 | 0.960 | 0.908-0.982 | 1.343 | 0.880 | -0.002 |
| Mandibular left canine | 26 | 7.623 | 6.156 | 7.054 | 6.121 | 0.970 | 0.932-0.987 | 1.134 | 0.741 | 0.287 |
| | | | | | | Intrusion (mm) | | | | |
| Mandibular right central incisor | 26 | 0.231 | 0.343 | 0.211 | 0.311 | 0.996 | 0.992-0.998 | 0.028 | 0.818 | 0.012 |
| Mandibular right lateral incisor | 26 | 0.243 | 0.326 | 0.229 | 0.280 | 0.991 | 0.980-0.996 | 0.039 | 0.869 | 0.005 |
| Mandibular right canine | 26 | 0.155 | 0.250 | 0.147 | 0.224 | 0.995 | 0.989-0.998 | 0.023 | 0.905 | 0.007 |
| Mandibular left central incisor | 26 | 0.242 | 0.344 | 0.223 | 0.310 | 0.995 | 0.989-0.998 | 0.033 | 0.830 | 0.010 |
| Mandibular left lateral incisor | 26 | 0.279 | 0.313 | 0.253 | 0.284 | 0.989 | 0.976-0.995 | 0.044 | 0.753 | 0.016 |
| Mandibular left canine | 26 | 0.207 | 0.340 | 0.197 | 0.304 | 0.995 | 0.989-0.998 | 0.031 | 0.908 | 0.002 |

SD = Standard deviation. ICC = Intraclass Correlation Coefficient. CI = Confidence Interval. D = Dahlberg. BA = Bland-Altman. Mm = millimeters. $p < 0.05$.

**Table 2:** Results of the inter-examiner agreement in the buccolingual translation, intrusion and rotation movements.

| Tooth | n | Examiner 1 (RS) | | Examiner 2 (JP) | | Type of movement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | ICC | 95% CI | D | P | BA |
| | | | | | | Buccolingual translation (mm) | | | | |
| Maxillary right canine | 26 | 0.257 | 0.224 | 0.288 | 0.263 | 0.980 | 0.957-0.991 | 0.047 | 0.648 | -0.031 |
| Maxillary right first premolar | 26 | 0.412 | 0.363 | 0.394 | 0.329 | 0.887 | 0.743-0.948 | 0.155 | 0.855 | 0.017 |
| Maxillary right second premolar | 26 | 0.412 | 0.363 | 0.394 | 0.329 | 0.916 | 0.813-0.962 | 0.319 | 0.857 | -0.039 |
| Maxillary right first molar | 26 | 0.329 | 0.227 | 0.341 | 0.249 | 0.887 | 0.747-0.949 | 0.105 | 0.853 | -0.012 |
| Maxillary right second molar | 26 | 0.365 | 0.257 | 0.371 | 0.267 | 0.955 | 0.900-0.990 | 0.074 | 0.937 | -0.005 |
| Maxillary left canine | 26 | 0.259 | 0.187 | 0.268 | 0.213 | 0.882 | 0.736-0.947 | 0.091 | 0.863 | -0.009 |
| Maxillary left first premolar | 26 | 0.434 | 0.460 | 0.535 | 0.608 | 0.853 | 0.671-0.934 | 0.277 | 0.503 | -0.100 |
| Maxillary left second premolar | 26 | 0.539 | 0.557 | 0.483 | 0.418 | 0.878 | 0.729-0.945 | 0.228 | 0.682 | 0.056 |
| Maxillary left first molar | 26 | 0.356 | 0.271 | 0.379 | 0.251 | 0.840 | 0.643-0.928 | 0.135 | 0.756 | -0.022 |
| Maxillary left second molar | 26 | 0.237 | 0.160 | 0.294 | 0.211 | 0.823 | 0.599-0.922 | 0.108 | 0.283 | -0.057 |
| Mandibular right canine | 26 | 0.270 | 0.200 | 0.328 | 0.291 | 0.816 | 0.583-0.919 | 0.151 | 0.410 | -0.062 |
| Mandibular right first premolar | 26 | 0.328 | 0.356 | 0.333 | 0.344 | 0.809 | 0.573-0.914 | 0.194 | 0.956 | -0.005 |
| Mandibular right second premolar | 26 | 0.498 | 0.566 | 0.474 | 0.588 | 0.859 | 0.679-0.938 | 0.281 | 0.884 | 0.0332 |
| Mandibular right first molar | 26 | 0.375 | 0.347 | 0.387 | 0.381 | 0.857 | 0.675-0.937 | 0.183 | 0.900 | -0.011 |
| Mandibular right second molar | 26 | 0.286 | 0.200 | 0.244 | 0.297 | 0.910 | 0.791-0.961 | 0.091 | 0.867 | -0.006 |
| Mandibular left canine | 26 | 0.360 | 0.352 | 0.381 | 0.338 | 0.883 | 0.735-0.949 | 0.156 | 0.830 | -0.016 |
| Mandibular left first premolar | 26 | 0.404 | 0.443 | 0.402 | 0.444 | 0.975 | 0.942-0.989 | 0.112 | 0.987 | 0.001 |
| Mandibular left second premolar | 26 | 0.376 | 0.440 | 0.400 | 0.527 | 0.988 | 0.973-0.995 | 0.103 | 0.861 | -0.055 |
| Mandibular left first molar | 26 | 0.382 | 0.354 | 0.427 | 0.377 | 0.978 | 0.952-0.990 | 0.081 | 0.656 | -0.045 |
| Mandibular left second molar | 26 | 0.240 | 0.209 | 0.293 | 0.249 | 0.943 | 0.871-0.975 | 0.078 | 0.412 | -0.044 |
| | | | | | | Rotation (degrees) | | | | |
| Mandibular right central incisor | 26 | 6.706 | 5.343 | 6.557 | 5.005 | 0.956 | 0.896-0.981 | 1.476 | 0.922 | 0.149 |
| Mandibular right lateral incisor | 26 | 6.859 | 7.583 | 7.102 | 7.348 | 0.986 | 0.966-0.994 | 1.275 | 0.913 | -0.565 |
| Mandibular right canine | 26 | 8.244 | 6.978 | 8.356 | 7.165 | 0.980 | 0.952-0.992 | 1.361 | 0.958 | -0.112 |
| Mandibular left central incisor | 26 | 6.467 | 4.645 | 6.816 | 5.827 | 0.966 | 0.918-0.986 | 1.467 | 0.824 | -0.968 |
| Mandibular left lateral incisor | 26 | 5.715 | 4.847 | 6.291 | 5.270 | 0.981 | 0.953-0.992 | 1.136 | 0.704 | -0.862 |
| Mandibular left canine | 26 | 8.046 | 6.402 | 8.480 | 6.969 | 0.982 | 0.957-0.993 | 1.342 | 0.829 | -0.818 |
| | | | | | | Intrusion (mm) | | | | |
| Mandibular right central incisor | 26 | 0.193 | 0.316 | 0.188 | 0.289 | 0.992 | 0.983-0.987 | 0.036 | 0.956 | 0.004 |
| Mandibular right lateral incisor | 26 | 0.255 | 0.320 | 0.233 | 0.383 | 0.937 | 0.859-0.972 | 0.120 | 0.826 | 0.021 |
| Mandibular right canine | 26 | 0.115 | 0.343 | 0.131 | 0.350 | 0.987 | 0.970-0.994 | 0.056 | 0.867 | -0.016 |
| Mandibular left central incisor | 26 | 0.238 | 0.325 | 0.236 | 0.349 | 0.990 | 0.979-0.0996 | 0.045 | 0.987 | 0.001 |
| Mandibular left lateral incisor | 26 | 0.281 | 0.311 | 0.261 | 0.295 | 0.989 | 0.976-0.995 | 0.045 | 0.809 | 0.020 |
| Mandibular left canine | 26 | 0.214 | 0.337 | 0.227 | 0.389 | 0.927 | 0.837-0.967 | 0.132 | 0.897 | -0.013 |

SD = Standard deviation. ICC = Intraclass Correlation Coefficient. CI = Confidence Interval. D = Dahlberg. BA = Bland-Altman. Mm = millimeters. $p < 0.05$.

Measurements demonstrated excellent intra-examiner agreements within the linear measures, with mean errors smaller than 0.07 mm (the largest mean intra-examiner difference was found for the buccolingual movement of the left mandibular first molar: 0.377 ± 0.345 mm [first measure] and 0.304 ± 0.279 mm [second measure]) (Table 1). For the rotation movement, the mean difference was smaller than 0.72° in the left mandibular central incisor (7.043 ± 5.512° [first measure] and 6.322 ± 5.211° [second measure]) (Table 1). Inter-examiner agreements were adequate within the linear measures, with a difference smaller than 0.06 mm (the largest intra-examiner measure was found for the buccolingual movement of the left maxillary second premolar: 0.539 ± 0.557 mm [first measure] and 0.483 ± 0.418 mm [second measure]) (Table 2). For the rotation movement, the mean error was smaller than -0.58° in the left mandibular lateral incisor (7.15 ± 4.847° [first measure] and 6.291 ± 5.270° [second measure]) (Table 2).

In the linear and rotation measures, Dahlberg values were always smaller than 1 mm and smaller than 1.5°, respectively, demonstrating that no systematic error was found for intra- and inter-examiners (Tables 1 and 2).

## DISCUSSION

The present study was the first to use the association between the SlicerCMF® software and the Autodesk Inventor® engineering program, using the basic principle of the Universal Coordinate System (UCS). This technique allowed us to determine a single point in the region of the palatine rugae, in the maxilla, and a single point in the lingual region of the mandible, at the mucogingival junction. The results proved to be reliable and reproducible for superimposing 3D orthodontic models of the maxilla and mandible in STL format. In addition, this software is free of charge and easily accessible by the clinical and scientific community, which reduces the financial investment for carrying out research.

Since Broadbent[21] and Baumrind, Frantz[22] investigations on head-film measurements, there has been a challenge to determine an accurate method to set up landmarks to improve treatment planning, description, and predictability. Point identification error is a systematic problem and over the years several studies have proposed different methods to control it.[8,12,19,22-24] The search for stable structures that are not influenced by orthodontic movement has been the main prerogative of current studies.[7] Even in cases of orthodontic aligners, in which no movement of posterior teeth is planned, making them supposedly immobile, tooth movement is observed.[3] In this study, we standardized a method to establish landmark points on the maxilla and mandible, to reduce this identification error. In the present method, the points were created by the intersection of two lines (vertical and horizontal), both traced on anatomical structures. Furthermore, this landmark generated by UCS geometry promotes better three-dimensional control of the point location and a more reliable superimposition.

Studies have pointed out that both the palatal rugae region and the mucogingival region are stable for model superimposition, using a wide area of the maxilla and mandible, respectively.[1,7-12,19,24-26] The greatest difficulties in superimposing STL models have been in the mandible.[7,13,19] One of the points used that proved stable for mandibular superimposition is the Torus, located on the lingual alveolar surface; however, this is a structure that is not present in all patients[11] — thus, its use was discarded in the present research. The region of the mucogingival junction has been chosen for 3D superimpositions in the mandible because it is easy to locate and because it is stable and does not change,[19] even during intrusion and extrusion movements of the teeth or with mandibular growth.[1,19,24,25] Usually in the literature, these points are demarcated along the mucogingival junction from the first molar on the right side to the first molar on the left side, totaling 13 marks on average.[1,19,24] The enhanced number of marks might increase the chance of errors and possibly decrease the reliability of the method. The solution to this impasse in the present study was to use the Cartesian axes associated with a single point at the mucogingival junction in the mandibular region. Through the demarcation of a single point in each model, the three Cartesian axes (X, Y, and Z) were generated and the software aligned these axes in T0 and T1 models, creating infinite points of spatial superposition with stability and reproducibility, as it is a stable and accessible structure present in all cases.[1,7,19,24]

In the maxilla, studies have shown that the rugae regions, especially the second and third rugae, are stable regions for superimposition.[1,11,24,25] In the current study, the Cartesian axes with a single point in the medial region of the second rugae was used for superimposition of the maxillary models. This area is considered safe because it is not affected by tooth movement,[8,10,19] thus decreasing the chance of errors during similar points marking.

Several studies seek to increase the reliability of superposition by searching for spatial reference planes using manual tools for the elaboration of the coordinates.[6,11,12,16,19,27] The use of only one point in each 3D model was possible due to the use of the UCS coordinate system. Through UCS in Autodesk Inventor®, it was possible to automatically match the Cartesian axes by reading the coordinates of the points in the two models, T0 and T1, and thereby evaluating the displacements of the X (buccolingual displacement), Y (mesiodistal displacement) and Z (vertical displacement) coordinates. Thus, it was possible to observe each variation individually, without approximation mechanisms or manual interference. This method is an essential tool for many precision operations in engineering and can be used in Dentistry, reducing the amount of work required for the superimposition of 3D models.

Autodesk Inventor® is commonly used in bioengineering for stress and strain assessment, which requires accurate positioning of the models before mechanical analyses.[28,29] In the present research, this software was fundamental to ensure the correct positioning of the models, which is essential in studies for 3D models superimposition. Autodesk Inventor®, as well as other CAD/CAM software, is compatible with several 2D and 3D file extensions, especially the so-called "neutral formats", such as Standard Triangle Language (STL), and Parasolid (x_t).[24] The use of this software proved to be very useful in this study, since the maxilla and mandible scans performed in Invisalign® orthodontic treatments use the STL format. Thus, it was possible to easily manipulate the models using Autodesk Inventor® 2D and 3D design tools.

The software used in our research was the freely available SlicerCMF®, which is commonly used in Dentistry and has demonstrated its accuracy and reliability.[19] It has been used for superimposing 3D models of the maxilla, despite using several points on the palatal rugae,[19,30] and for superimposing points on the mucogingival region of the mandible, using 13 points as a reference for superimposition.[1,19] Herein, we used the SlicerCMF® for single point demarcation on both T0 and T1 models. The superimposition was not performed by this software as it requires more than one point for this purpose.[19] In this study, the points in the lingual mucosa gingival region were easily visualized and demarcated, and registered through the association with the X, Y, and Z coordinates generated by the software itself.

In the present research, the treatment was focused on mild to moderate malocclusions, with duration of eight months between T0 and T1. After the treatment with the aligners, there were few changes in the adjacent gingival tissues; however, none of them could hinder the identification of similar points or structures in T0 and T1, allowing the proper superimposition of the 3D models. The same anatomical structures used in this research can be visualized in more severe malocclusions, showing that there are no limitations to the use of the new superimposition method proposed in this study.[13,24]

Considering the ICC of each movement, high values in the linear movements expressed in millimeters were obtained. The lowest value for ICC was for the rotation, expressed in degrees. The reason was the high sensitivity of Autodesk Inventor® for angular measurements, especially for values smaller than 5°. During insertion of the points on the incisal edges, minimal displacements in the buccolingual direction within the incisal edge could alter the reading of the angle formed by the two lines (T0 and T1), especially when the STL mesh was enlarged in the models. A different situation was found in the linear measurements, as small horizontal displacements did not affect the result so significantly, due to the size of the measurements. This was an exploratory study, and future studies may consider linear measurement error with a threshold of less than 1 mm and angular measurements of less than 1.5°. Regarding the systematic error, a study stated that less than 1 mm and 1.5° for linear and angular,[20] respectively, are acceptable, but in the present study, the magnitude of these values may mean clinically relevant movements.

The STL models were obtained retrospectively by scanning exclusively with iTero®, as carried out in other studies,[31-33] and the spatial position of the models was established by this program automatically. Our focus was to standardize the methodology by choosing cases treated with the same align system, as well as using STL files obtained from the same scanner brand and handled by two operators. We believe that these precautions make the standardization of the methodology more effective. In future studies, another scanner brand may be used to evaluate if this is a factor that influences the spatial positioning of the models.

Regarding the limitation of the current study, we need to point out that superposing models and measuring tooth movement was not possible in cases in which restorative or periodontal procedures were performed during the orthodontic treatment. A total of 27 participants were selected for the study. One patient was lost to follow-up and discontinued evaluation due to carrying out restorative treatment in T1; so the study was carried out with the remaining 26 participants who had agreed to participate. Another important point is the non-comparison between our method and others in the literature, to assess the accuracy of our systematization. Our main objective was to describe this accessible method that has proven to be effective for superimposing models, and it will be necessary to analyze the accuracy and predictability of this new method as compared with others.[1,19] Thus, further studies are needed to determine the level of accuracy of the methodology.

Inexperience with engineering software can become a real challenge and limitation for dental researchers. However, in this study a very detailed step-by-step procedure was developed explaining complex and unfamiliar commands, which may become easy and intuitive after professional training. After the high agreement and reproducibility results achieved with this program, it may become a new and useful diagnostic tool for outcome assessment and orthodontic treatment predictability within all clinicians' reach.

## CONCLUSIONS

We can conclude that an effective method for superimposing 3D models using UCS geometry was created, using the 3D SlicerCMF® and Autodesk Inventor® free softwares. This model was effective in promoting the superposition of the maxillary and mandibular models and in measuring tooth movements, such as tooth expansion, rotation, intrusion, and extrusion.

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## AUTHORS' CONTRIBUTIONS

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*Writing the article:*
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*Critical revision of the article:*
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*Overall responsibility:*
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## REFERENCES


1. Garib D, Miranda F, Massaro C, Lauris JRP, Yatabe MS, Janson G, et al. Three-dimensional mandibular dental changes with aging. Am J Orthod Dentofac Orthop. 2021;159(2):184-92.
2. Krarup S, Darvann TA, Larsen P, Marsh JL, Kreiborg S. Three-dimensional analysis of mandibular growth and tooth eruption. J Anat. 2005;207(5):669-82.
3. Charalampakis O, Iliadi A, Ueno H, Oliver DR, Kim KB. Accuracy of clear aligners: A retrospective study of patients who needed refinement. Am J Orthod Dentofac Orthop. 2018;154(1):47-54.
4. Sachdev S, Tantidhnazet S, Saengfai NN. Accuracy of tooth movement with in-house clear aligners. J World Fed Orthod. 2021;10(4):177-82.
5. Klaus K, Xirouchaki F, Ruf S. 3D-analysis of unwanted tooth movements despite bonded orthodontic retainers: a pilot study. BMC Oral Health. 2020;20(1):308.
6. Camardella LT, Breuning H, Vilella OV. Are there differences between comparison methods used to evaluate the accuracy and reliability of digital models? Dental Press J Orthod. 2017;22(1):65-74.
7. Stucki S, Gkantidis N. Assessment of techniques used for superimposition of maxillary and mandibular 3D surface models to evaluate tooth movement: a systematic review. Eur J Orthod. 2020;42(5):559-70.

8. Jang I, Tanaka M, Koga Y, Iijima S, Yozgatian JH, Cha BK, et al. A novel method for the assessment of three-dimensional tooth movement during orthodontic treatment. Angle Orthod. 2009;79(3):447-53.

9. Pan Y, Wang X, Dai F, Chen G, Xu T. Accuracy and reliability of maxillary digital model (MDM) superimposition in evaluating teeth movement in adults compared with CBCT maxillary superimposition. Sci Rep. 2020;10(1):19384.

10. Vasilakos G, Schilling R, Halazonetis D, Gkantidis N. Assessment of different techniques for 3D superimposition of serial digital maxillary dental casts on palatal structures. Sci Rep. 2017;7(1):5838.

11. An K, Jang I, Choi DS, Jost-Brinkmann PG, Cha BK. Identification of a stable reference area for superimposing mandibular digital models. J Orofac Orthop. 2015;76(6):508-19.

12. Choi DS, Jeong YM, Jang I, Jost-Brinkmann PG, Cha BK. Accuracy and reliability of palatal superimposition of three-dimensional digital models. Angle Orthod. 2010;80(4):497-503.

13. Kuralt M, Fidler A. Assessment of reference areas for superimposition of serial 3D models of patients with advanced periodontitis for volumetric soft tissue evaluation. J Clin Periodontol. 2021;48(6):765-73.

14. Camardella LT, Vilella OV, Breuning KH, de Assis Ribeiro Carvalho F, Kuijpers-Jagtman AM, Ongkosuwito EM. The influence of the model superimposition method on the assessment of accuracy and predictability of setup models. J Orofac Orthop. 2021;82(3):175-86.

15. Westerlund A, Tancredi W, Ransjo M, Bresin A, Psonis S, Torgersson O. Digital casts in orthodontics: a comparison of 4 software systems. Am J Orthod Dentofac Orthop. 2015;147(4):509-16.

16. Talaat S, Kaboudan A, Bourauel C, Ragy N, Kula K, Ghoneima A. Validity and reliability of three-dimensional palatal superimposition of digital dental models. Eur J Orthod. 2017;39(4):365-70.

17. Felter M, Lenza MMO, Lenza MG, Shibazaki WMM, Silva RF. Comparative study of the usability of two software programs for visualization and analysis of digital orthodontic models. J Dent Res Dent Clin Dent Prospects. 2018;12(3):213-20.

18. Liu L, Wang X, Guan M, Fan Y, Yang Z, Li D, et al. A mixed reality-based navigation method for dental implant navigation method: A pilot study. Comput Biol Med. 2023;154:106568.

19. Garib D, Miranda F, Yatabe MS, Lauris JRP, Massaro C, McNamara JA, Jr., et al. Superimposition of maxillary digital models using the palatal rugae: Does ageing affect the reliability? Orthod Craniofac Res. 2019;22(3):183-93.

20. Cançado RH, Lauris JR. Error of the method: what is it for? Dental Press J Orthod. 2014;19(2):25-6.

21. Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod. 1931;1:45-66.

22. Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am J Orthod. 1971;60(2):111-27.

23. Lee SY, Kim H, Lee D, Park C. Superimposition of a cone beam computed tomography (CBCT) scan and a photograph: A dental technique. J Prosth Dent. 2021;125(2):212-5.

24. Ioshida M, Munoz BA, Rios H, Cevidanes L, Aristizabal JF, Rey D, et al. Accuracy and reliability of mandibular digital model registration with use of the mucogingival junction as the reference. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019;127(4):351-60.

25. Brindis MA, Block MS. Orthodontic tooth extrusion to enhance soft tissue implant esthetics. J Oral Maxillofac Surg. 2009;67(11 Suppl):49-59.

26. Pazera C, Gkantidis N. Palatal rugae positional changes during orthodontic treatment of growing patients. Orthod Craniofac Res. 2021;24(3):351-9.

27. Ruellas AC, Tonello C, Gomes LR, Yatabe MS, Macron L, Lopinto J, et al. Common 3-dimensional coordinate system for assessment of directional changes. Am J Orthod Dentofac Orthop. 2016;149(5):645-56.

28. Hamed HA, Marzook HA, Ghoneem NE, El-Anwar MI. Angulated dental implants in posterior maxilla DEA and experimental verification. Open Access Maced J Med Sci. 2018;6(2):397-401.

29. Yang J, Li Y, Shi X, Shen M, Shi K, Shen L, et al. Design and analysis of three-dimensional printing of a porous titanium scaffold. BMC Musculoskelet Disord. 2021;22(1):654.

30. Anacleto MA, Souki BQ. Superimposition of 3D maxillary digital models using open-source software. Dental Press J Orthod. 2019;24(2):81-91.

31. Houle JP, Piedade L, Todescan R, Jr., Pinheiro FH. The predictability of transverse changes with Invisalign. Angle Orthod. 2017;87(1):19-24.

32. Morales-Burruezo I, Gandia-Franco JL, Cobo J, Vela-Hernandez A, Bellot-Arcis C. Arch expansion with the Invisalign system: Efficacy and predictability. PLoS One. 2020;15(12):e0242979.

33. Ko J, Bloomstein RD, Briss D, Holland JN, Morsy HM, Kasper FK, et al. Effect of build angle and layer height on the accuracy of 3-dimensional printed dental models. Am J Orthod Dentofac Orthop. 2021;160(3):451-8 e2.

**Supplemental Table 1**. Sample size calculation. The sample size calculation for comparative studies that involve the comparison of two groups (inter- or intra examiner) was performed to verify the number of patients to be used in the research. To determine the value of N an equation comparing two means was used, as previously described by Eng (2003)[1]. Thus, the formula for calculating the sample size for a reliable estimate of the population mean is given bellow.

Equation:

$N = 4\ \delta^2(Zcrit + Zpwr)^2/D^2$

Where:

N = total number of individuals in the sample

δ = standard deviation of the studied variable.

Zcrit = normal standard deviation of the selected significance criterion.

Zpwr: normal standard deviation of the selected statistical power.

D = Minimum expected difference between the 2 means.

Rerefence for equation development:

As a reference for the expected value of standard deviation of the mean and the minimum expected difference between 2 means, values referring to the three-dimensional (3D) dental changes (in millimeters) measured in the anteroposterior (A-P) plane of the right first premolar and right canine from the article by Garib et al., (2021)[2] were used (page 16 of the article, Table), as they were one of the most unstable biological variables found in this study. The standard deviation found for the A-P in the right canine was 1.39; while the difference between the means of A-P measurements from the right canine and the right first premolar was 0.4489 [(-0,41) – 0.26]. A significance criterion of 0.05 (normal standard deviation = 1.96) and statistical power of 0.80 (normal standard deviation = 0.842) were selected based on the article Eng (2003)[1]

Solving the equation with these values provides:

$N = 4 \times (1.39)^2 \times (1.96 + 0.842)^2 / ((-0{,}41) - 0.26]^2$

N = 47.83

Participants:

As indicated in the equation for sample calculation, the value of N corresponds to the sum of the 2 groups being compared. Thus, the predicted value of N for each experimental group is approximately 23.9 (N = 47.83 divide for 2 groups).

Thus, the predicted N value was rounded to 24 patients and an additional of 10% (26.4 patients per group, rounded to 27 participants) was added planning possible losses during the orthodontic treatment.

A total of 27 participants were selected for the study. One sample lost to follow-up and discontinued evaluation due to carrying out the restorative treatment in T1 and the study remained with 26 participants that agreed to participate.

## References

1. Eng J. Sample size estimation: how many individuals should be studied? Radiology. 2003;227(2):309-13.doi:10.1148/radiol.2272012051

2. Garib D, Miranda F, Massaro C, Lauris JRP, Yatabe MS, Janson G, et al. Three-dimensional mandibular dental changes with aging. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2021;159(2):184-92.doi:10.1016/j.ajodo.2019.12.021

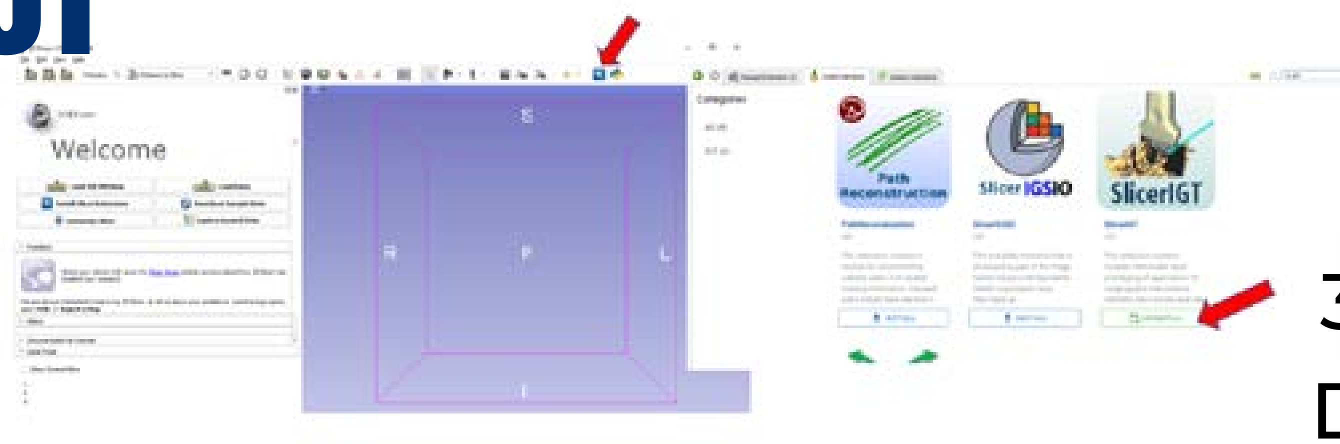
**Supplemental Table 2**. Inclusion and exclusion criteria and inter- e intra- examiner's calibration

| |
|---|
| **Inclusion criteria:** patients who had Class I, II and III malocclusion with moderate inferior crowding of up to 4 mm, change in overbite (from 3 to -5 mm), permanent dentition, presence of all teeth up to the second molars, aged 18 to 45 years. |
| **Exclusion criteria:** patients who had restorations in the teeth moved during treatment, non-cooperating patients-with craniofacial syndromes or anomalies, and those with signs or symptoms of inflammation in the periodontal tissues. Three cases were discarded, two because the mesh was distorted for unknown reasons and one because a composite resin restoration was inserted in a tooth after movement altering the dental proportion, resulting 11 pairs of STL models. All participants were treated by the same professional in a private clinic in Belo Horizonte, Minas Gerais, Brazil and the cases were selected retrospectively. |
| **Inter e intra examiner's calibration:** To evaluate the calibration of the main examiner (RS) with the software, a total of 22 measurements were taken, after superimposition 10 on posterior teeth in the bucco-lingual direction of canines, first and second premolars, first and second molars mandibular and maxillary represented by the X axis, in millimeters; 6 measurements in the vertical direction on anterior teeth of canines and mandibular incisors, movement represented by the Z axis in millimeters; and, 6 measurements on anterior teeth for the mesio-distal rotation, carried out by mandibular and maxillary incisors and canines, analyzed in degrees. The superimposition of 11 STL models were performed, totaling 242 measurements in 286 teeth, in both phases T0 (initial) and T1 (refinement), and repeated 2 times with a 15-day interval between them. To evaluate the accuracy and reliability, the same measurements were repeated by two examiners (RS- and GS) of the 11 cases. The two examiners did not participate in the orthodontic treatment. |

**Supplemental Table 3:** Step by step process to choose mandibular and maxillary superimposition points using UCS working geometry in initial and final STL models.

Slicer's version 4.11
http://slicer.org).

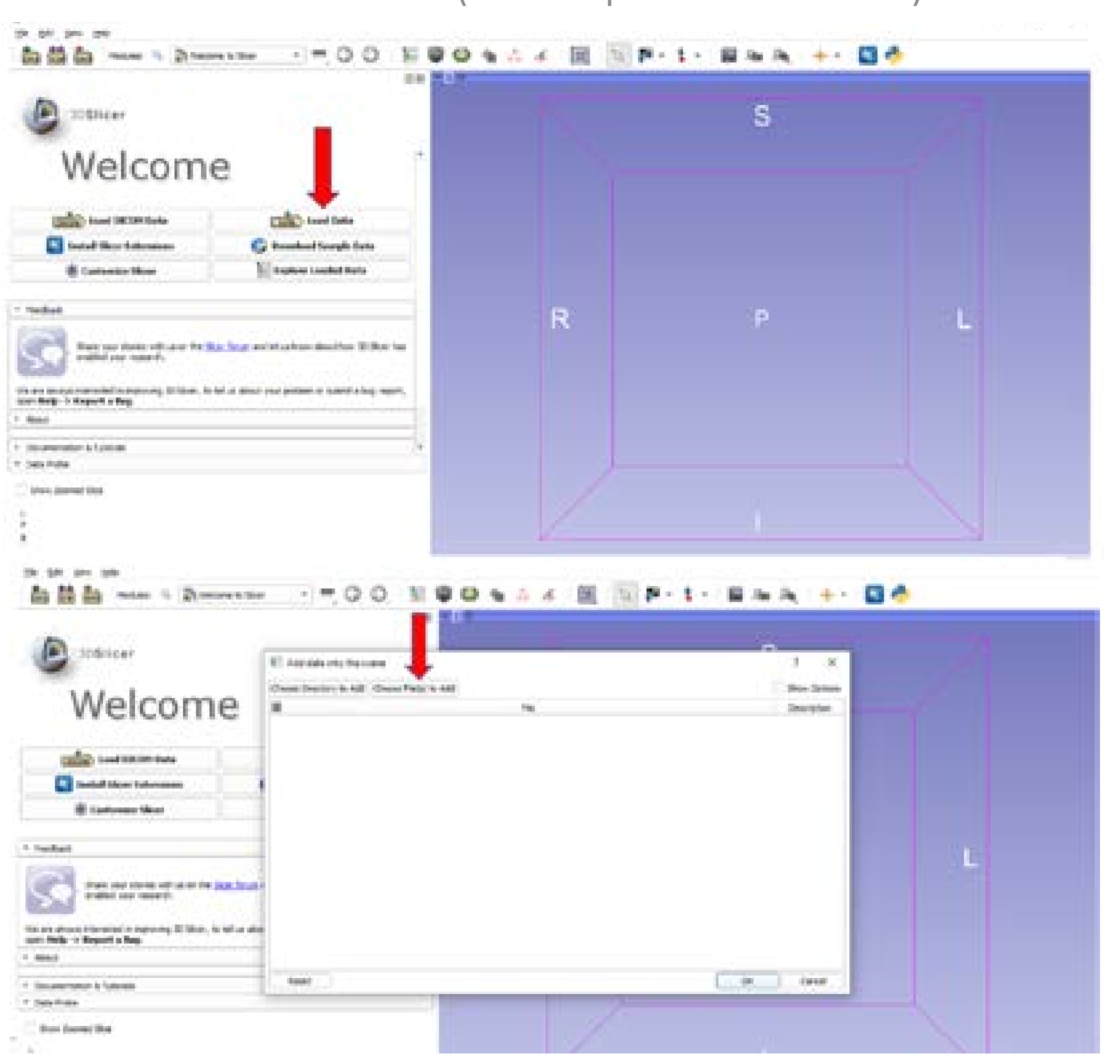
**01** Install IGT extension on 3D Slicer software (red arrow)




3D

**02** Open 3D SLICER in the initial screen and upload your STL file.
Click on: "Load data" ( red arrow).

Choose File ( red arrow) to upload STL model and then in "choose a file to add" (second picture red arrow).




SLICER

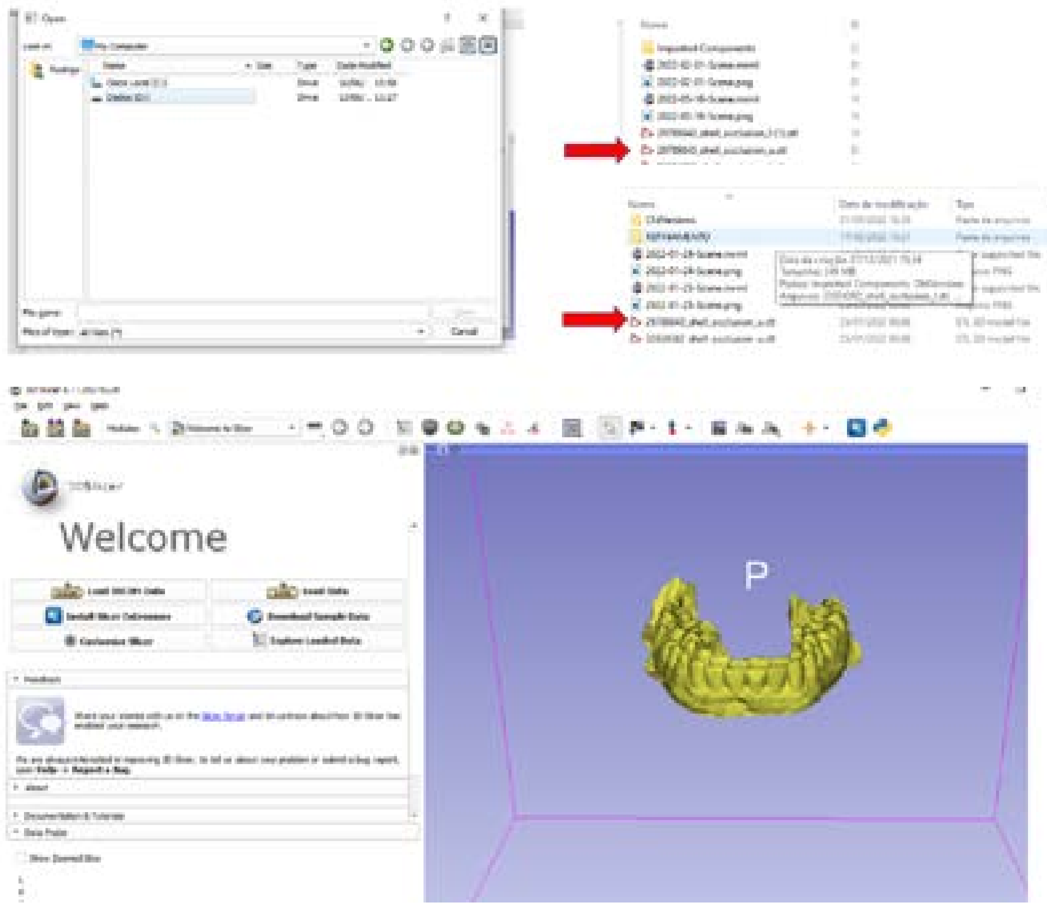
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

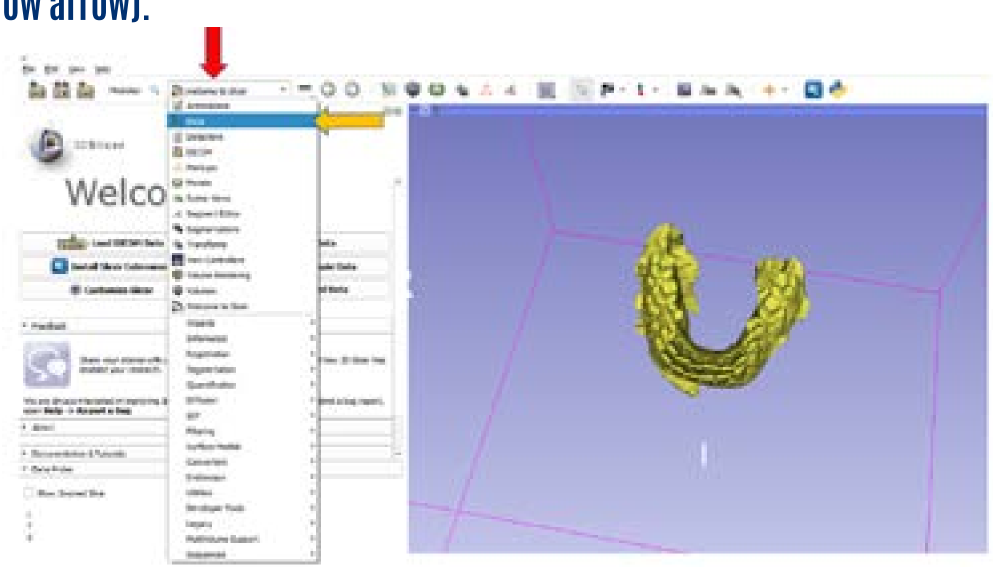
3D SLICER

### 03 Select the initial and final STL models (red arrows) of the same arch (upper ou lower).

**Select STL models and click on: “OK”.** Both, initial and final, will appear on the screen.




### 04 Select one of the models to change it's color. It will make it easier to analyze. Click on “Welcome to Sliced (red arrow), and select “data” (yellow arrow).

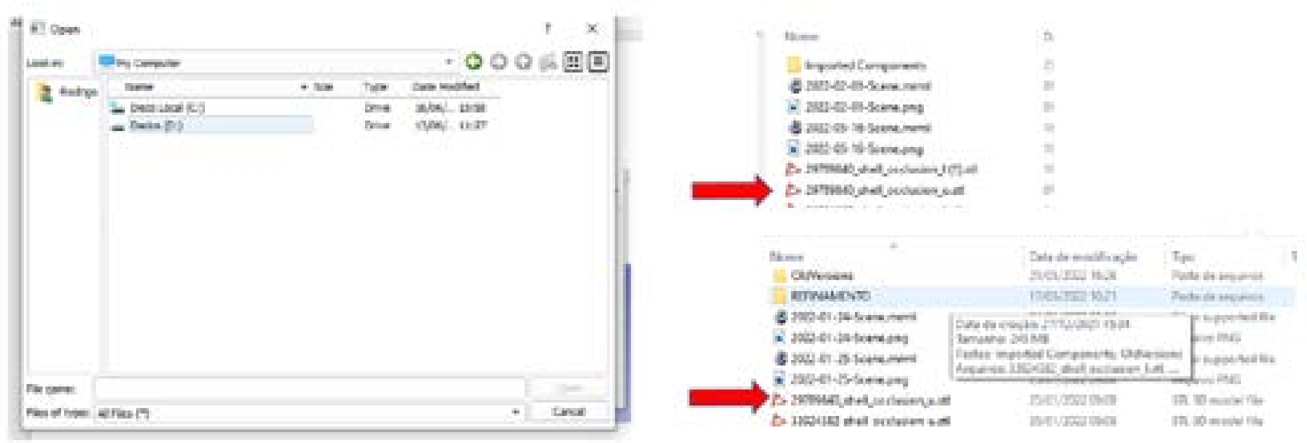


## Step by Step process to

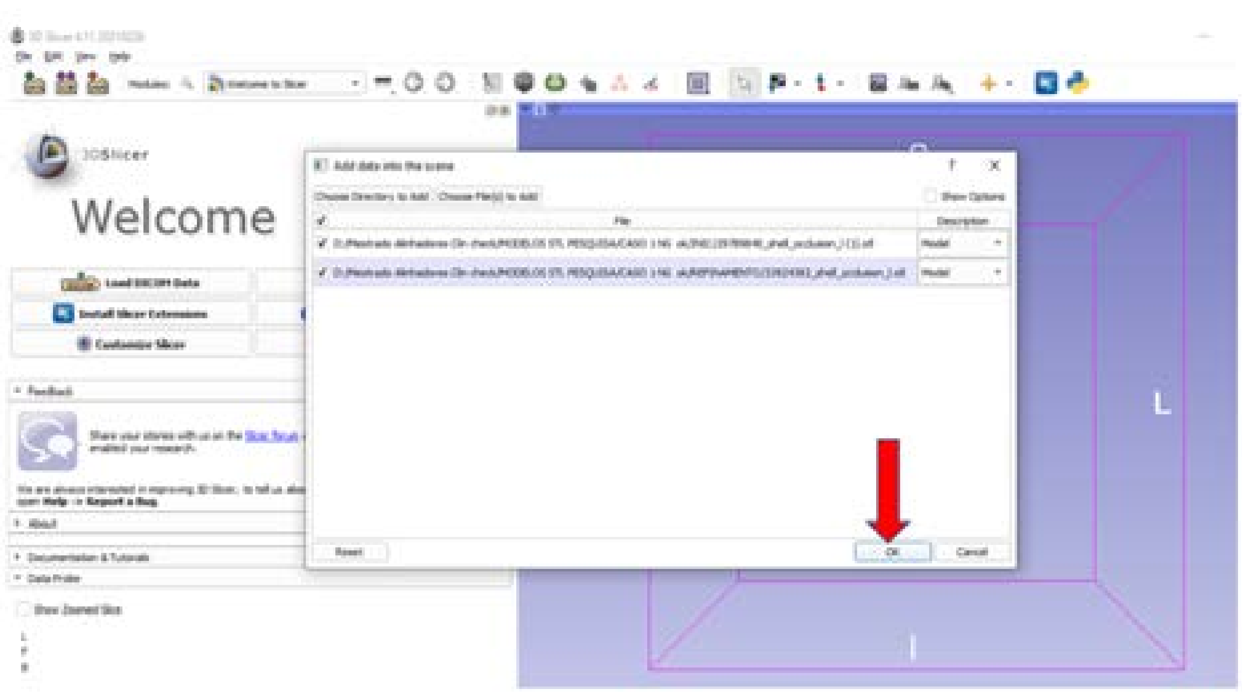
CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

**05** **Select the initial and final STL models (red arrows) of the same arch (upper ou lower).**

3D SLICER



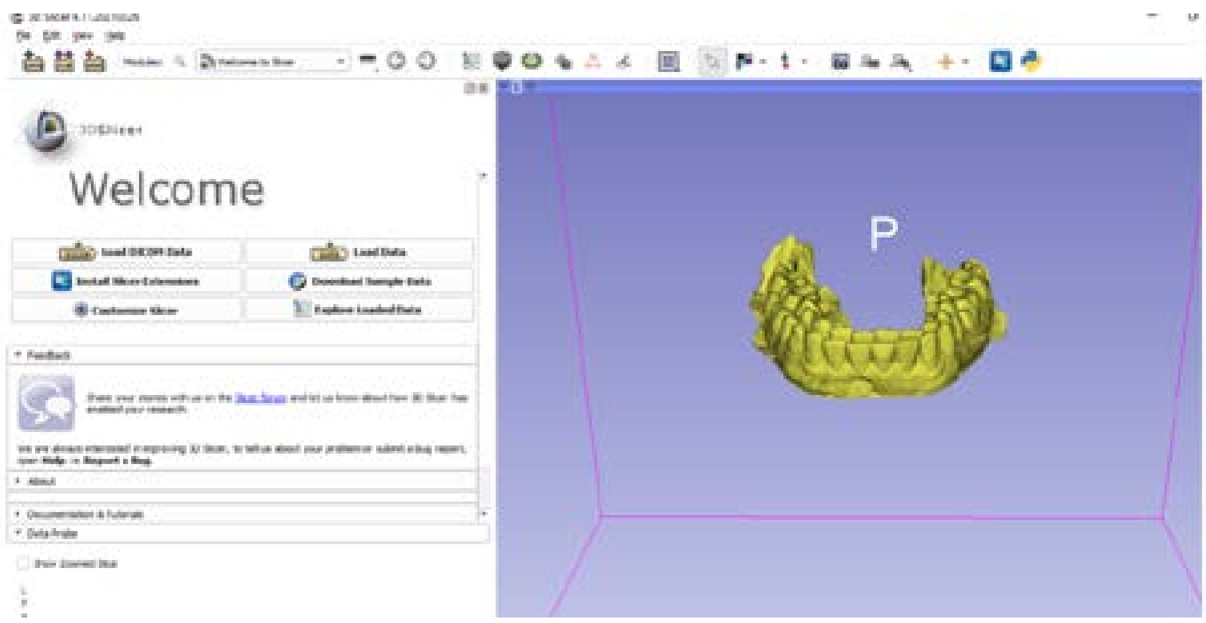
Select STL models and click on: “OK”.



## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

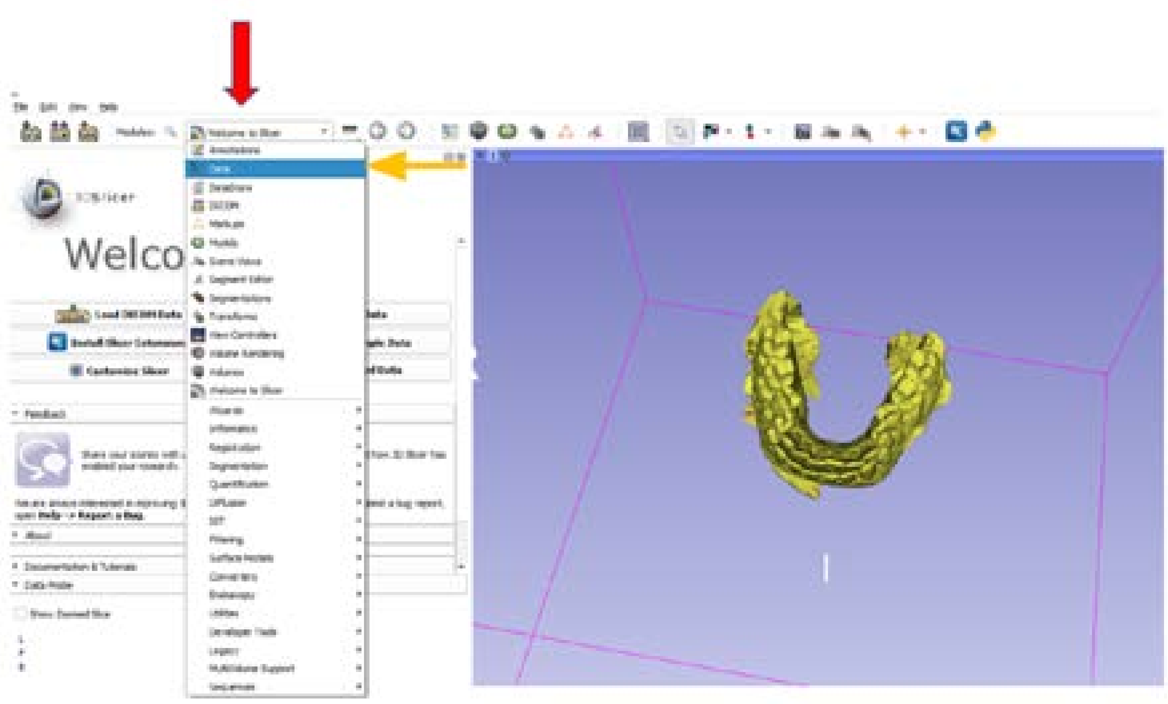
Both, initial and final, will appear on the screen.




3D SLICER

## 06

**Click on "welcome to slicer"( red arrow) and select " data"( yellow arrow).**



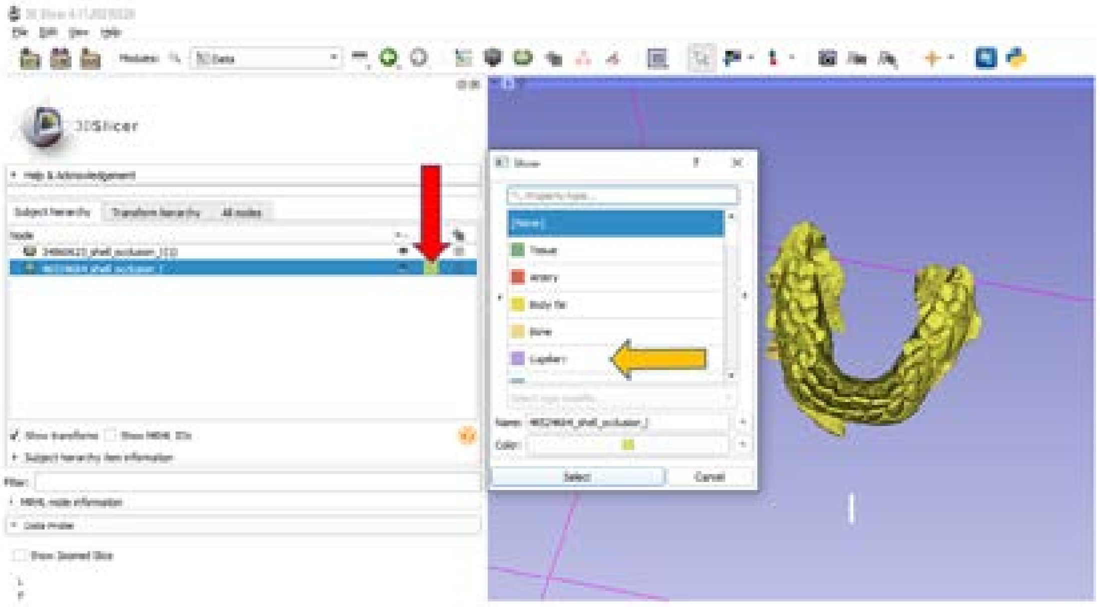
## Step by Step process to

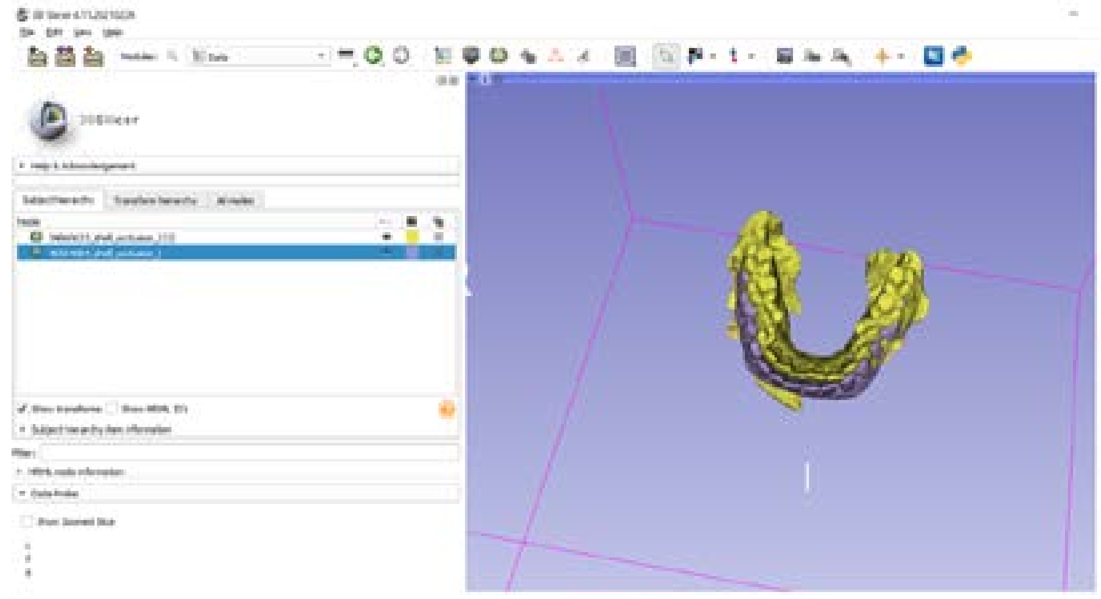
CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

# 07

**Click in one of the models ( red arrow) and then select the color you want ( yellow arrow). Press "select" to continue.**

You will see initial and final models into different colors.





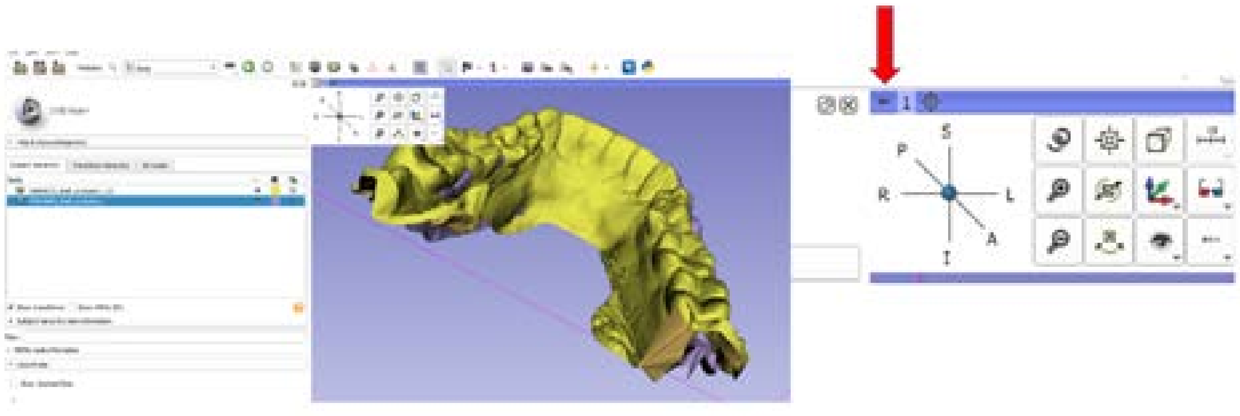
3D SLICER

## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 08 By clicking on the button indicated by the red arrow, models can be positioned to better visualize the point of interest.

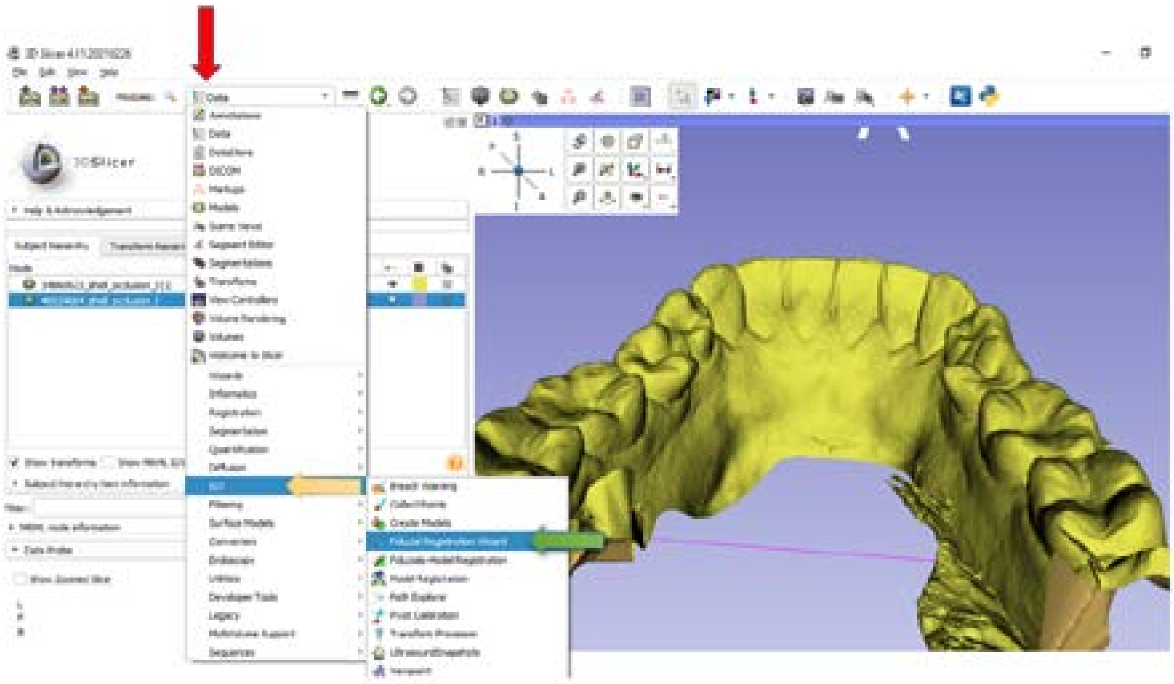
Lower arch can be positioned to better visualize lingual region of incisor. In the same way, upper arch can be positioned to better visualize palate rugosity.



3D SLICER

### 09 Identify initial and final models

First click on "data,"(red arrow), then on IGT (yellow arrows) and finally on Fiducial Registration Wizard (green arrow).



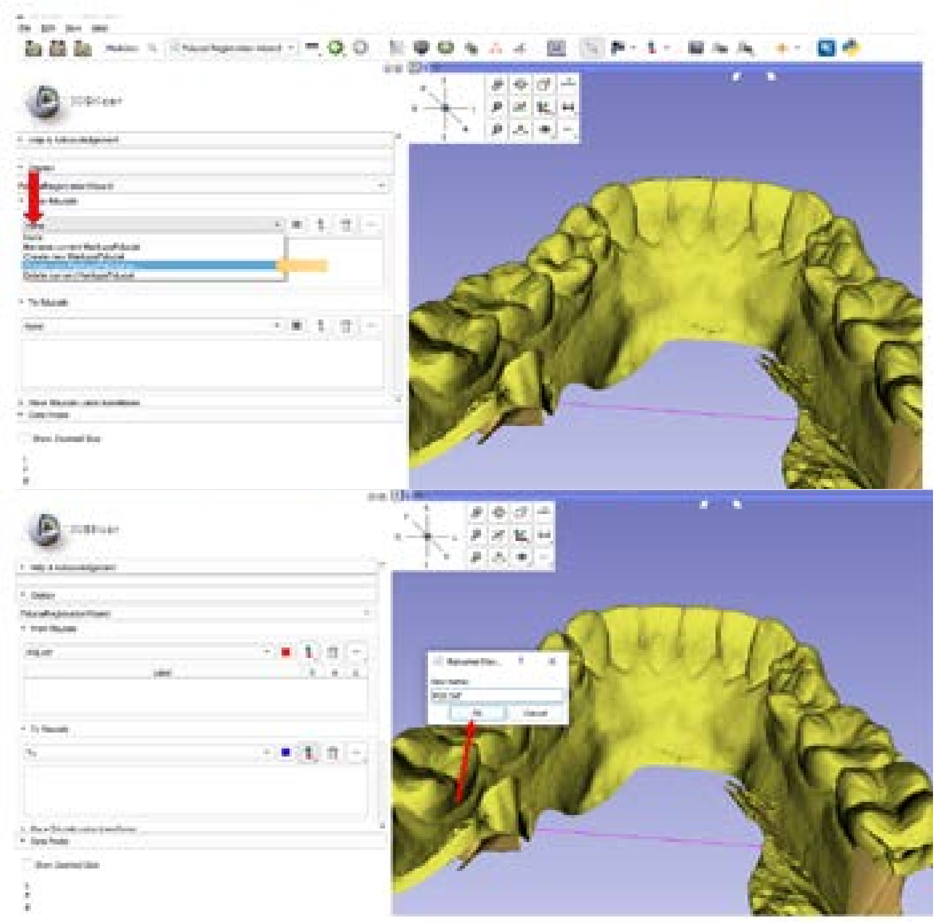
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

3D SLICER

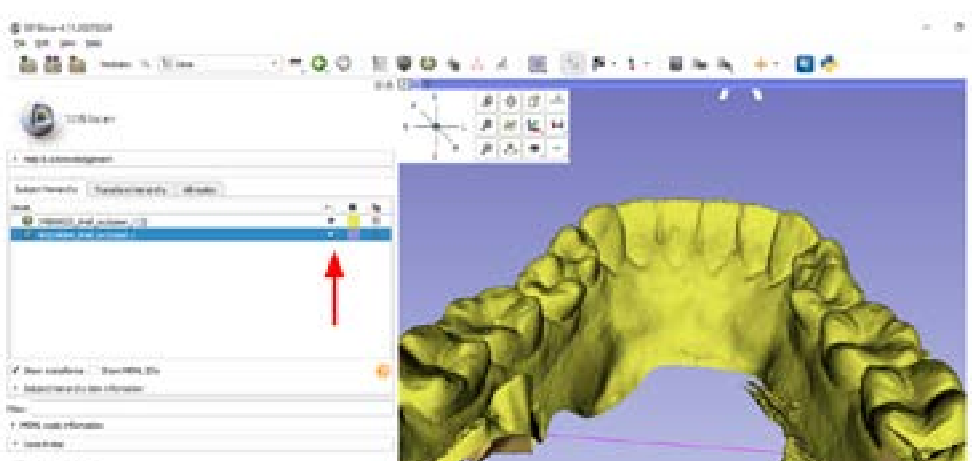
### 10 We are going to identify the models by changing their name

First click “none”(red arrow) and then on “Create new markups fiducial as” (yellow arrow) to change models identification. Repeat the process with the other STL model.



### 11 Marking the maxilar or mandibular point is on each model

To make it easier, you can remove the visibility of one of the models by clicking on the icon ( red arrow).



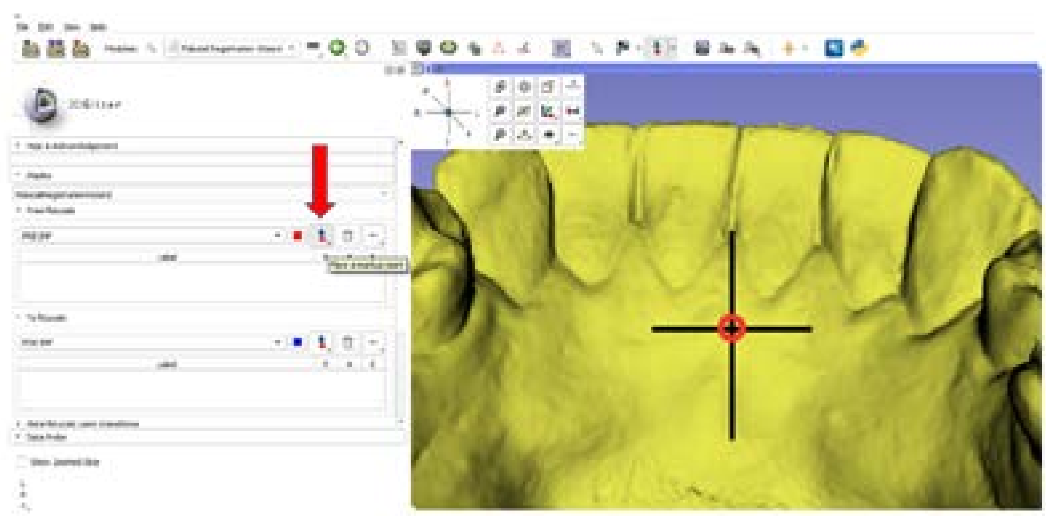
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

3D SLICER

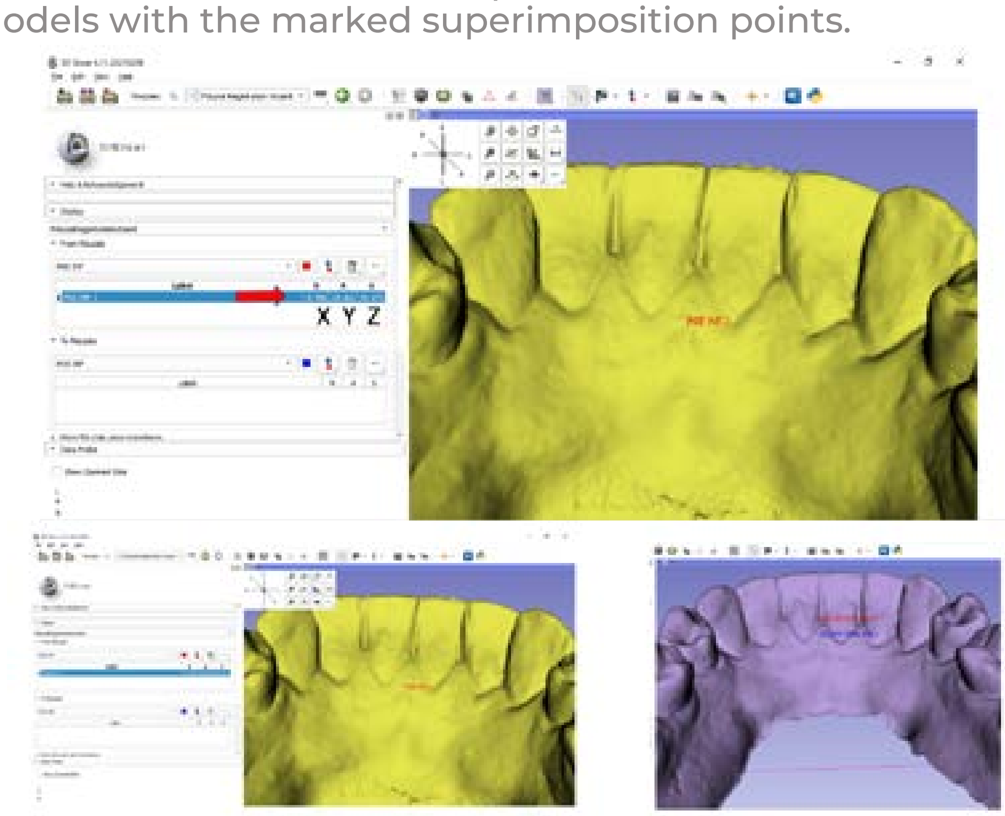
### 12 Mandibular landmarck

To select a landmark press "Place markup point“(red arrow). Then, position the cursor at the intersection point between the dental and papillary midline and the mucogingival line (red circle).



### 13 Universal Coordinate System

The program will generate a UCS coordinate( red arrow) that will be used to overlay models the Autodesk program. Repeat the process with T1 model. In the second picture we can observe T0 and T1 models with the marked superimposition points.

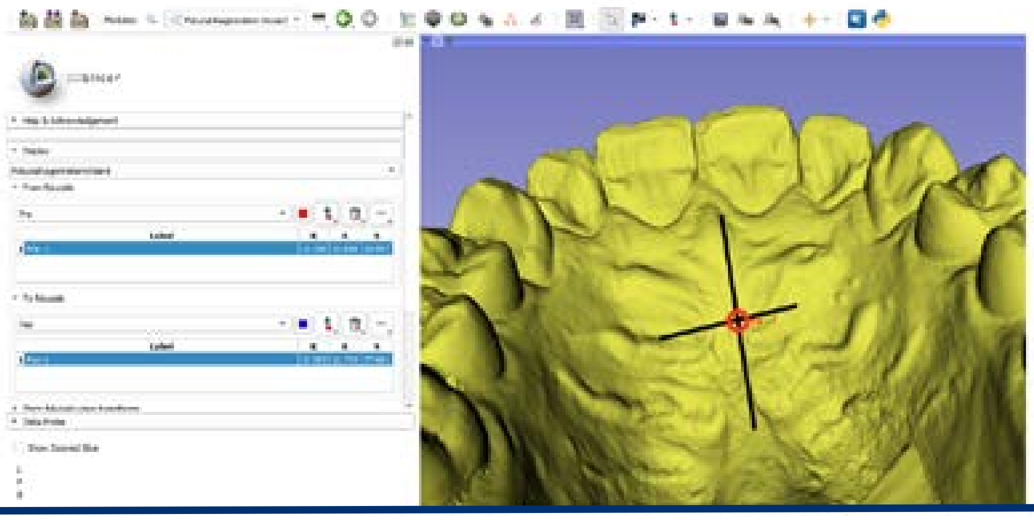


## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 14 Maxillary landmark

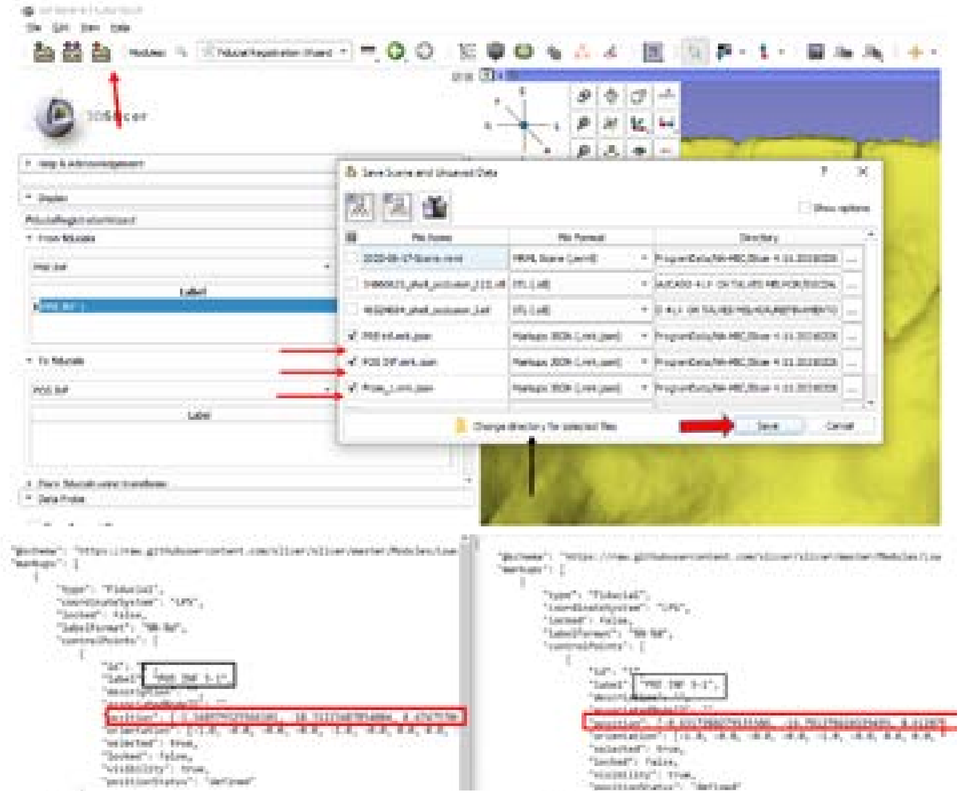
Maxilary landmark was demarcated at the point of intersection between the medial vertical line of the midpalatal suture and the horizontal line located in the upper part of the 2nd crease of the palatal rugae.



3D SLICER

### 15 Save landmark position and copy UCS coordinates

Red arrows indicate the process to save landmark positioning information. After saving information you will need to copy and paste USC coordinates ( red rectangle) to use this information in Autodesk software.



## Step by Step process to

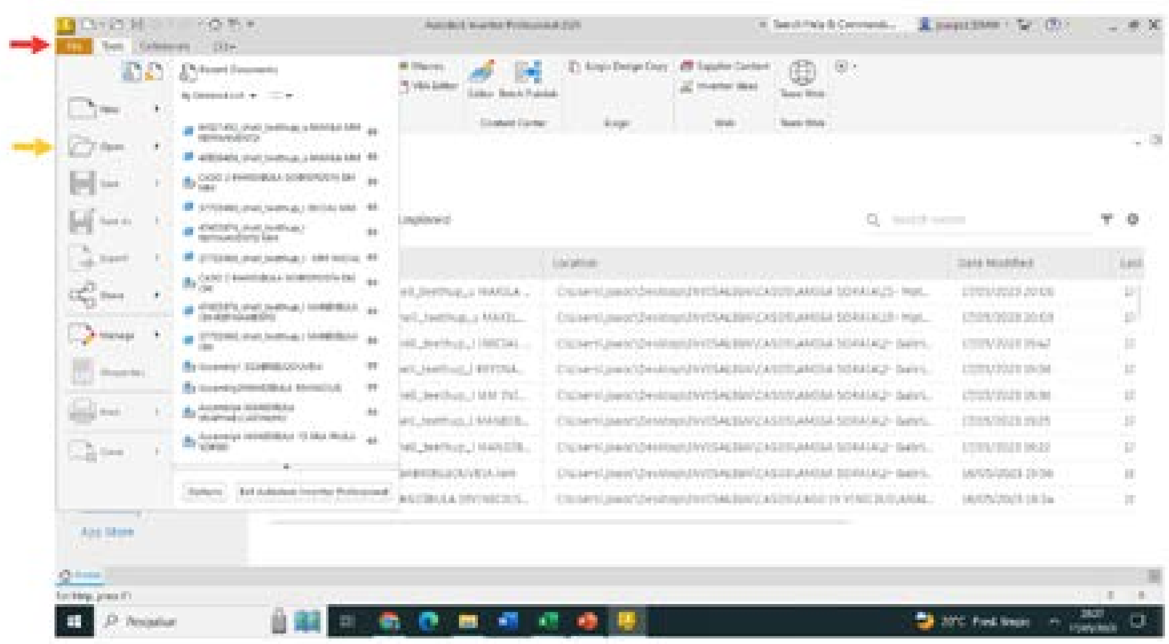
### CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

Software calibration: The configuration is saved when opening other files. It is only necessary to do it once.

**16**

### Start calibration

Click on “File” (red arrow) then “Open” (yellow arrow)



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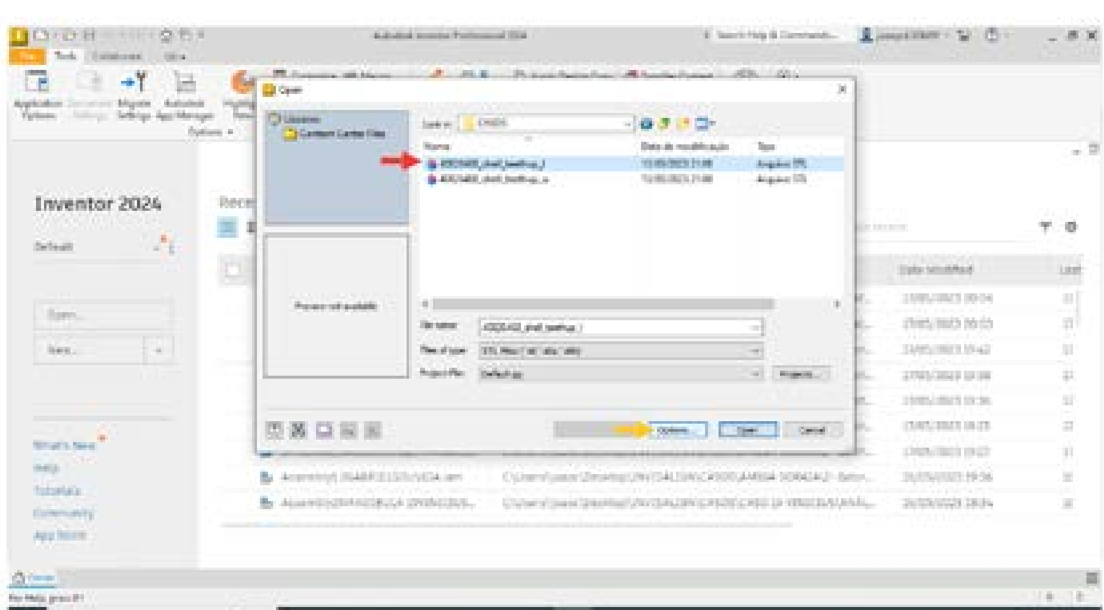
**17**

### Search the folder on your computer. When you find the file click on "open".

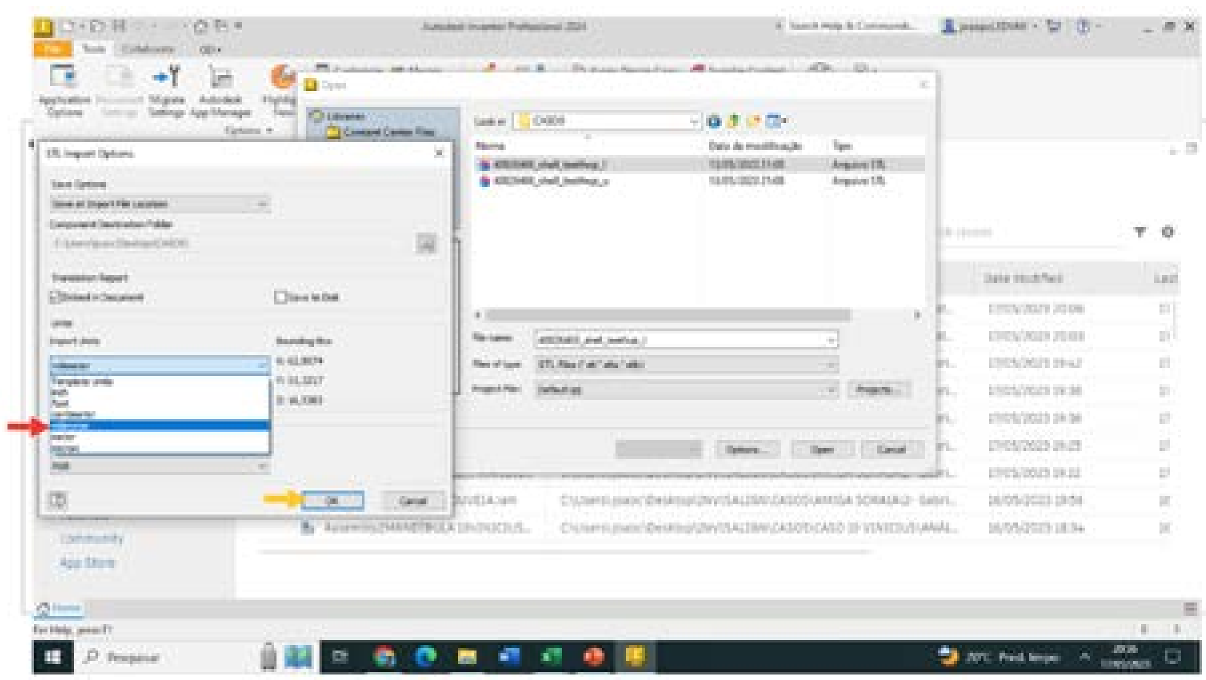
Select the file in STL format (red arrow). Then click on “options.” (yellow arrow).



## Step by Step process to

### CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

**18** Then, click on "Import Units" , select the measurement unit "millimeter" (red arrow). After that, click on the "ok" button (yellow arrow).



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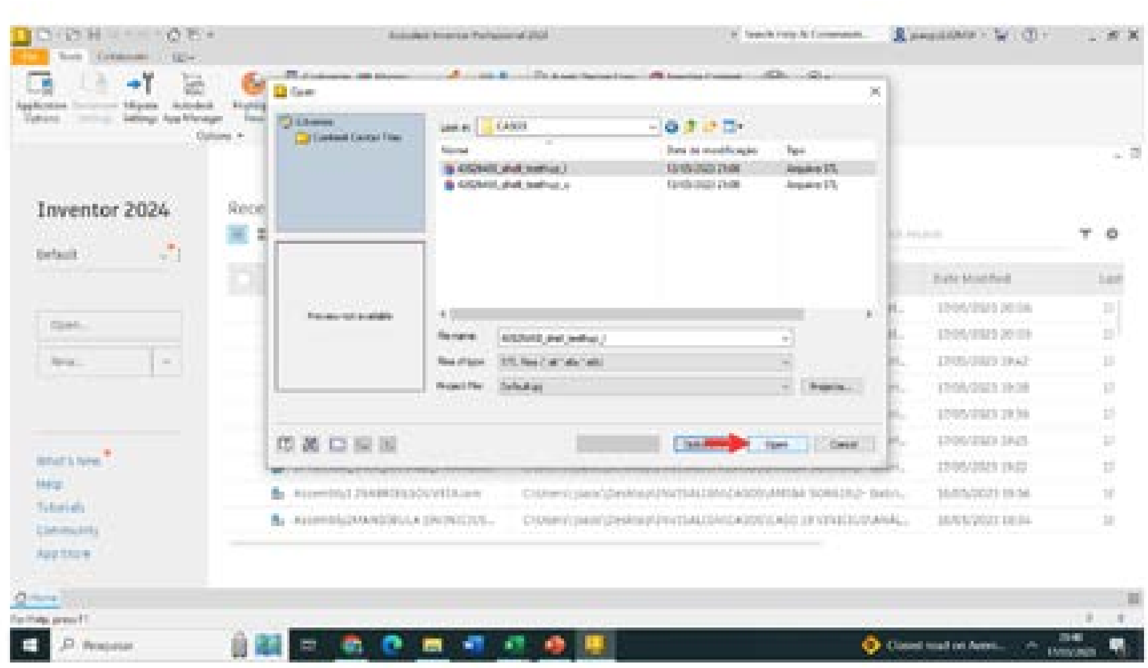
**19** To finish this process click on "open" (red arrow).



## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

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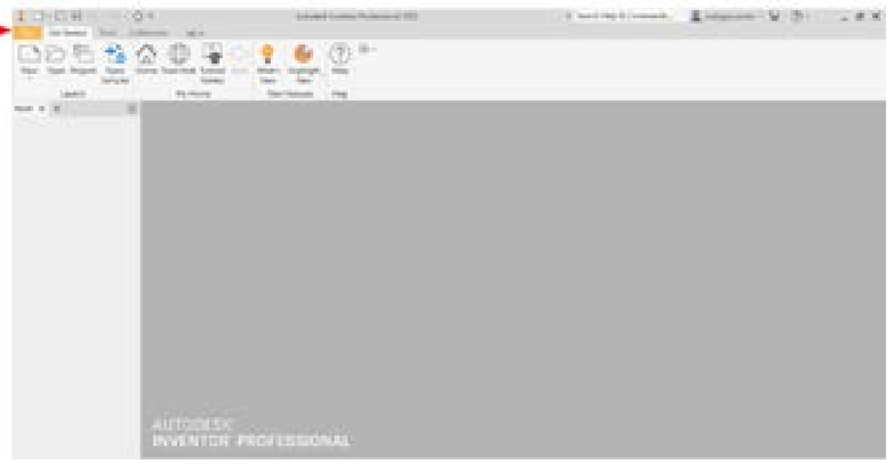
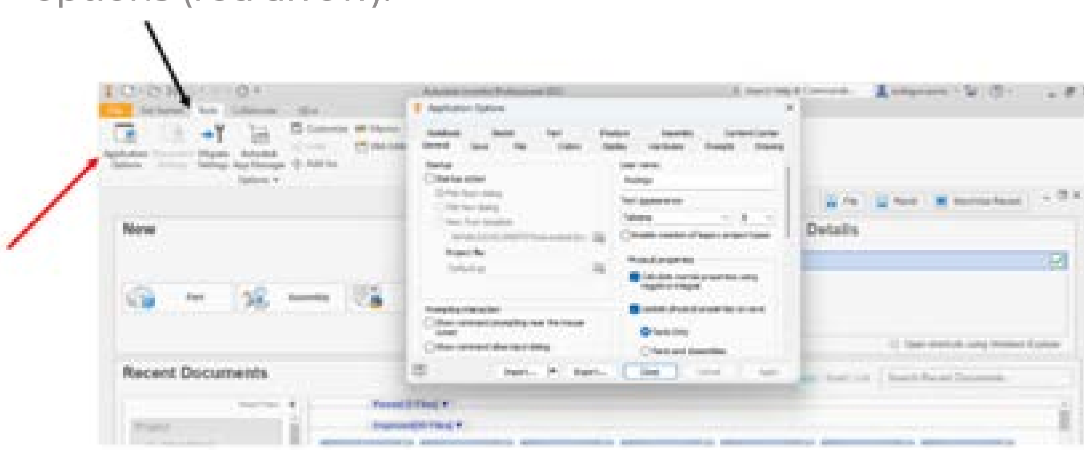
### 20 Continue the calibration process in Autodesk software

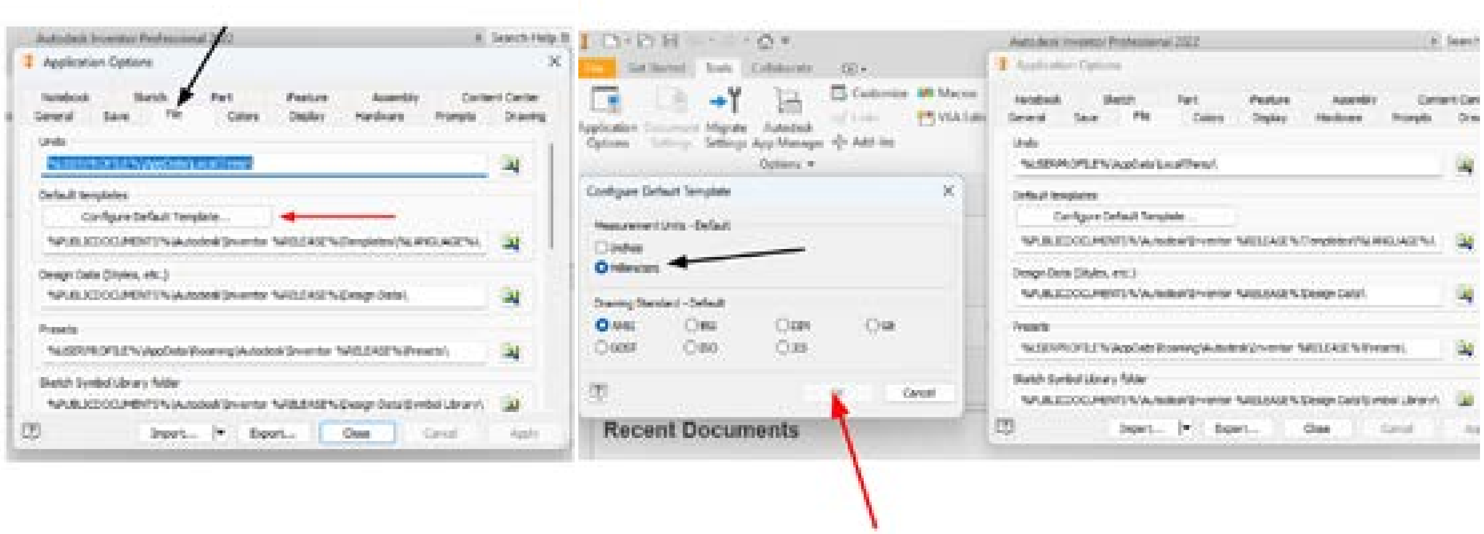
Click on " file" (red arrow)



Then, click on "tools"( black arrow) and after on "application options (red arrow).



After that click on "file" (black arrow) and on "configure default template" (red arrow). Set "millimeters" as the unit of interest (second picture black arrow) and then click on "ok"( second picture red arrow).

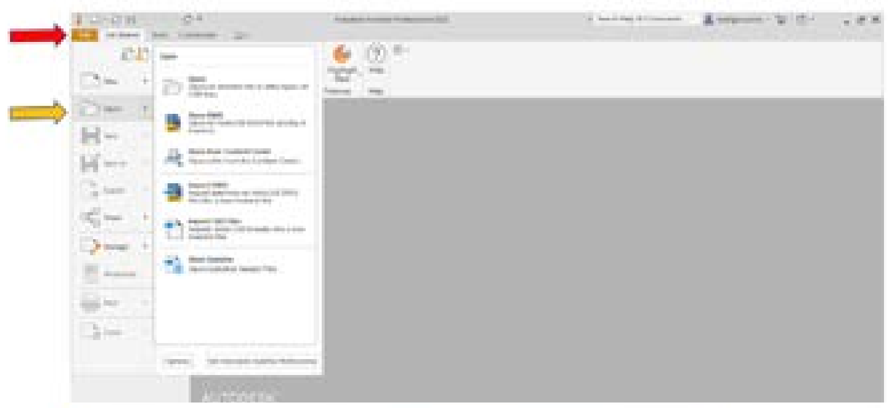


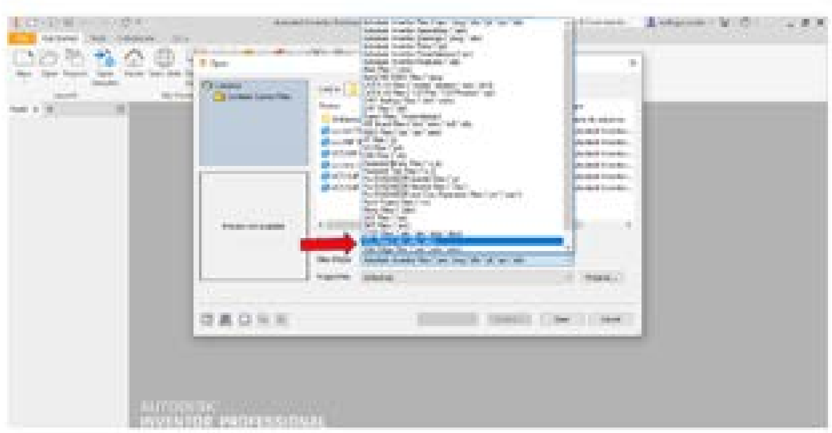
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 21 Open and select T0 STL model after laandmark registration

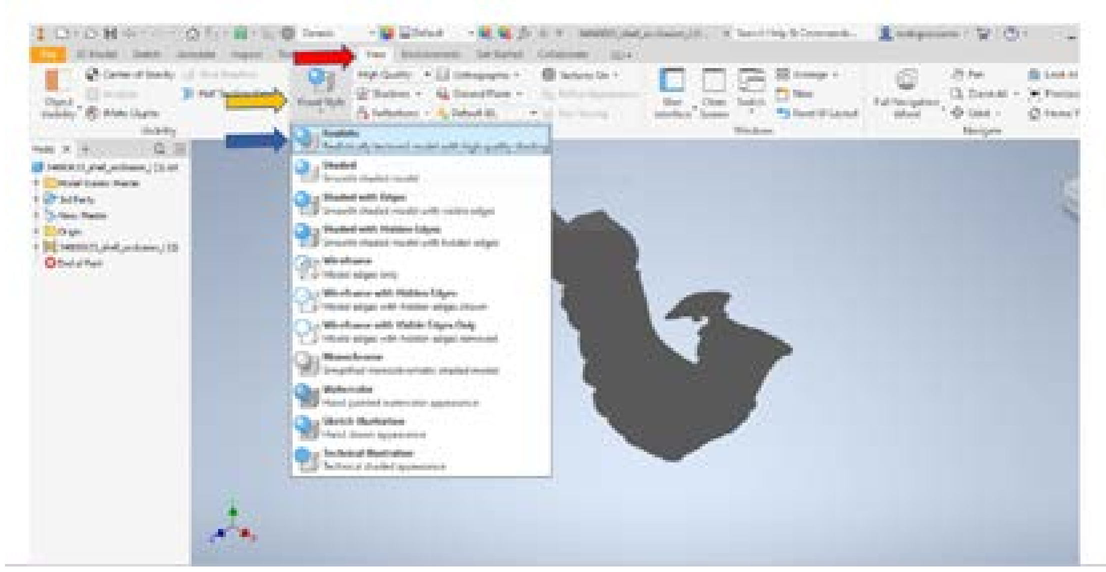
Click on " file" (red arrow) and then on "open " (yellow arrow). Select initial model (second picture red arrow).





### 22 Visualize STL model

To better visualize teeth and arch morphology please click on "view" (red arrow), "view style" (yellow arrow) and then " realistic" (blue arrow).



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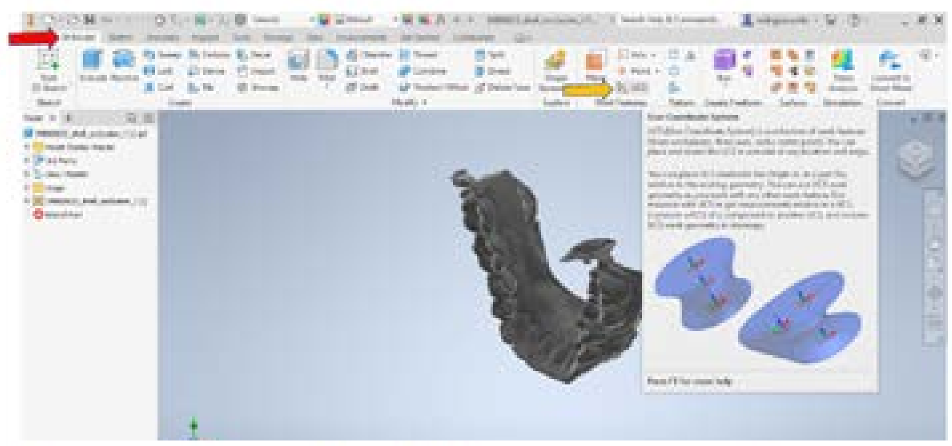
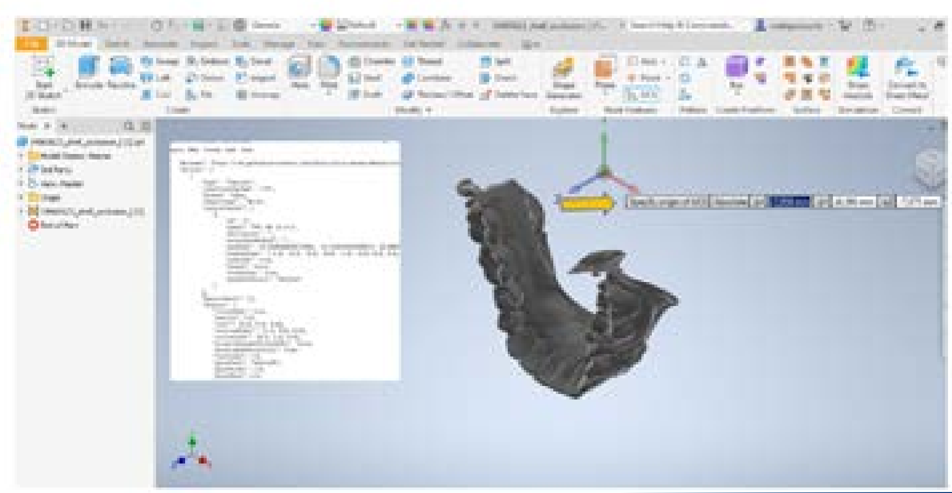
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 23 Insert USC coordinates

Click on " 3D model"( red arrow) and then on "UCS" (yellow arrow). Copy the coordinates ( one by one ) in the following order: X,Y Z. When you are finished click on “enter” twice and save T0 model. Insert negative sign if necessary. Repeat the same process with T1 model.





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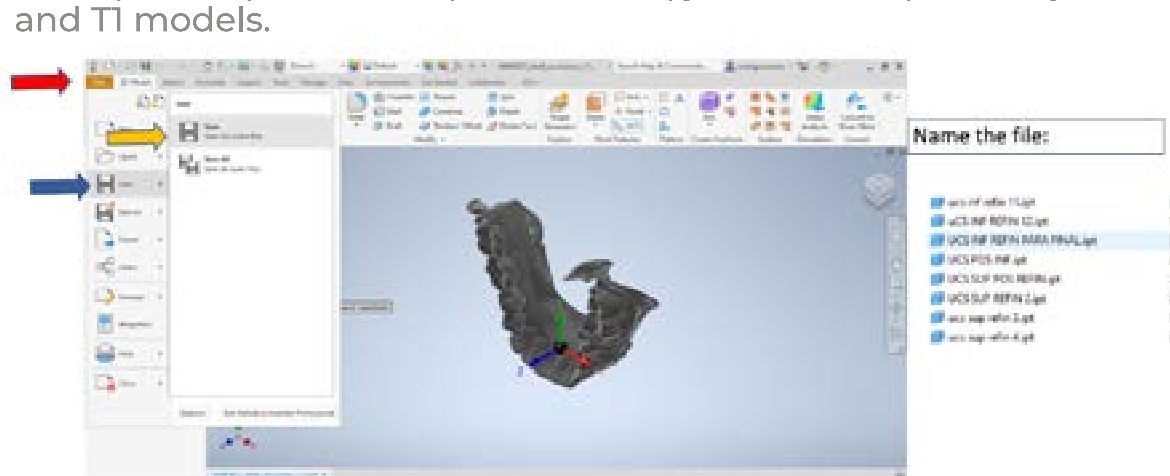
### 24 Save T0 and T1 models with UCS coordinates

Save files to superposition process. Click on " file"(red arrow),"save"(blue arrow) and " save"( yellow arrow). Identify T0 and T1 models.

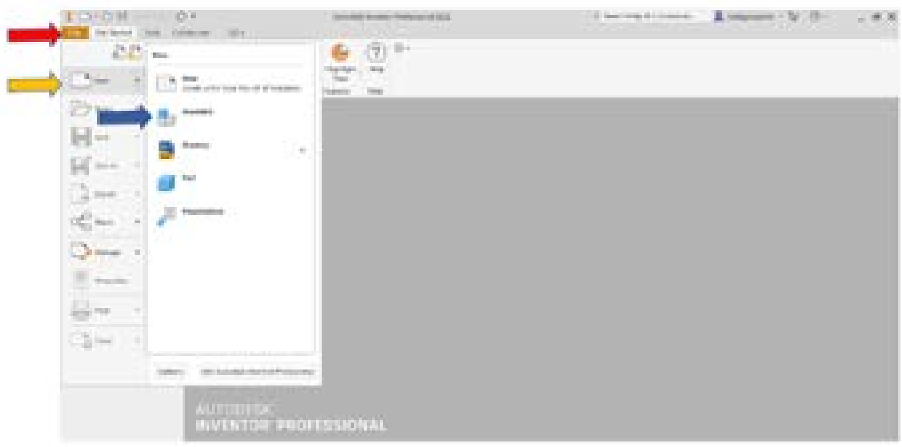


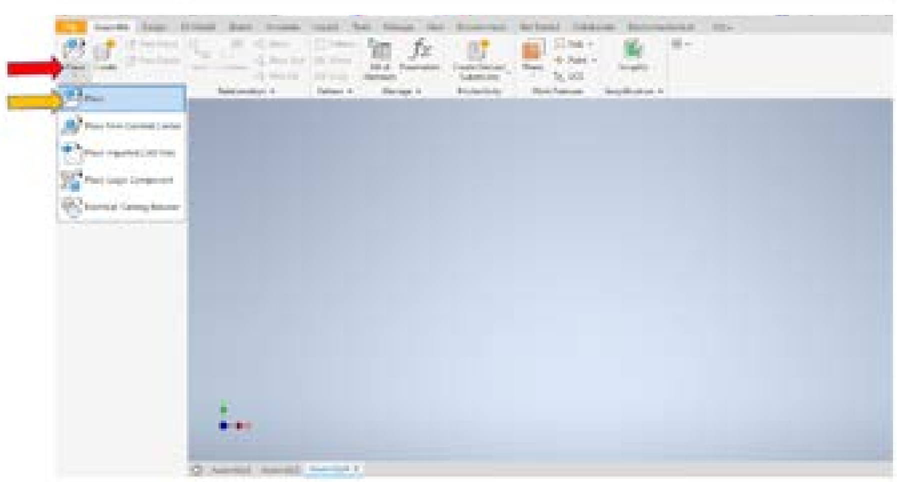
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 25 Superposition of 3D T0 and T1 models

To start superposition go to "File" (red arrow), "new"( yellow arrow) and "assemble"(blue arrow. Then click on "place"( red arrow in the second pic and "place" (yellow arrow second picture).





### 26 Superposition of 3D T0 and T1 models

Select T0 and T1 models (red arrow) pressing "control". Then click on "open"( yellow arrow).

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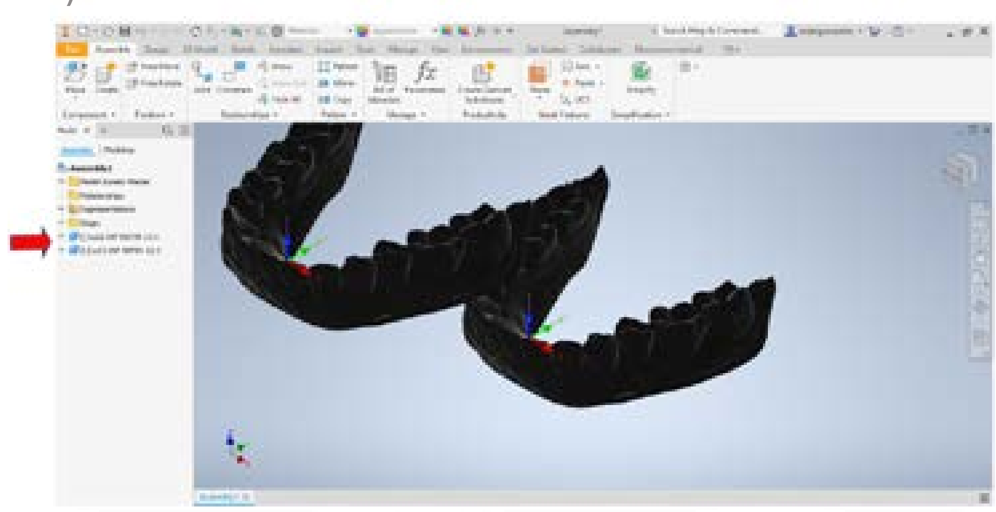
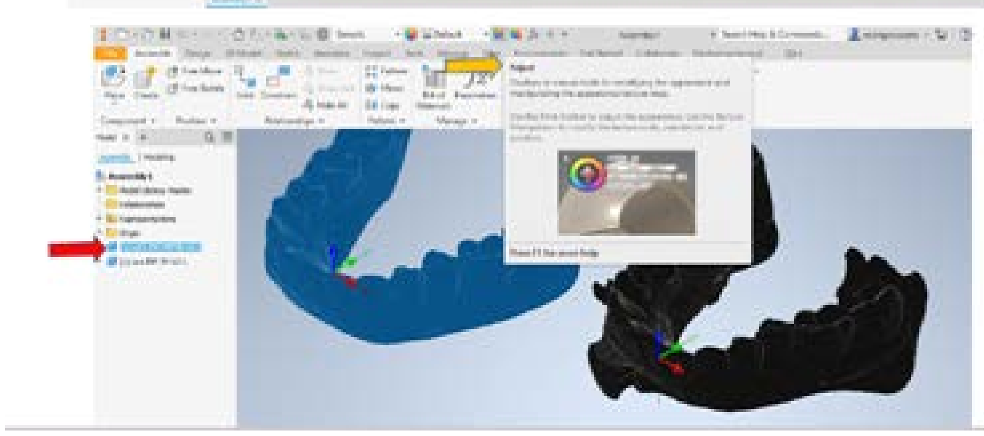
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 27 Models will open with UCS coordenate vectors

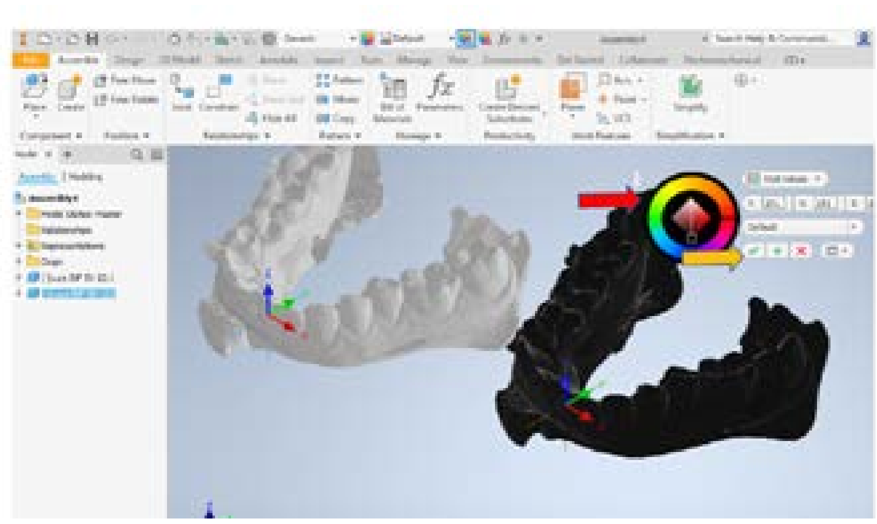
Both, T0 and T1 3D models will open (red arrow). Observe that UCS coordinates will apear (blue, greed and red vectors in initial and final models). Change the color of the initial model to simplify visualization. Click on the model ( second picture red arrow) and "adjust" (yellow arrow).





### 28 Change initial models color to better visualize superposition

Modify color using color cursor (red arrow) and then confirm the color you want to change ( yellow arrow).



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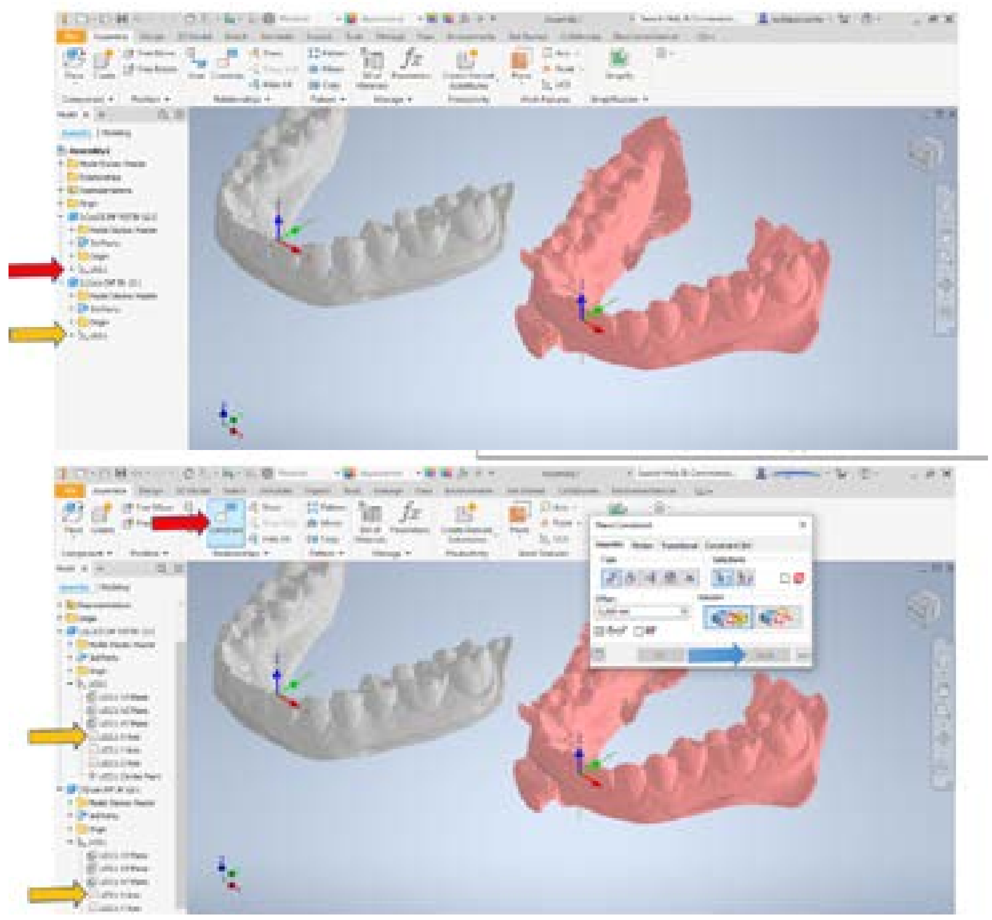
## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 29 Finalize models superposition

Click on "ucs 1" (red and yellow arrows) for each model. Then select "constrain" (second picture red arrow), press UCS X axis in both models (second picture yellow arrows) and "apply" (blue arrow). Repeat this process to insert Y and Z coordinates.



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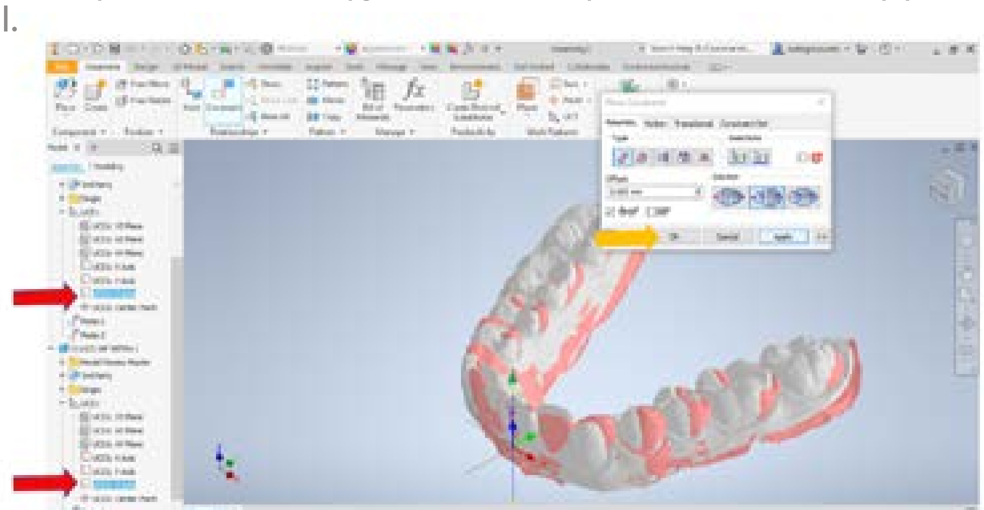
### 30 Save superposition

After completing superposition by inserting "Z" UCS coordinate (red arrows) click on "ok" ( yellow arrow) and save overlapped model.

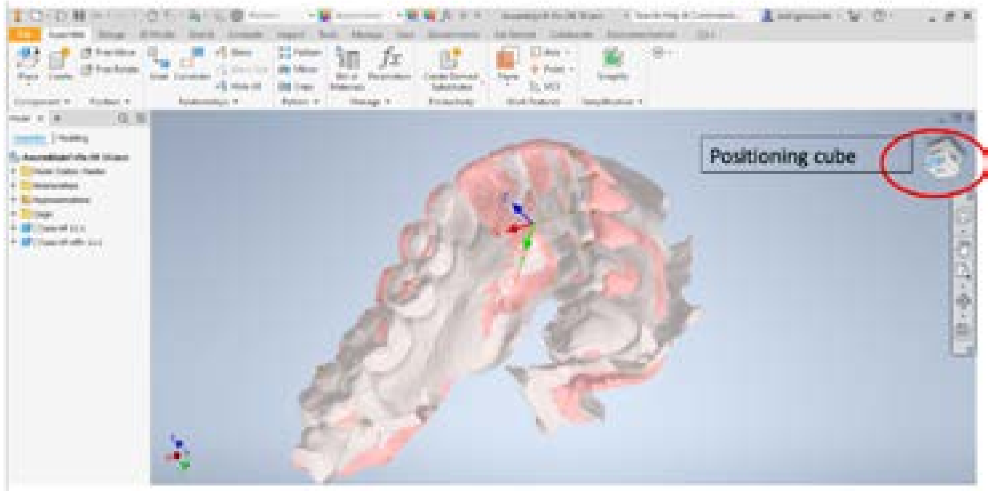


## Step by Step process to

CHOOSE MANDIBULAR AND MAXILAR SUPERPOSITION POINTS USING UCS WORK GEOMETRY IN INITIAL AND FINAL STL MODELS

### 31 Superposed models analysis

To move the model click on the middle of the mouse button and drag model using the positioning cube (red circle)

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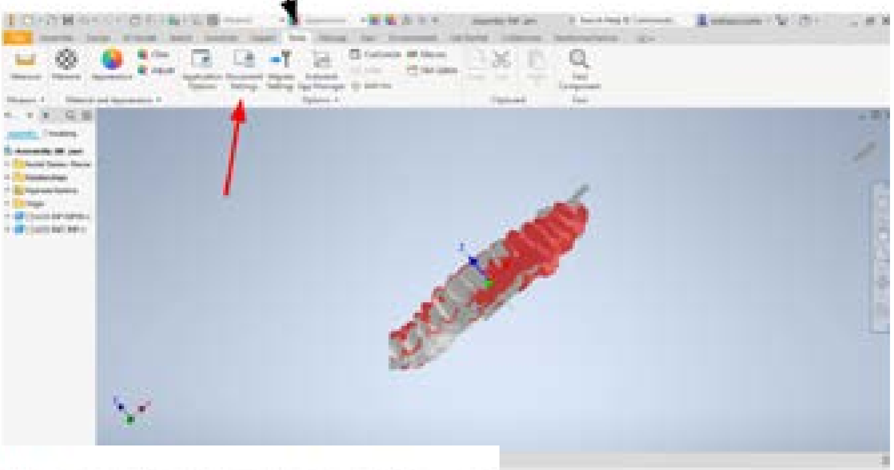
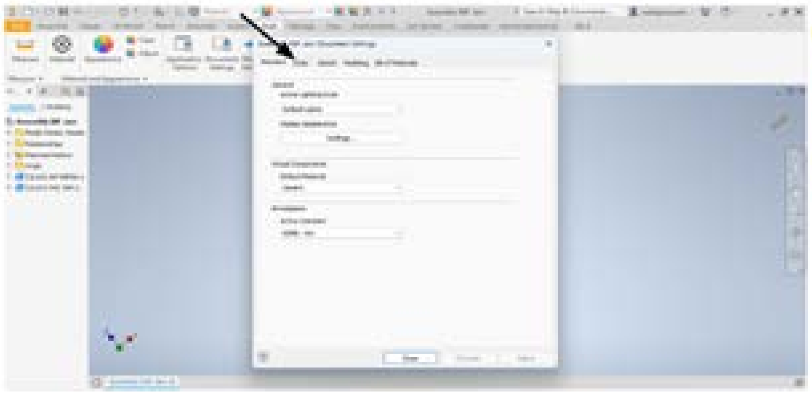
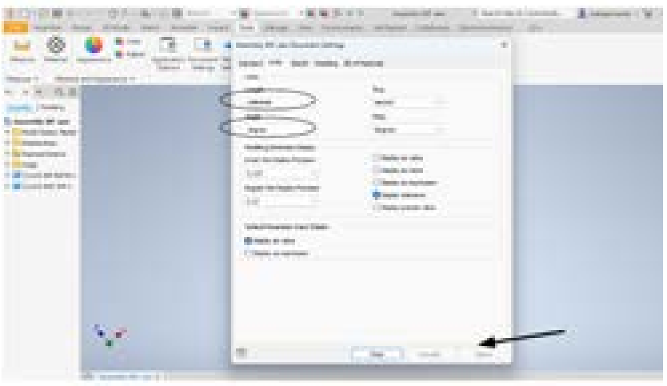
### 32 Calibrate the software for tooth movement analysis

Click on : "tools" (black arrow) and then on "document settings" (red arrow). After that, click on "units"(second picture black arrow).
choose Choose "millimeters" and "degrees "(black circles) and click on "apply" ( third picture black arrow).





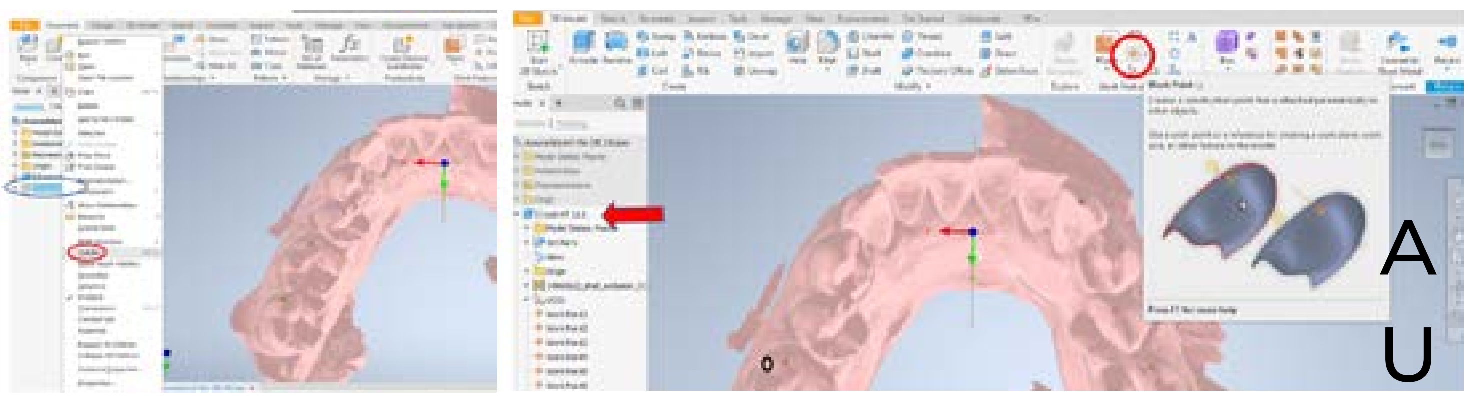


## Step by Step process to

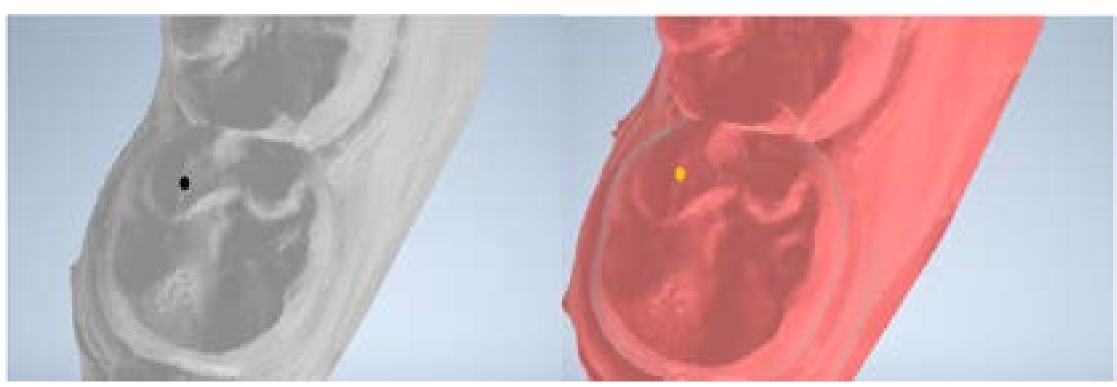
analyze tooth movement in the superimposed model

### 33 Buccal-lingual translation (x- axis)

Select T0 model (red arrow) by making T1 invisible. For that, click on T1 model (black arrow) and select and disable "visibility" (red circle). Then click on T0 model (red arrow), "work points"(second picture red circle). After that, choose a point on the vestibular cuspid tip of first molar (black circle). Repeat the process in T1 model. Use the positioning cube to position the model in order to facilitate the marking of points.

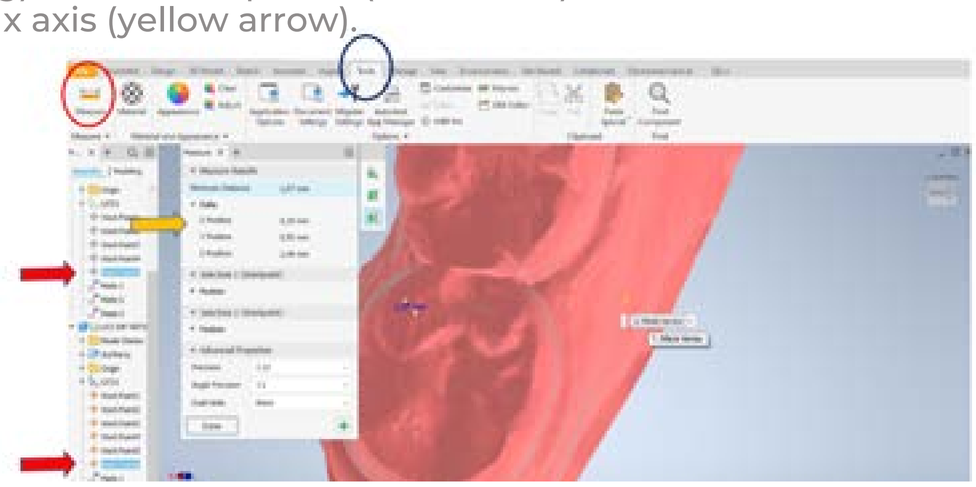


**Select the points on T0 (black circle) and T1 models (yellow. circle)**



**Measure the distance between points:**

Click on "Tools" (black ring) and then on measure"( red ring).Select both points (red arrows) . Click on " read delta result" on x axis (yellow arrow).



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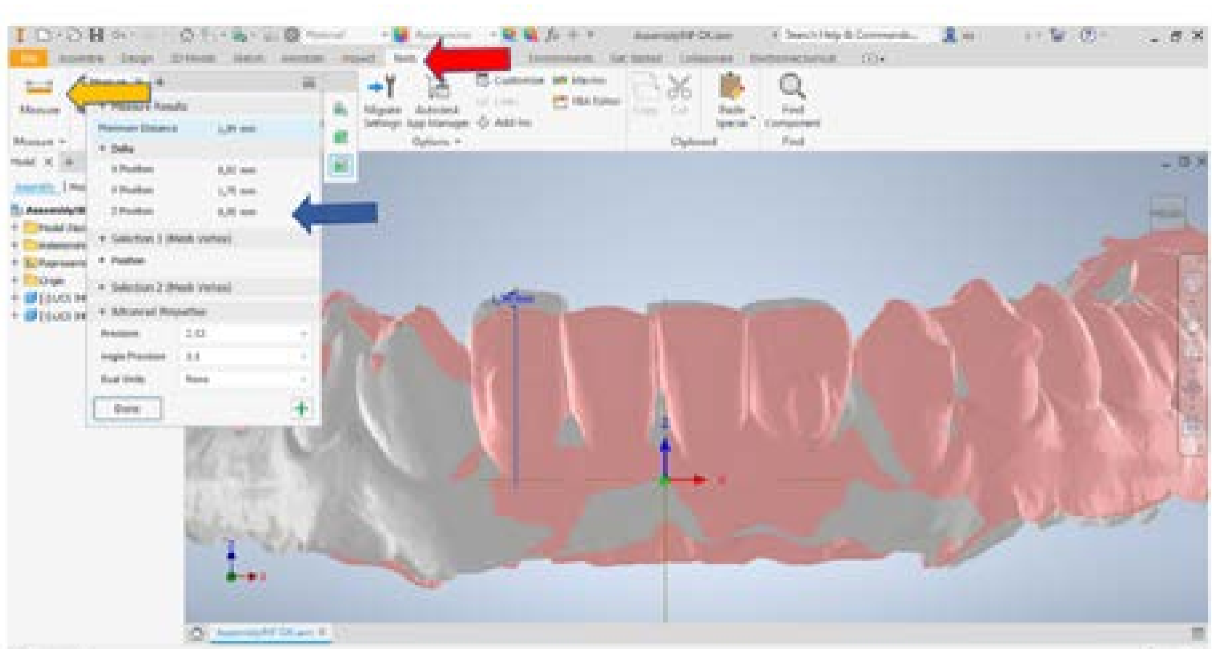
## Step by Step process to

analyze tooth movement in the superimposed model

### 34 Vertical changes: Intrusion or extrusion ( Z - axis )

Click on "tool", (red arrow) then on "measure" (yellow arrow). Select a poin in the incisal edge in the middle of the incisor. After that ,observe the result in: "delta z (blue arrow)".



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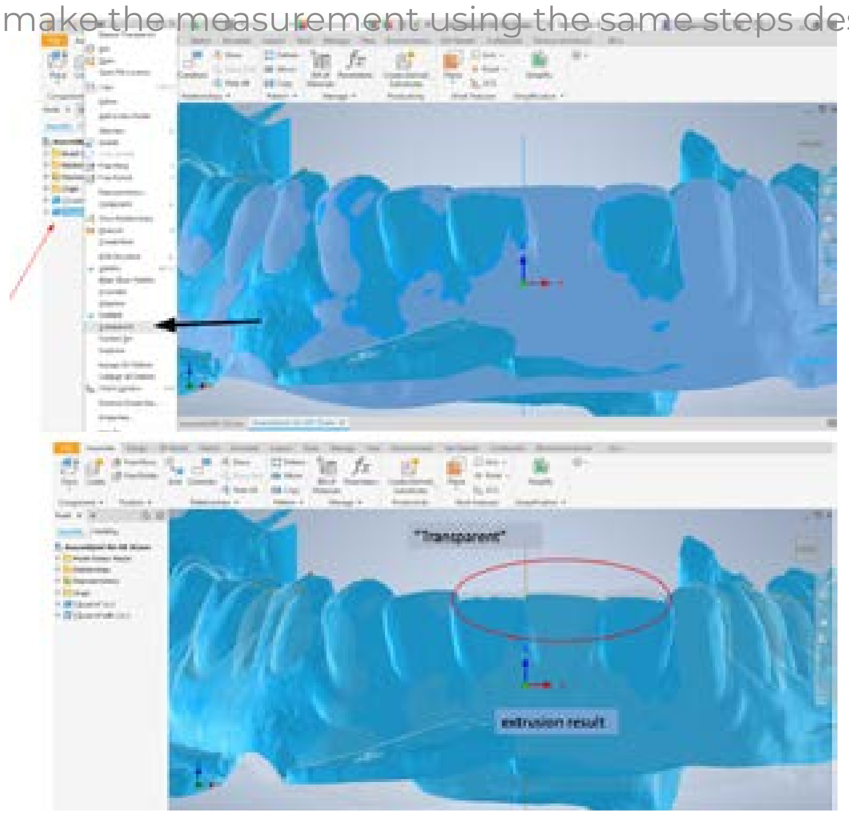
if you have difficulty measuring this movement, select T0 model (red arrow), click on the left button and select "transparent " (black
 arrow) make the measurement using the same steps described above.



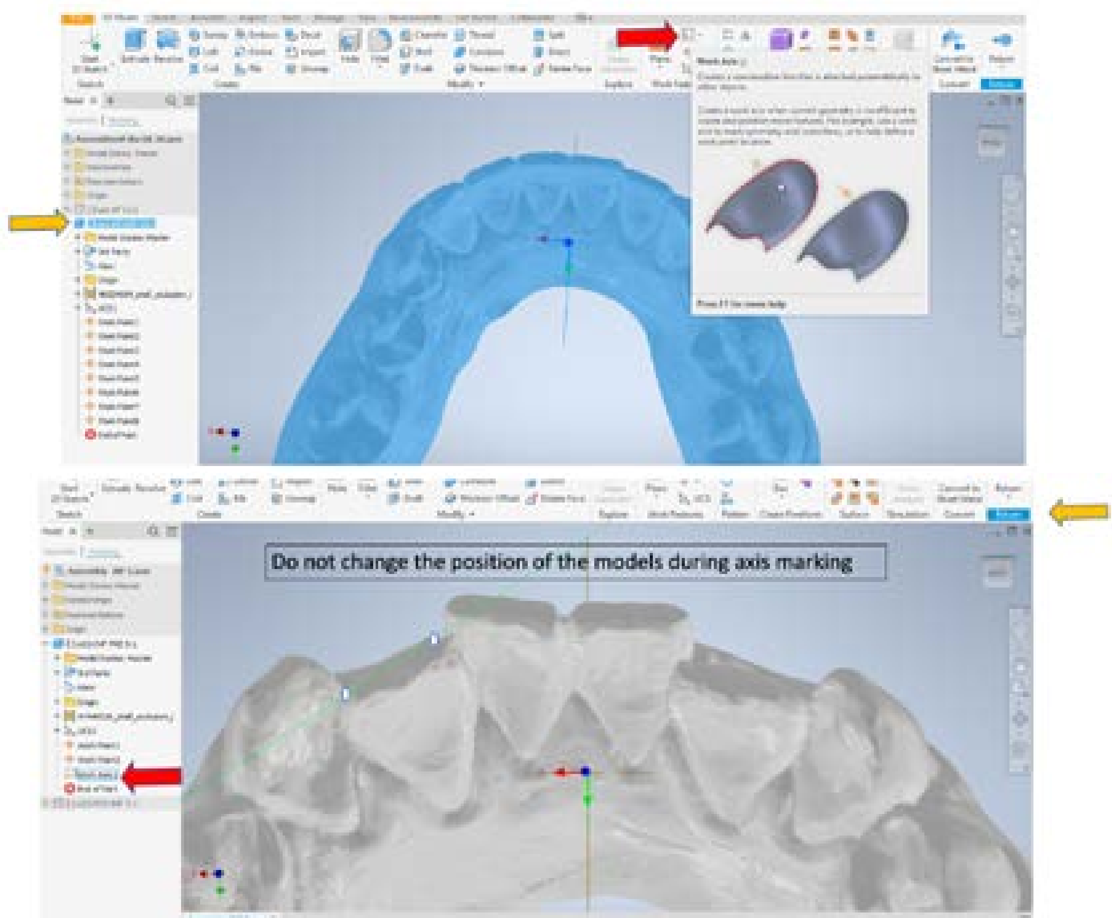
## Step by Step process to

analyze tooth movement in the superimposed model

**35**

### Rotation

Select initial model (yellow arrow), then click on "work axis"(red arrow).Do not change de position of the model during measure (red arrow of the second picture). Select a point in the mesial and in the distal parte of the incisal edge (white circles). Click on "return" (yellow arrow of the second picture). Repeat the same process with the final model.

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### Measuring rotation angle

Click on measure (red arrow), select work 1 and 2 (yellow arrows). Then, observe measure result in: "angle"(blue arrow).