

3D PRINTING IN PROSTHODONTICS: ACCURACY ASSESSMENT AND FABRICATION OF HIGH-PRECISION DENTAL MODELS

Hamidi Fouad¹, Hocine Hossam², Florin-Octavian Froimovici^{3*}, Vlad-Gabriel Vasilescu^{4*}, Ana Maria Tancu⁵, Marina Imre⁵, Lucian Toma Ciocan⁴

¹ Student, “Carol Davila” University of Medicine and Pharmacy, 050474 Bucharest, Romania; fouad.hamidi@stud.umfcd.ro

² Student, Faculty of Science and Technology, University of Haute-Alsace, 68093 Mulhouse, France; hossam.hocine@uha.fr

³ Doctoral School, “Carol Davila” University of Medicine and Pharmacy, 050474 Bucharest, Romania; florin-octavian.froimovici@drd.umfcd.ro

⁴ Discipline of Dental Prosthesis Technology, Faculty of Dentistry, “Carol Davila” University of Medicine and Pharmacy, Dionisie Lupu Street, No. 37, District 2, 020021 Bucharest, Romania; vlad.vasilescu@umfcd.ro ; lucian.ciocan@umfcd.ro

⁵ Discipline of Prosthodontics, Faculty of Dentistry, “Carol Davila” University of Medicine and Pharmacy, 37 Dionisie Lupu Street, District 2, 020021 Bucharest, Romania; marina.imre@umfcd.ro , anamaria.tancu@umfcd.ro

Corresponding author: Florin-Octavian Froimovici, e-mail: florin-octavian.froimovici@drd.umfcd.ro
Vlad-Gabriel Vasilescu, vlad.vasilescu@umfcd.ro

ABSTRACT

Aim of the study:

This study aims to comprehensively evaluate the dimensional accuracy of 3D printed working models used in dental applications, by comparing three different 3D printers: Planmeca Creo C5, Xprint, and Anycubic Photon Mono X 6Ks. The primary goal is to assess the clinical feasibility of each device in producing precise dental models for full coverage crowns.

Materials and methods:

A digital reference model was created via high-resolution extraoral scanning using the PlanScan Lab scanner. This reference model was then printed using three target printers. Each printed model underwent a standardized post-processing protocol involving washing with Form Wash L machine and dual-wavelength UV curing with Twin Cure V system. STL files were analyzed using CloudCompare software through superimposition with the reference model, followed by fine registration and deviation mapping. The raw data, exported as histograms, were further processed with a custom C++ program designed to quantify deviation distributions using Gaussian, sigmoid, linear, and strict threshold-based methods. This allowed precise evaluation of each printer's performance against sub-millimetric tolerance ranges (0.2 mm to 0.5 mm).

Results:

Xprint exhibited the highest accuracy, with 91.19% of surface points within the 0.2 mm threshold, increasing to 98.57% at 0.5 mm. Anycubic showed moderate performance, with 84.4% of points within 0.2 mm and over 96% above 0.3 mm. Planmeca Creo C5 demonstrated limited precision, with only 47.75% within 0.2 mm and clinically acceptable accuracy reached only beyond 0.4 mm. These results indicate significant variability in dimensional fidelity between printing systems.

Conclusions:

Among the evaluated printers, Xprint is best suited for applications demanding high precision, such as full coverage crowns well adapted to preparation margin line. Anycubic is adequate for conventional prosthodontics and orthodontic appliances where tolerances above 0.3 mm are clinically acceptable. Planmeca Creo C5, while less accurate, remains viable for diagnostic models, provisional restorations, and educational use. These findings underscore the importance of aligning printer capabilities with the clinical requirements of each dental application. The integration of software-based analysis and statistical modeling enhances decision-making in digital dentistry, supporting optimized clinical outcomes.

Key words: 3D printing in dentistry, dimensional accuracy, dental working models, full coverage crowns

INTRODUCTION

3D printing technology has revolutionized dental medicine by providing personalized and efficient solutions for the fabrication of working models, surgical guides, and dental prostheses. In the context of increasing demands for precision and efficiency 3D printers have become indispensable tools in dental laboratories. However, selecting an appropriate printer remains a challenge, as their performance varies significantly depending on the printing technology employed, the settings used, and the quality of the materials.

Among the most commonly used printers on the market are the Planmeca Creo C5, Xprint, and Anycubic MonoX 6KS, each featuring distinct technical specifications and cost structures.

The accuracy of working models is critical to the success of dental treatments, such as the fabrication of crowns and bridges to implant planning. Any dimensional deviation can result in occlusal discrepancies, compromised marginal fit, or even treatment failure. Therefore, the comparative evaluation of 3D printers is not merely a technical consideration, but one with direct implications for the quality of patient care.

In this study, we analyze models printed using the Planmeca Creo C5, Xprint, and Anycubic MonoX 6KS by employing 3D scanning and CAD superimposition techniques to identify deviations and compare performance. The results will provide valuable insights for dental clinicians and technicians in selecting the most appropriate printer according to their specific requirements.

The aim of this study is to evaluate the dimensional accuracy of 3D-printed working models intended for the fabrication of full-coverage crowns, through a comparative analysis of three widely used 3D printers: Creality C5, Xprint, and Anycubic MonoX 6KS.

The specific objectives of the study were as

follows:

1. Analysis of the dimensional deviations of the printed models.
2. Comparison of the technological performance of the three printers based on printing and post-processing parameters.
3. Assessment of the feasibility of integrating these printers into dental laboratories, considering both cost-efficiency and operational complexity.

MATERIALS AND METHODS

In the context of a prosthodontic approach, we integrated a series of devices and procedures to optimize the quality and accuracy of dental models. The protocol ensures both clinical compliance and reproducibility.

Starting from a reference model obtained via extraoral scanning using the Planmeca PlanScan™ Lab—a scanner renowned for its high precision—we generated three distinct .STL files. Each .STL file was subsequently materialized through 3D printing using a specific printer: Planmeca Creo C5, Anycubic X6KS, and Xprint. This comparative approach enabled the evaluation of each printer's performance in faithfully reproducing the anatomical details of the reference model.

Post-processing, conducted with the Form Wash L system, removed any residual material, thereby ensuring the cleanliness and integrity of the printed surfaces.

Subsequently, full surface polymerization was performed using the Twin Cure V system, which completed polymerisation of the structure of the printed models, ensuring the optimal durability of the final pieces—essential for maintaining accuracy throughout the comparative analysis. Finally, a rigorous assessment of precision was conducted for each of the three printed models. This analysis enabled the identification of potential deviations and the optimization of production parameters, with the aim of providing high-quality, study-specific solutions.

For the comparative analysis of the 3D-printed

working models, CloudCompare software was used to evaluate differences among the models by means of superimposition and deviation quantification. This method ensures an objective assessment of the precision and accuracy of digital reproduction using 3D printing technologies.

Scanning Method

The scanning of a prepared working model (Kieffer), fabricated in dental stone, was performed using the Planmeca PlanScan™ Lab—an extraoral scanner of high precision, specifically designed for scanning gypsum models and dental impressions. It operates on the principle of structured light, capturing three-dimensional details with an accuracy of up to 15 µm [1].



Figure 1. Scanning of the reference model using Planscan Lab (Planmeca)

To obtain an accurate digital representation, the model was first prepared through cleaning and optimal positioning within the scanner. The dedicated software enabled the alignment of the depth images, removing artifacts and scattered points. Subsequently, by generating a triangular mesh, the depth images were transformed into a digital model ready for processing and export

into CAD software.



Figure 2. Aquisition of the 3D STL file

A critical aspect of the process was the periodic calibration of the scanner, required to maintain measurement accuracy. This procedure was carried out using an official recalibration kit, in accordance with the manufacturer's protocol.

3D Printing Process

After the scanning process and the acquisition of the digital models, the .STL files were imported and processed using the Chitubox software. This program enabled the slicing of the models to optimize their positioning within the printer's build volume and allowed for the addition of support structures, which are essential for maintaining the stability and accuracy of the parts during the additive manufacturing process.

In the preprocessing stage, a thorough integrity check of the models was performed to eliminate any mesh errors or artifacts resulting from the scanning-to-mesh conversion. Support parameters were adjusted according to the model geometry and the characteristics of the specific printer used, ensuring optimal fixation to the build platform and minimizing potential distortion.

The files prepared in Chitubox were then exported in a format compatible with the respective printers, thereby optimizing the fabrication process for the accurate reproduction of morphological details.

To ensure faithful anatomical reproduction and efficient manufacturing, the digital models were strategically positioned within the three-dimensional space prior to 3D printing. The

main objective of this stage was to minimize overhanging surfaces, thereby reducing the need for excessive support structures and optimizing material consumption. Additionally, correct model alignment helped reduce the risk of distortions caused by resin shrinkage during the polymerization process.

The Z-axis was aligned according to the printing direction—an essential strategy for preserving the integrity of critical morphological features. This orientation specifically enabled the faithful reproduction of preparation margins, occlusal surfaces, and other delicate anatomical structures, thereby preventing accuracy loss due to potential fabrication artifacts.

Support Generation and Adjustment

To adequately support the models during printing, automatically generated supports were created using Chitubox's built-in algorithm. Initially, the system placed supports according to the software's predefined parameters, with the primary function of ensuring model stability throughout the polymerization process.

Since standard supports may interfere with critical areas of the model, manual adjustments were made to optimize the distribution of attachment points. This stage included:

- Avoiding the placement of supports on critical areas, such as occlusal surfaces, preparation margins, and functional contact zones, in order to prevent structural alterations that could compromise model accuracy.
- Redistributing support points to minimize mechanical impact during removal, thus reducing the risk of imperfections on the final model surface.
- Selecting an optimal balance of support sizes, ensuring sufficient model stability without compromising the fidelity of morphological details [2].

Collision Detection and Distortion Prevention

To validate the effectiveness of the support structures and prevent potential fabrication errors, the “Preview” function in Chitubox was used. This feature enabled the identification and correction of any collisions between the supports and the model. When interference points were detected, the placement of supports was manually adjusted to ensure a balanced distribution.

Another critical aspect in optimizing support structures was the prevention of distortions caused by resin shrinkage during the photopolymerization process. To minimize this risk, supports were concentrated in non-critical areas, such as the model base, thereby avoiding the generation of internal stresses that could compromise the final accuracy of the printed structures [3].

Through the application of these measures, the goal was to obtain dental models with high morphological fidelity, ensuring both the precise reproduction of anatomical details and efficient post-print handling, with minimal impact on surface quality. funcțională.

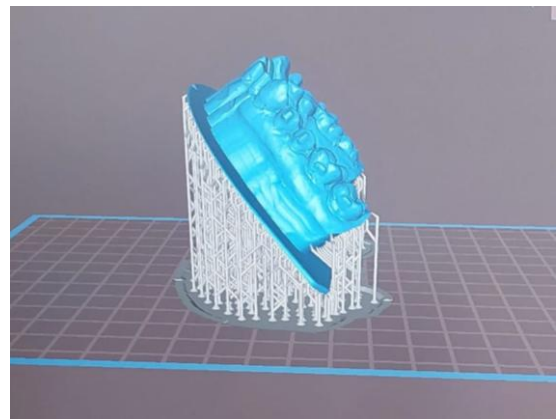


Figure 3. Support structure modelling using Chitubox software



Figure 4. Model printed using Planmeca Creo C5 printer



Figure 5. Model printed using Anycubic MonoX 6KS



Figure 6. Model printed using Xprint

Post-Processing

Post-processing in 3D printing refers to the stage of finishing the printed parts after the completion of the printing process, with the

aim of improving their aesthetic appearance, functionality, and mechanical properties. This phase is essential for transforming printed models into a final product suitable for practical use.

Specific post-processing methods may vary depending on the printing technology employed and the material used. For instance, in the case of FDM (Fused Deposition Modeling) printing [4], it is necessary to remove the support structures, followed by surface finishing through sanding. In the case of SLA (Stereolithography) printing, the printed parts require washing to remove any uncured resin, as well as exposure to UV light to complete the curing process [5].

The removal of support structures was the first step in the post-processing of the 3D-printed parts and was essential for preparing the models for cleaning and finishing. Supports are temporary structures created during printing to stabilize the models; they are distributed across the entire surface of the part. To remove the supports, cutting pliers and specialized tools were used to trim the supports as close as possible to the part's surface without causing damage. This process required careful attention and precision to avoid scratches or cracks on the surface, a stage that inherently carries an increased risk of human error. After support removal, the parts were prepared for cleaning in the Form Wash L cleaning tank [6].

Form Wash L is an automatic cleaning device for 3D-printed parts, developed by Formlabs, designed to remove uncured resin residues from the surfaces of parts printed using SLA (stereolithography) technology. Thus, it represented an ideal solution for the post-processing of the 3D-printed parts incorporated in this study, ensuring high-quality results. The device is equipped with a washing platform and a detachable basket, allowing for the cleaning of parts either directly on the build platform or after their removal [7].

The cleaning process began by filling the tank

with a solvent (isopropyl alcohol). The parts were then immersed in the tank and agitated to remove resin residues. After washing, the parts were lifted and allowed to drain, followed by air drying [8].



Figure 7. Form Wash L

Twin Cure V is a post-curing device designed for the optimal hardening of 3D-printed objects made from photopolymerizable resins. It utilizes an advanced dual-wavelength LED irradiation system combined with a rotating platform, ensuring uniform polymerization [9].

The device is equipped with dual-wavelength UV LEDs (365 nm and 405 nm), enabling the polymerization of a wide range of resins, including those requiring deep curing. This technology ensures homogeneous hardening and prevents the formation of under-cured layers that could compromise the mechanical strength of the printed parts [10].

The automatic rotation system of the platform ensures uniform exposure of the object to UV light. The platform rotates at a constant speed, eliminating shadows and irradiation variations that could affect the quality of polymerization.

The user can select from multiple irradiation modes tailored to different resin types and objects. The "Front and Cap" mode primarily exposes the front and top surfaces of the object, while the "Back and Cap" mode targets the back and top surfaces. The "Full" mode provides total exposure for optimal polymerization across the entire surface.

The curing time is adjustable via three preset settings (10, 20, and 30 minutes). This flexibility allows the process to be adapted according to the thickness and density of the resin used.

The interior of the curing chamber is designed with a reflective coating that enhances UV light diffusion, thereby increasing curing efficiency. This coating also reduces light intensity losses, ensuring faster and more complete polymerization.

Thanks to its advanced technology and optimized functions, the Twin Cure V provides rapid, uniform, and efficient curing of 3D prints, thereby guaranteeing superior quality and enhanced durability of dental restorations and medical devices [11].

Data Collection

The following outlines, step by step, the procedure used to compare two STL models: the "Master Model" and the analyzed models "Anycubic," "Creo," and "X-print."

Within the CloudCompare software, under the "File" menu, the "Open" option was selected to load the two models for comparison (using CTRL+click to select multiple models). The two opened models are illustrated in Figure 8.

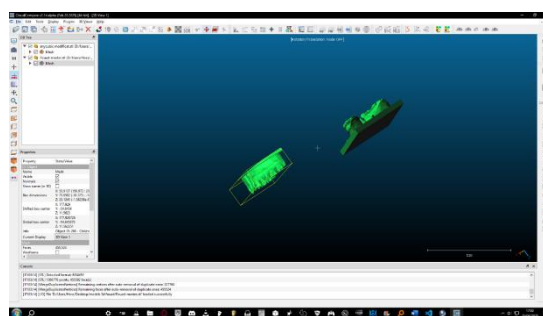


Figure 8. Screenshot of the 2 STL models imported into Cloud Compare

Using the "Translate/Rotate" tool, the models were manipulated within the 3D coordinate system to enhance visualization of both models (Figure 9).

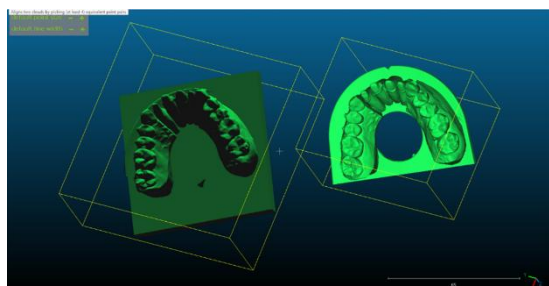


Figure 9. Screenshot of the 2 STL models after using Translate/Rotate

Right-clicking allowed translation of a model, while left-clicking enabled rotation. Subsequently, the “Align two clouds by picking (at least 4) equivalent point pairs” tool was employed to select the model to be aligned relative to the other (Figure 10).

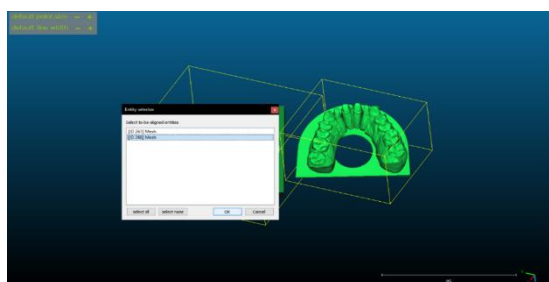


Figure 10. Model alignment

Next, a minimum of four points were selected on the model to be aligned, followed by the corresponding points on the reference model in the same order (i.e., the Ax point on the model to be aligned corresponds to the Rx point on the reference model, where x denotes the point number) (Figure 11).

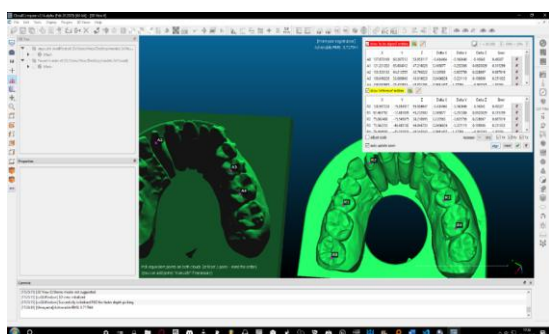


Figure 11. Selection of matching point between Master Model and Anycubic test model

The selected points progressively appeared in the window at the top right, within the

corresponding model's table. Once all points were entered, the “Align” button located at the bottom right of this window was activated, initiating an initial approximate alignment of the two models (Figures 12 and 13).

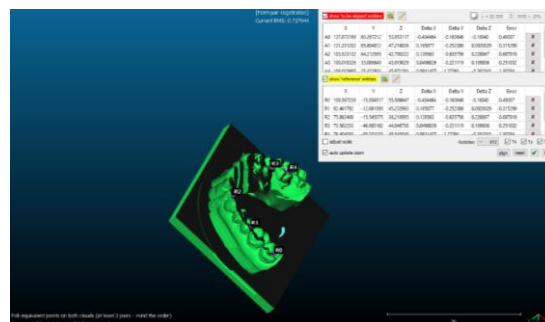


Figure 12. Model superimposition

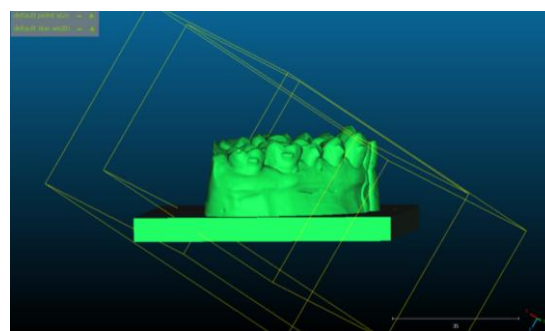


Figure 13. Model superimposition

Following this, the models were cleaned to remove areas likely to introduce errors by using the “Segment” tool. A polygonal shape was drawn over the area to be cleaned on the model and detached by pressing the “O” key (Figures 14, 15, and 16).

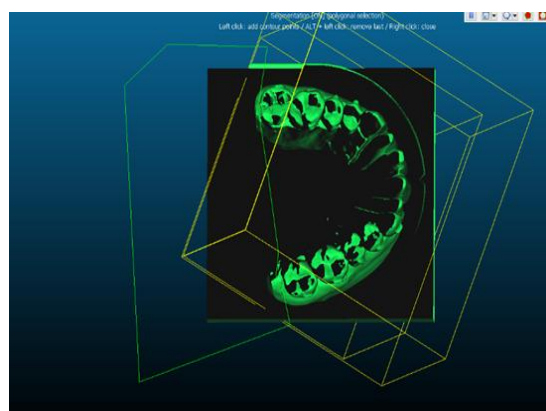


Figure 14. Model cleaning

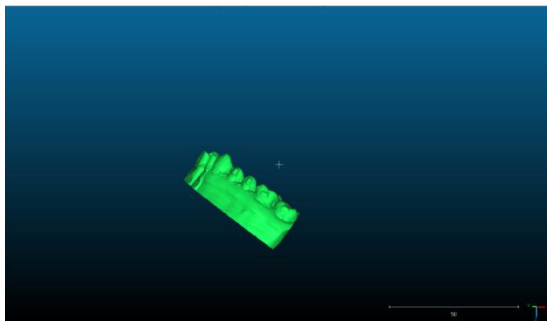


Figure 15. Cleaned models

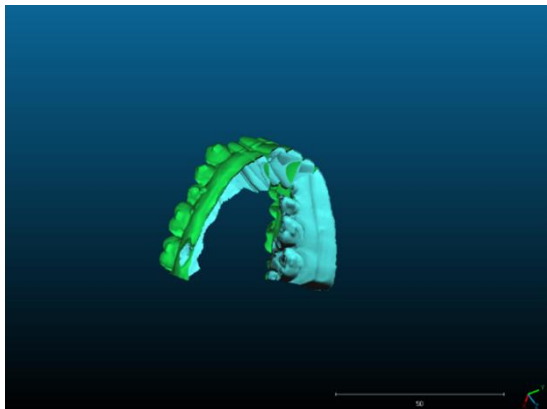


Figure 16. Models after cleaning and superimposition

After automatic alignment, the “Finely register already (roughly) aligned entities (clouds or meshes)” tool was applied to refine the alignment between the two models (Figures 17, 18, and 19).

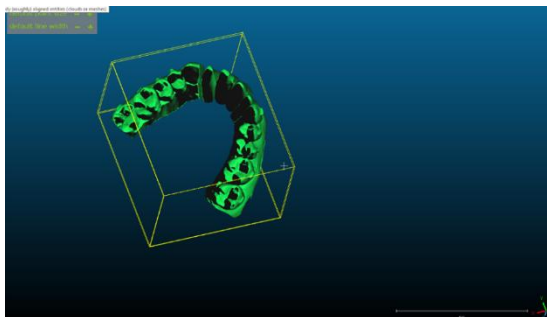


Figure 17. Alignment refinement

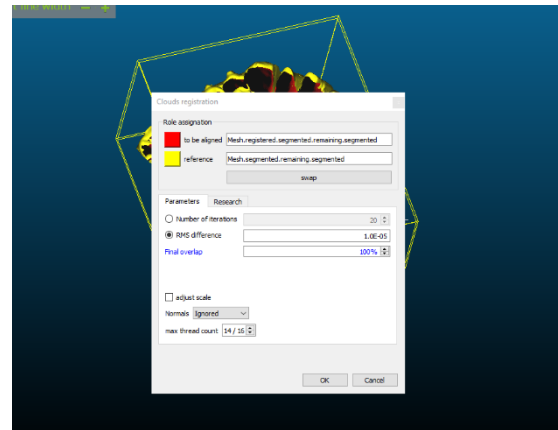


Figure 18. Alignment refinement

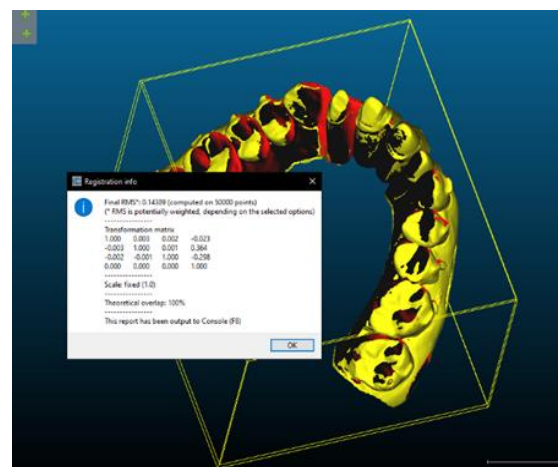


Figure 19. Alignment refinement

From this point onward, to analyze the differences between the two visual models, the “Compute cloud/mesh distance” tool was used (Figure 20).

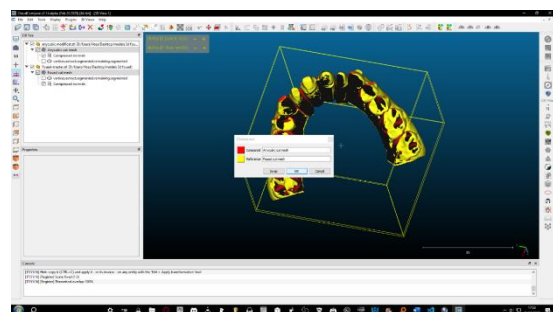


Figure 20. Alignment refinement

After initially clicking the red “Compute” button, a histogram in Excel format was generated, representing the alignment of points in the file named “Approximate distances” (Figure 21).

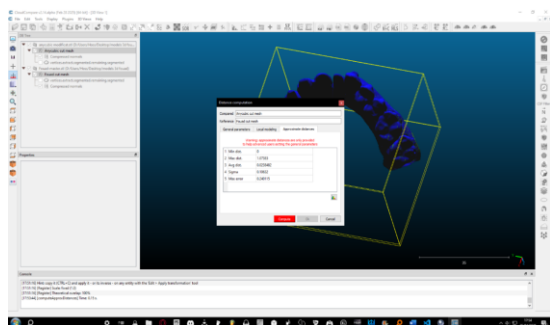


Figure 21. Histogram export in EXCEL formatting

Next, the button resembling the Excel file logo was selected (Figure 22).

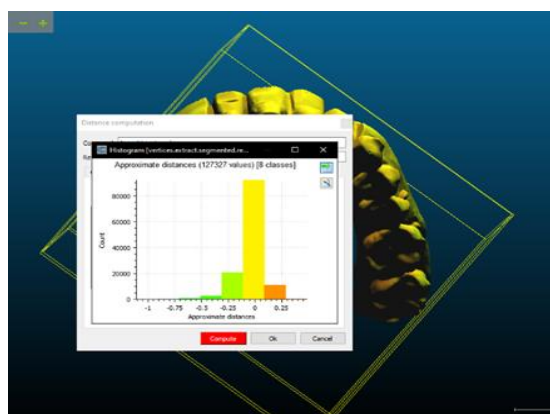


Figure 22. Histogram

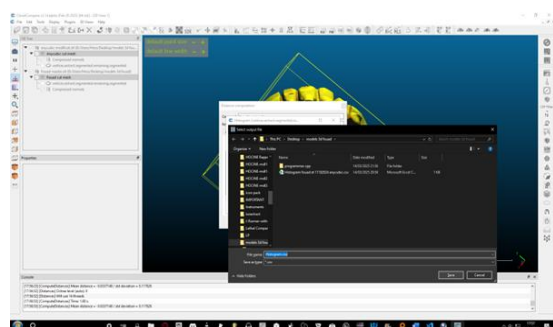


Figure 23. Data export

Upon completion of all comparison steps between the two STL models, CloudCompare produced a CSV file (Figure 23). This file contains raw data—namely, the calculated distances between points of the two models, grouped into value intervals.

Subsequently, a similar comparison was performed between the “Master Model” and the “Creo” model (Figures 24 and 25), as well as between the “Master Model” and the

“XPrint” model (Figures 26 and 27), following the same procedure described previously: approximate alignment, cleaning of models, fine alignment, comparison of model points, and generation of the CSV file.

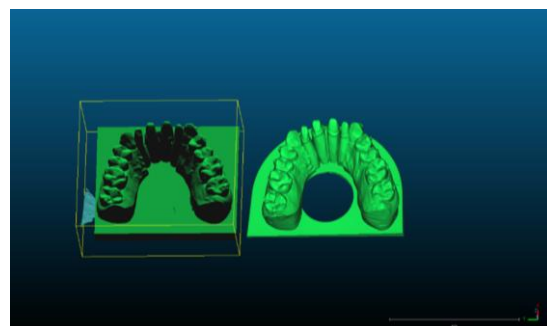


Figure 24. Master model and Creo C5 model



Figure 25. Cleaning and superimposition of the 2 models

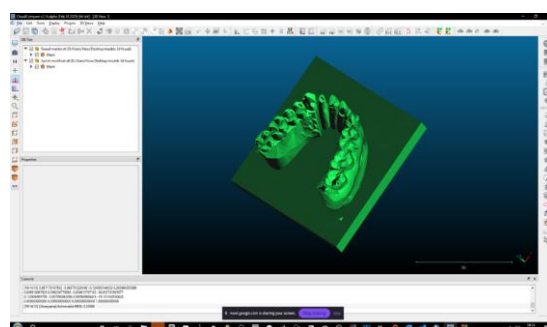


Figure 26. Superimposition of Master and Xprint models

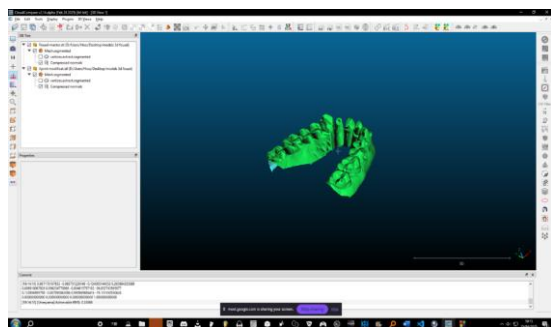


Figure 27. Cleaning and superimposition of the Master and Xprint models

The information contained in the CSV files is difficult to interpret directly, as it is purely technical and lacks clear visual analysis. Therefore, this file requires further processing in order to extract useful information, such as the percentage of points with an error below a certain threshold or to evaluate the overall accuracy of the model alignment.

Thus, the CSV file represents the raw foundation of the analysis but requires additional processing through dedicated software or statistical tools to draw meaningful conclusions about the quality of the comparison.

Since no existing software effectively reads and analyzes the CloudCompare histogram, we decided to develop our own tool. We created a program in C++ to analyze the data contained in this Excel file. The program calculates the number of points below a specified distance difference threshold using several formulas, including Gaussian, sigmoid, linear, and exact methods.

The program was developed in the Code: Blocks IDE and is based on the data structure of the Excel files generated by CloudCompare following a comparison between two models.

General Description of the CSV Analysis Software

This C++ program is designed to analyze the distribution of data around a central point according to a tolerance defined by the user. Specifically, it reads data from a CSV file that

contains several “classes” (numerical intervals), each associated with a number of points. The program then calculates how many of these points are close to the desired center, employing various methods to measure “closeness.” Both strict methods and methods that consider the distance of each point from the center are used.

During operation, the program prompts the user to enter a maximum threshold and subsequently calculates several percentages indicating how well the data are concentrated around zero.

Program Design

We began by creating a structure named Class. This structure contains, for each class, an identifier (id), the number of points (value), and the start and end limits of the interval (classStart and classEnd). In this context, a “class” represents a numerical interval grouping a set of data points.

Next, several important functions were developed. The first function reads data from the CSV file, which is a table of semicolon-separated values. Additional functions compute a “weighting” based on the distance of each point from the center. Weighting assigns a value between 0 and 1 depending on how close a point is to the center.

There are three main types of weighting:

- Linear weighting, where the importance of a point decreases steadily as it moves away from the center.
- Gaussian weighting, where most points are concentrated around the center and importance decreases in a bell-shaped manner (similar to a normal distribution).
- Sigmoid weighting, where points near the center are highly important, but beyond a certain distance, importance rapidly declines.

Additionally, there is a function that calculates a “raw” percentage, which simply checks whether intervals fall completely or partially within the defined threshold, without weighting.

All these functionalities are integrated into a main function that runs each time the user wishes to perform a new calculation by changing the threshold.

Program Applications

In the field of dentistry, this program can be used to analyze the accuracy of treatments or measurements. For example, when using a 3D camera to scan a dental impression, each scanned point may have a slight deviation from its ideal position.

This program can import those errors and calculate the percentage of points very close to the ideal position. In this way, a clinician can assess the precision of the scan.

By adjusting the threshold, the clinician can observe variations in impression quality: whether most points are near the center or if there is greater dispersion. Thus, precision between two different impressions can be compared, or the effectiveness of a new impression technique can be evaluated.

Using different weighting types provides diverse perspectives on the data:

- Linear weighting helps with gradual error evaluation.
- Gaussian weighting favors points very close to the center.
- Sigmoid weighting allows a clear distinction between acceptable and unacceptable points.

The most representative method is the exact correspondence, which directly indicates the percentage of points below the threshold.

This program measures how well points are concentrated around the center. It uses multiple methods to evaluate the distance of points from the center, providing either weighted or strict results. Its purpose is to assist in precision analysis—for instance, of a dental scan or implant positioning.

The user simply needs to load the data, select a threshold, and then interpret the displayed

results (Figure 28).

```

D:\Users\Hoss\Desktop\models 3d fouad\programmes cpp\pourcent d0gressif.exe
Loaded data from : 8 classes
Amount of points : 127327
Specify the max threshold (current value : 0.5) : 0.3
Results with a threshold of 0.3 :
Linear match : 77.36%
Gaussian match : 82.11%
Sigmoid match : 67.89%
Rough match : 96.28%

Loaded data from : 8 classes
Amount of points : 127327
Specify the max threshold (current value : 0.30) : 0.2
Results with a threshold of 0.20 :
Linear match : 68.31%
Gaussian match : 75.00%
Sigmoid match : 57.67%
Rough match : 84.46%

Loaded data from : 8 classes
Amount of points : 127327
Specify the max threshold (current value : 0.20) : _

```

Figure 28. Program coding in C++

RESULTS

Below is a summary table of the exact correspondences (Rough Match) between the different models and the “Model master”:

Modèle comparé à « Fouad »	Seuil (en mm)	% de correspondance
Anycubic	0.2	84.40%
Anycubic	0.25	90.64%
Anycubic	0.3	96.28%
Anycubic	0.35	97.64%
Anycubic	0.4	98.18%
Anycubic	0.45	98.72%
Anycubic	0.5	99.24%
Creo	0.2	47.75%
Creo	0.25	58.67%
Creo	0.3	69.59%
Creo	0.35	80.51%
Creo	0.4	91.43%
Creo	0.45	95.40%
Creo	0.5	98.94%
XPrint	0.2	91.19%
XPrint	0.25	92.42%
XPrint	0.3	93.65%
XPrint	0.35	94.88%
XPrint	0.4	96.11%
XPrint	0.45	97.34%
XPrint	0.5	98.57%

Figure 29. Results

DISCUSSIONS

In dental medicine, the fabrication of working models via 3D printing demands exceptionally high dimensional accuracy, especially for definitive restorations, implant-supported prostheses, and orthodontic appliances. Typically, an error tolerance of $\leq 0.2\text{--}0.3$ mm is required to ensure optimal fit of restorations and clinical success.

The analyzed table presents the compliance

rates of three 3D printers—Anycubic, Creo, and XPrint—compared to a reference model, across various error acceptance thresholds ranging from 0.2 mm to 0.5 mm.

In this comparative study, we evaluated the dimensional accuracy of the three 3D printers Anycubic, Creo, and XPrint by confronting their produced models against a reference model, considering tolerance thresholds from 0.20 mm to 0.50 mm. The clinical objective was twofold: to validate the suitability of each technology for demanding dental applications and to guide clinicians in selecting the most appropriate equipment for their specific needs.

Clinical Analysis of the Anycubic Printer

At a 0.2 mm threshold, the compliance rate is 84.40%, which remains acceptable but at the lower limit for high-precision restorations. From 0.3 mm, compliance rises to 96.28% and exceeds 98% at thresholds of 0.4 mm and above.

Clinical interpretation

Anycubic is suitable for conventional prosthetic restorations (crowns, bridges on natural teeth), orthodontic aligners, and standard surgical guides. Its use for implant-supported restorations or complex aesthetic works should be approached cautiously when a tolerance below 0.3 mm is required.

Clinical Analysis of the XPrint Printer

XPrint exhibits a compliance rate of 91.19% already at the 0.2 mm threshold, with continuous improvement up to 98.57% at 0.5 mm.

Clinical interpretation

This printer is perfectly adapted to the highest demands in dental medicine, including implant restorations, complex aesthetic works, customized surgical guides, and orthodontic devices requiring extreme precision.

Clinical Analysis of the Creo Printer

At a 0.2 mm threshold, the compliance rate is relatively low (47.75%), reaching acceptable accuracy (>90%) only from 0.4 mm onward.

Clinical interpretation

Creo is better suited for fabricating study models, provisional devices, and orthodontic mock-ups where strict submillimetric precision is not critical. Its use for definitive restorations is contraindicated.

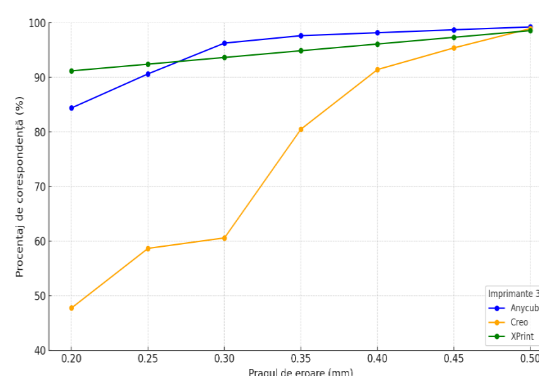


Figure 30. Matching percentage variation according to error threshold

The table provides a classification of the three tested 3D printers (XPrint, Anycubic, and Creo) based on clinical recommendations according to their dimensional accuracy. It reflects each technology's adaptability to the specific needs of dental practice:

1. XPrint ranks first due to its high precision, recommended for complex cases requiring perfect fit, such as implant restorations, aesthetic restorations, and customized surgical guides. It meets the highest standards in dental medicine, ensuring reliability in procedures demanding submillimetric accuracy.
2. Anycubic, ranked second, is a solid choice for conventional prosthetic restorations such as crowns and bridges, as well as standard surgical guides and orthodontic aligners. Although precise, it has a wider tolerance margin, making it less suited for highly complex works but a viable option for routine dental practice.
3. Creo holds the third position, recommended for applications where extreme precision is not mandatory, such

as study models, provisional devices, and orthodontic prototypes. While it does not reach the precision level of the other two printers, it is effective for prototyping and preliminary orthodontic treatment stages.

Following the comparative analysis of the dimensional accuracy of the three 3D printers (Anycubic, XPrint, and Creo), it can be concluded that each technology exhibits specific advantages and limitations depending on clinical requirements. The XPrint printer proves to be the most suitable for dental procedures that demand extremely high precision, making it ideal for implant-supported restorations and complex aesthetic work. Anycubic emerges as an efficient solution for conventional prosthetic restorations and standard orthodontic devices, while Creo is more appropriate for applications that do not require strict submillimetric accuracy, such as study models and provisional appliances. Therefore, the selection of the appropriate 3D printer should be guided by the clinical case specificity and the exact precision requirements of each dental intervention.

Planmeca Creo C5 is a DLP (Digital Light Processing) 3D printer dedicated exclusively to dental applications, designed to produce accurate models through a layer-by-layer manufacturing process. It employs additive manufacturing via photopolymerization, based on the stratified exposure of a liquid resin to 385 nm UV light, causing progressive hardening of the material. This high-precision 3D printing method is particularly suited for dental applications where fine detail and exact fit are critical, with a pixel size of 50 microns and a 25 to 100 microns adjustable layer height.

The system operates through a controlled polymerization process, where each resin layer is solidified before the build platform elevates to allow the formation of the next layer. Unlike filament extrusion (FDM) or powder sintering (SLS) technologies, Planmeca Creo C5's approach ensures a smooth surface and high detail accuracy, ideal for fabricating dental

models, surgical guides, and customized prosthetic frameworks.

This technology is optimized for specific biocompatible resins tailored to dental use, enabling direct printing of clinically usable devices following appropriate post-polymerization processes.

Anycubic Photon Mono X 6Ks uses MSLA (Masked Stereolithography) technology, where a monochrome LCD selectively masks a 405 nm UV light source to cure resin layer by layer. This approach allows faster print speeds and reduced maintenance compared to traditional SLA printers. The monochrome 9.1-inch 6K screen (5760 × 3600 pixels) with a high contrast ratio of 380:1 delivers sharp, precise details in 3D prints.

Hardware-wise, the Photon Mono X 6Ks features a generous build volume of approximately 195 × 122 × 200 mm, enabling simultaneous production of multiple parts or large models. The mechanical system relies on a dual Z-axis equipped with anti-backlash gears, ensuring micron-level precision. The build platform, manufactured via laser engraving technology, guarantees optimal model adhesion and minimizes deformation or detachment during printing.

A key technical aspect is the LightTurbo matrix light source, which produces uniform, parallel UV light. This significantly reduces visible layer lines and grid effects, resulting in smooth surfaces and superior finish quality. Uniform lighting also accelerates resin curing, optimizing print speeds between 15 and 60 mm/h depending on settings.

Slicing software such as Anycubic Photon Workshop or specialized dental solutions (e.g., CHITUBOX Dental) complete the technological package, enabling quick and intuitive parameter setup like layer thickness, exposure time, and peel speeds to achieve optimal results for various resin types, including biocompatible dental materials.

In summary, by combining a high-resolution

screen, precise mechanical system, and innovative light source, the Anycubic Photon Mono X 6Ks represents a robust, efficient 3D printing solution capable of producing detailed models essential for applications demanding high accuracy and quality, such as dentistry.

xPRINT's strength lies in its 8K monochrome LCD screen with an impressive resolution of 7680×4320 pixels, allowing an XY precision of 28.5 microns. This makes it suitable for applications requiring high detail levels: prosthetic models, aesthetic restorations, surgical guides, or orthodontic models.

Its generous build volume ($219 \times 123 \times 250$ mm) enables simultaneous printing of multiple works, significantly reducing production time and enhancing clinical efficiency, especially in clear aligner treatments involving successive model series.

Another critical element is the Fresnel lens optical system combined with a 405 nm UV LED light source, ensuring uniform light distribution and consistent results without artifacts or deformations. Such homogeneity is crucial in dentistry, where even minimal dimensional deviations can compromise restoration fit.

xPRINT is optimized for use with xRESIN materials but is also compatible with numerous certified dental resins, including Class I and IIa biocompatible types, essential for intraoral applications that require strict safety and biocompatibility standards.

CONCLUSIONS

The evaluation of the accuracy of 3D-printed models in the dental field has highlighted both the current capabilities and limitations of this technology. Despite the significant advancements in 3D printing, model accuracy remains a critical factor for the clinical success of dental restorations. The printers analyzed produced varying results—some proving suitable for routine dental applications, while

others were less appropriate for the stringent demands of complex restorations.

In the current context, 3D printing constitutes an increasingly viable and high-performing solution for applications such as model fabrication, conventional dental prostheses, and standard orthodontic devices. However, for restorations requiring extreme precision—such as implant-supported cases or complex aesthetic work—further technological improvements are necessary to ensure a perfect fit and long-term clinical reliability.

The future of 3D printing in dentistry appears promising, driven by ongoing advancements in materials, software, and printing equipment. It is highly likely that the accuracy of printed models and components will continue to improve, allowing for greater treatment customization, reduced treatment times, and lower costs.

As the technology evolves, it will be essential to continuously assess its clinical applications to ensure they meet quality, safety, and durability standards. Furthermore, the integration of artificial intelligence and machine learning technologies should be considered to optimize model design and tolerance management. The adoption of 3D printing in the dental sector may also foster a more collaborative approach, enabling closer cooperation between clinicians, technicians, and researchers to further personalize treatments.

In conclusion, although 3D printing already represents a significant advancement in dentistry, its future lies in the continuous improvement of precision, speed, and versatility of applications. It is evident that this technology will play a key role in transforming dental practice, offering innovative solutions for both patients and professionals in the field.

Acknowledgement

All authors acknowledge the support of Interdisciplinary Center of Research and Development in Stomatology, Digital Techniques in Dentistry Laboratory, from U.M.F. "Carol Davila" Bucharest.

REFERENCES

1. Mousa N., Hussein M., Elashiry M., Ghoneim A., Alamoudi W., Lin C.P., Fawzy A. Comparison of digital intraoral scanners accuracy for scanning multiple prepared teeth: an in vitro study. *Scientific Reports*, vol. 9, 2019, p. 1–13, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6854270/>, accesat la data de 24 mai 2025;
2. M. Elashmawi, A. M. Elsharkawy, M. A. Elshazly, "Optimization of Digital Light Processing Three-Dimensional Printing of the Removable Partial Denture Frameworks; The Role of Build Angle and Support Structure Diameter", *Materials*, vol. 15, no. 6, 2022, pp. 2316, <https://www.mdpi.com/1996-1944/15/6/2316>, accesat le 24 mai 2025.
3. Liu, Y., Zhang, H., Wang, J., & Chen, Y. (2021). Design for the reduction of volume shrinkage-induced distortion in digital light processing 3D printing. *Additive Manufacturing*, 38, 101766. https://www.researchgate.net/publication/352766965_Design_for_the_reduction_of_volume_shrinkage-induced_distortion_in_digital_light_processing_3D_printing accesat la 24 mai 2025
4. Dizon, J. R. C., Gache, C. C. L., Cascolan, H. M. S., & Cancino, L. T. (2021). *Post-Processing of 3D-Printed Polymers*. *Technologies*, 9(3), 61. Disponibil online la: <https://www.mdpi.com/2227-7080/9/3/61> accesat la 24 mai 2025
5. Koziol, M., Olesik, P., Wiecek, J., & Wacławski, K. (2021). *Effect of Post-Process Curing and Washing Time on Mechanical Properties of mSLA Printouts*. https://www.researchgate.net/publication/354266541_Effect_of_Post-Process_Curing_and_Washing_Time_on_Mechanical_Properties_of_mSLA_Printouts accesat la 24 mai 2025.
6. Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T. Q., & Hui, D. *Additive manufacturing (3D printing): A review of materials, methods, applications and challenges*, *Composites Part B: Engineering*, vol. 143, 2018, pp. 172–196. <https://doi.org/10.1016/j.compositesb.2018.02.012> accesat la 24 mai 2025
7. Katheng A., Kanazawa M., Komagamine Y., Iwaki M., Namano S., Minakuchi S. Effect of post-rinsing time and method on accuracy of denture base manufactured with stereolithography, *The Journal of Advanced Prosthodontics*, vol. 14, nr. 1, 2022, pp. 45–55, <https://doi.org/10.4047/jap.2022.14.1.45>, accesat la 24 mai 2025.
8. Harmatys W., Gaska A., Gaska P., Gruza M. *Identification of the Influence of IPA Rinsing Times on Surface Roughness of SLA-Printed Parts Made of Different Materials*, *Materials*, vol. 18, nr. 9, 2025, art. 2082, <https://doi.org/10.3390/ma18092082>, accesat la 24 mai 2025.
9. Kirby S., Pesun I., Nowakowski A., França R. *Effect of Different Post-Curing Methods on the Degree of Conversion of 3D-Printed Resin for Models in Dentistry*, *Polymers*, vol. 16, n° 4, 2024, art. 549, <https://doi.org/10.3390/polym16040549>, consulté le 24 mai 2025.
10. Hassanpour, M., Narongdej, P., Alterman, N., Moghtadernejad, S., Barjasteh, E., *Effects of Post-Processing Parameters on 3D-Printed Dental Appliances: A Review*, *Polymers*, vol. 16, nr. 19, 2024, p. 2795, <https://doi.org/10.3390/polym16192795>, accesat la 24 mai 2025.
11. Kim, R. J. Y., Kim, D.-H., Seo, D.-G., *Post-polymerization of three-dimensional printing resin using a dental light curing unit*, *Journal of Dentistry*, 2023, <https://doi.org/10.1016/j.jds.2023.07.028>, accesat la 24 mai 2025.