

Effect of support arrangements on 3D printing denture accuracy: An *in vitro* study

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Abstract

Purpose: Supports are essential for ensuring dimensional accuracy in 3D printing; however, an excessive number of supports compromises printing efficiency. This study aimed to investigate how a varying number of support arrangements affects the precision and trueness of 3D-printed dentures.

Methods: Three denture base printing files were designed, each with different numbers of supports: 40 (group 40), 55 (group 55), and 70 (group 70). Thirty samples were printed and measured across the groups. Accuracy was evaluated by assessing trueness and precision using the root mean square error (RMSE). The error areas in each group were analyzed through micro-computed tomography (micro-CT) 3D imaging.

Results: Group 70 showed a significantly lower RMSE for trueness than Group 40 ($P < 0.05$), but showed no significant difference from Group 55 ($P \geq 0.05$). For precision, Group 70 outperformed both Groups 40 and 55 ($P < 0.05$), which did not differ significantly ($P \geq 0.05$). Micro-CT revealed no mismatches in the palatal region. Discrepancies—areas where the supports in Groups 40 and 55 did not accurately align with those in Group 70—were predominantly observed at initiation points of overhangs in thinner sections.

Conclusions: Based on these results, this study recommends placing support structures strategically around overhangs and thin-walled areas to enhance the accuracy of 3D-printed denture fabrication. These findings indicate that optimizing support placement, rather than merely increasing the number of supports, is crucial in improving the quality and reliability of 3D-printed dental prostheses.

Keywords: Denture, 3D Printing, Support, Printing accuracy, Efficient support placement

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1. Introduction

In recent years, advances in computer-aided design/computer-aided manufacturing (CAD/CAM) have led to significant progress in the field of restorative dentistry[1]. Compared with conventional approaches, fabricating removable restorations using CAD/CAM technology provides benefits including improved adaptation to the oral gingiva[2], reduced denture weight[3], minimized processes[4], and easy fabrication to duplicate existing dentures[5]. The CAD/CAM steps can be classified into additive manufacturing (AM) or subtractive manufacturing (SM). AM is more economical and productive

than SM due to less waste material generation, burr consumption, and the simultaneous fabrication of multiple products[6]. However, various factors can affect the accuracy of the products, including the type of material[7], printing angulation[8], layer thickness[9], post-curing procedure[10], and support structure[11].

WHAT IS ALREADY KNOWN ABOUT THE TOPIC?

» Supports are essential in 3D printing to maintain structural integrity, particularly in models with overhangs and complex geometries, ensure correct layer adhesion, and prevent collapse. However, they present drawbacks, including increased material use, rougher surface finishes, longer print times, and difficulties in removal.

WHAT THIS STUDY ADDS?

» This study highlighted the importance of tailored support placement in 3D printing for accurate denture fabrication. The optimization of the support arrangement allows clinicians to achieve precise and efficient denture production, ensuring a better fit for patients.

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The 3D printing involves building objects by releasing materials layer-by-layer. This manufacturing method leads to accuracy issues when a new layer has a different footprint from that of the previous layer[12]. Overhang parts, which are any part of a model that extends horizontally or at an angle beyond the previous layer, require supporting structures to resist the deformation and collapse caused by various forces during fabrication. Although gravity can influence deformation in unsupported regions, recent studies have suggested that the primary source of deformation in stereolithography (SLA)-based 3D printing may be the force required to separate the resin from the bottom of the resin tank after curing each layer[13]. This separation force can generate significant stress, particularly in geometrically complex structures like removable dentures. Therefore, the support structures play a dual role: resisting gravitational forces and counteracting the stress caused by resin separation during the printing process. Support structures in 3D printing play a critical role in ensuring printability by guiding the deposited material to follow the intended design, balancing the printed structure to avoid collapse, and preventing distortion during polymerization[12]. Support structures are essential in rapid prototype 3D printing technologies, including SLA[14], which is commonly used to print removable dentures. SLA printers cure the liquid resin layer-by-layer utilizing a UV light source. When a resin layer is cured, it solidifies and becomes self-supporting[15]. However, if the features in the design extend outward without any support from the layers below, they may collapse or deform during printing. To address this issue, support structures are typically added to the model during slicing[15]. The complex shape and geometry of the denture design, including overhangs, undercuts, and partially thin sections, necessitate the use of support structures for the denture base in CAM.

Despite the indispensable role of the support structure in 3D processes, its excessive utilization causes undesirable outcomes, including increased material consumption, longer production times, higher costs, and difficulties in the post-processing and finishing of manufactured parts[15]. In addition, more support leads to a wider area to finish, which may cause surface damage[16–18]. A wide area requiring modification may alter the surface properties of the denture base and potentially compromise the accuracy. To address these issues, the industry is exploring optimized designs and strategic positioning or orientation of models to minimize the need for supports[19–21]. Additionally, redesigning the original shape[22] or using soluble support materials has been suggested[23,24]. However, achieving precise 3D printing of dentures is more crucial than in other industrial products, as it is essential to ensure an accurate fit to the patient’s oral cavity. Therefore, employing strategic and efficient supports based on empirical evidence is imperative for optimizing manufacturing processes. Namano *et al.* examined the precision and trueness of denture printing by reducing the number of palatal and border supports and concluded that reducing the number of palatal and border supports is favorable for efficient denture printing with optimal accuracy[25].

In this study, we created three denture models with different numbers of supports and investigated how the placement of supports in specific locations affects the accuracy of denture printing, aiming to identify an efficient support placement method for printing dentures. The accuracy of each group was evaluated by comparing the images obtained using the model scan with those obtained using the original design. Additionally, micro-CT images from each group were compared to measure the location, volume, thickness, and angle of the areas where errors occurred. The null hypothesis

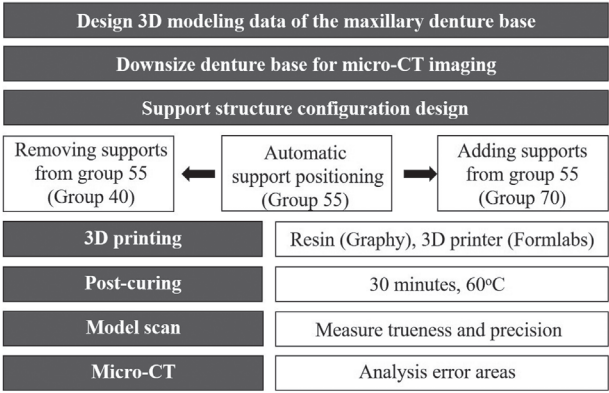


Fig. 1. Flowchart of the experimental process. The diagram illustrates the workflow for designing, printing, and analyzing the maxillary denture base.

was that each group with a different number of supports would show similar accuracy and that the parts printed accurately would not differ from those printed incorrectly in terms of thickness and angle. This study aimed to investigate the effect of the support arrangement on the accuracy of 3D-printed dentures.

2. Materials and Methods

2.1. 3D CAD design and 3D printing

Figure 1 shows a flowchart of the experimental process. The intaglio surfaces of all the denture bases were scanned using a laboratory scanner (Identica Blue T500; Medit) to obtain virtual test data. The original Standard Tessellation Language (STL) file was downsized in a modeling software—Meshmixer (Autodesk, San Rafael, CA, USA)—using ‘units/dimensions’ in the ‘analysis’ function to enable imaging by micro-CT. The dimensions of the original STL file, calculated in Meshmixer, were 69.68 mm × 50.29 mm × 39.95 mm, and the downsized dimensions were 39.59 mm × 28.57 mm × 22.70 mm (along the X, Y, and Z axes, respectively). The dental model STL file was loaded into slicing software (Preform, Formlabs, Somerville, MA, USA). The orientation of the STL file was set to 45°, based on highly accurate printing results from a previous study[26], and 55 supports were automatically generated using the support generation feature of the software (Group 55). In a pilot study, we observed that when fewer than 55 supports were used, the printing process remained stable without significant collapse. Further, designs with as few as 40 supports exhibited no visible issues upon visual inspection. Based on these findings, we used the printing file with the number and positions of the supports automatically suggested by the program and utilized the ‘edit’ function in the ‘support’ feature to remove 15 supports from the Group 55 to create the Group 40. Subsequently, we added 15 supports to form the Group 70. Regarding support placement, we began with the software’s automatic distribution and manually adjusted it to ensure an even distribution across the denture structure, removing or adding supports as needed. **Figure 2** shows images of a CAD denture base placed on a build platform with three different support attachments. Each group was named according to the number of supports, and additional supports with increased support numbers are represented in different colors (green, red, and yellow), indicating incremental addition. Thirty specimens were fabricated, with 10 specimens per group. Micro-CT imaging

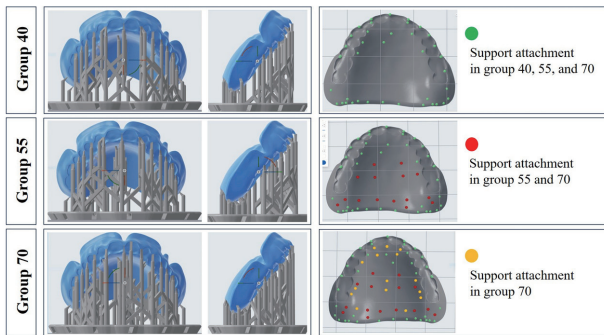


Fig. 2. Denture support designs of each group. Image showing comparison of support structures in 3D printing across three groups: Group 40, Group 55, and Group 70.

was performed intact without removing the supports, and laboratory scanning was performed after the supports were removed. The number of specimens was determined based on the results of a previous report[19] for 80% power and 0.05 significance level using an analytical software program (Statsmodels, Open source). 3D printing was conducted using an SLA 3D printer (Form 3, Formlabs, Somerville, MA, USA) with denture resin (THD, Graphy Inc., Seoul, Republic of Korea) at a layer thickness of 100 μm . Rather than the Formlabs 3D printer (Form 3), the printing parameters of Formlabs Gray V4 matched those of the Graphy's THD method. The energy per printed layer of the sample was 14mJ/cm². The 3D printing resin comprised urethane dimethacrylate, urethane dimethacrylate oligomers, and phenylbis (2,4,6-trimethylbenzoyl) phosphine oxide as the photoinitiators. The specimens were gently removed from the dedicated finish kit (Finish Kit, Formlabs, Somerville, MA, USA) using a scraper to avoid damage to the support. In the post-processing stage, the printed model was washed with 95% ethylene alcohol in a rotary machine (Twin Tornado, Medifive, Seoul, Republic of Korea) for 10 minutes, followed by post-curing in a curing machine (Form-cure, Formlabs, Somerville, MA, USA) at 60 °C for 30 minutes. Resin consumption and printing time were calculated using the Preform software (FormLab, Somerville, MA, USA).

2.2. Measurement of accuracy through STL file comparison

According to the International Standards Organization, trueness indicates the closeness of agreement between printed results and a digitally designed object, whereas precision indicates the closeness of agreement between printed results[27]. Each printed denture base was placed on a silicone index (EXAFLEX Putty, GC Corp, Tokyo, Japan) to ensure a consistent scanning direction for the laboratory scanner (Identica Blue T500, Medit, Seoul, Korea). The scanned data were saved as STL files and exported to a 3D-inspection software (Geomagic Control X, 3D Systems, Rock Hill, SC, USA). A specific area was segmented and used for alignment during the trueness analysis. The intaglio surface, including the border and palate of the denture base, was defined in the scanned file. Through "Initial Alignment," the denture bases of the test data were superimposed onto the reference data, and then "best-fit alignment" was performed based on the primary alignment. Scanned files were compared using "3D compare" and color-coded deviation maps were generated for each superimposition analysis. The nominal deviation was set at ± 50 μm , with a critical deviation at ± 300 μm and maximal deviation at ± 500 μm . Areas within the nominal deviation are displayed in green on

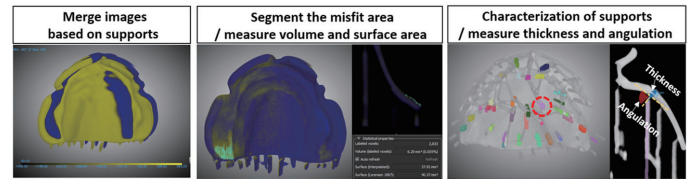


Fig. 3. Analysis of printing error parts in micro-CT images. Depiction of the three-step process for analyzing and characterizing support structures in a 3D printed maxillary denture base.

the color maps. To evaluate trueness, 3D surface deviation data were analyzed, including root-mean-square error (RMSE) calculations. To evaluate precision, all possible pairwise comparisons were used, as defined by the superimposition of different models generated using the same STL file. All the scanning and superimposition procedures were performed by a single investigator.

2.3. Analysis of printing error parts in micro-CT images

The printed sample images were acquired using an X-ray micro-CT system (SkyScan 1176; SkyScan, Aarselaar, Belgium). The X-ray system employs a microfocus tube with a spot size of 5 μm , producing X-rays in a cone-beam geometry. Images obtained without a filter, at a tube voltage of 40 kV and a tube current of 596 μA , were reconstructed using the reconstruction software CTAn (SkyScan, Aarselaar, Belgium). Dentures were analyzed using a 3D imaging program (Dragonfly, Comet Technology, Quebec, Canada). The specimen image files were imported into the program and subjected to image processing techniques to enhance the visibility of the denture boundaries. To minimize observer-induced errors, the software was configured to display Group 70 as opaque, while making the other groups transparent, enabling easy identification of the mismatched regions. Using the support parts as reference points for merging, manual alignment and superimposition of Groups 40 and 55 with Group 70 were first performed, followed by an automatic overlapping process to ensure precision. The mismatched areas between the denture image samples were identified through color-coded visualization, and the labeled voxels, volumes, and surface areas of the mismatched areas were assessed using a robot operating system. Similar processes were repeated by overlapping images within the same group to evaluate the repeatability of each group. To determine the characteristics of the supports, the thickness and angulation of the denture base at each support point were measured; denture thickness was assessed to identify the thinnest regions and angles between the denture base and supports were calculated. **Figure 3** shows visual images detailing the 3D imaging and analysis process. The left panel shows the images merged into two 3D models. The middle panel shows a segmented 3D model in which certain areas are highlighted, indicating mismatched areas and detailed measurement properties, including the volume and surface area of the segmented region. The right panel presents a 3D model with various colored markers and a zoomed-in view showing the methodology of the detailed measurement to analyze the supports and evaluate their thickness and angles.

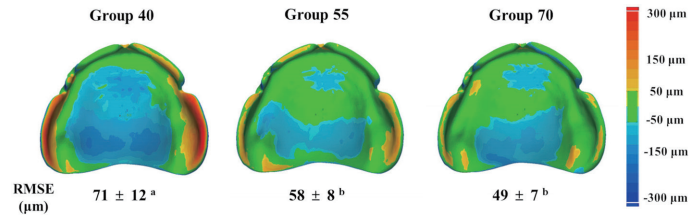


Fig. 4. Color map deviation patterns and root mean square estimate (RMSE) of trueness under different support number groups. Different superscript letters indicate statistically significant differences ($P < 0.05$).

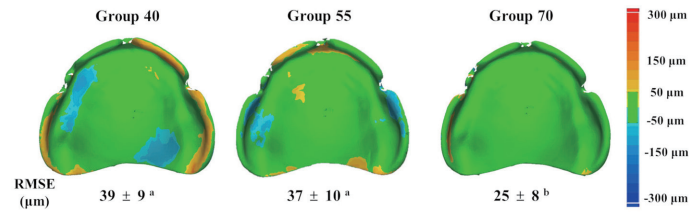


Fig. 5. Color map deviation patterns and root mean square estimate (RMSE) of precision under different support number groups. Different superscript letters indicate statistically significant differences ($P < 0.05$).

2.4. Statistical analysis

Statistical analyses were performed using GraphPad Prism version 9.1.0 (Boston, MA, USA). Data are expressed as means and standard deviations (SDs). The Kolmogorov–Smirnov test was used to assess data normality, and Levene’s test was used to evaluate the homogeneity of variance. One-way analysis of variance (ANOVA), followed by Tukey’s post-hoc multiple comparison test, was used to compare group means for the support angle and thickness at mismatching sites, as well as for trueness and precision. Welch’s ANOVA was used to analyze the volume and surface area of the mismatched sites. Statistical significance was set at $P < 0.05$.

3. Results

The 3D color-coded deviation maps were used to comparatively analyze the three groups. The color map indicates that deviations were present in both the positive and negative directions. **Figure 4** shows the trueness of the three groups compared with the reference model. The RMSE for trueness was the lowest for the denture printed with 70 supports, measuring $49 \pm 7 \mu\text{m}$. This value significantly differed from that of Group 40 ($71 \pm 12 \mu\text{m}$) ($P < 0.05$). In contrast, the RMSE for trueness in Group 55 was $58 \pm 8 \mu\text{m}$, showing no significant difference from Group 70 ($49 \pm 7 \mu\text{m}$) ($P \geq 0.05$). The deviation map for Group 70 showed the least deviation among the three groups, indicating that it was the best fit for the reference model. The RMSE of Group 70 significantly differed from that of Group 40 ($P < 0.05$).

The maps in **Figure 5** show the precision for each group. Significant deviations in the heat map indicate that a distribution of deviations is visible along the edges, as highlighted in orange and red. The RMSE value for Group 40 was $39 \pm 9 \mu\text{m}$. The deviation distribution in Group 55 was slightly lower than that in Group 40, suggesting a marginally improved accuracy. The RMSE for Group 55 was $37 \pm 10 \mu\text{m}$. The heat map for Group 70 revealed fewer and smaller regions of significant deviation, with most of the surface area remaining within

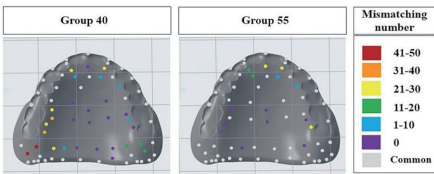


Fig. 6. Number of supports located in areas of mismatch, identified via micro-CT, compared between Group 70 and Groups 40 or 55. Supports marked in gray are common between the compared groups (Group 40 or Group 55) and Group 70.

Table 1. Volume and surface area in mismatching sites between the same groups

	Group 40	Group 55	Group 70	P value
Volume (mm ³)	7.12±2.78 ^c	3.46±1.33 ^b	1.33±0.17 ^a	<0.05
Surface area (mm ²)	70.7±29.28 ^c	52.51±31.22 ^b	24.28±3.76 ^a	<0.05

^{ab} Different superscript letters indicate statistically significant differences

$\pm 50 \mu\text{m}$ (green). The lowest RMSE value observed was $25 \pm 8 \mu\text{m}$, indicating better precision in the printed models. The values were significantly different from those of groups 40 and 50 ($P < 0.05$).

The volumes and surface areas of the mismatched sites were measured in the same groups. As shown in **Table 1**, the mismatched sites are areas where the 3D denture model did not align correctly. The volume and surface area of the mismatched sites decreased in Groups 40, 55, and 70, with statistically significant differences observed between the groups ($P < 0.05$).

Figure 6 illustrates the frequency of each type of support located in the mismatched areas observed in Groups 40 and 50, compared to Group 70. The supports were selected from the mismatched sites after matching the 3D images of Group 40 with those of Group 70 and similarly matching those of Groups 55 and 70. Among the supports, only those that increased in number across all three groups were selected. The supports are color coded in **Figure 6** from red (40–50 errors) to purple (0 errors), with red and orange indicating higher counts in the mismatched area. In Group 40, the majority of the area was marked in purple (0) and was concentrated in the central palatal region. Blue (1–10) and yellow (21–30) were distributed along the edges, while green (11–20) and red (41–50) colors appeared in certain regions. The error distribution in Group 40 showed a higher frequency of mismatches, particularly along the edges and in certain internal regions. In Group 55, the support distribution in the mismatched parts appeared to improve slightly. While the map shows some errors along the edges, there was a noticeable reduction in the areas marked in red and orange, suggesting a more consistent print quality compared to Group 40. Group 40 exhibited more supports in the mismatched area than Group 55.

Table 2 presents the angles and thicknesses of supports at the mismatched sites according to the number of mismatches. In Group 40, the support angle was the smallest for mismatches ranging between 21–30, but significant differences were only observed for mismatches of 0 and 11–20. No significant differences were observed in the support angle between Group 55 and the other groups ($P \geq 0.05$). In Group 40, the thickness of the supports was the lowest for mismatches between 41–50, while it was highest for mismatches in

Table 2. Angle and thickness of supports in mismatching sites

	Mismatching Number	Angle (°)	Thickness (mm)
Group 40	0	85.90 ± 11.85 ^{ab}	1.65 ± 0.34 ^{ab}
	1–10	75.02 ± 9.60 ^c	2.12 ± 0.67 ^c
	11–20	86.97 ± 4.80 ^b	1.99 ± 0.78 ^c
	21–30	72.89 ± 9.01 ^c	1.84 ± 0.34 ^{bc}
	31–40	76.35 ± 6.05 ^c	1.89 ± 0.13 ^{bc}
	41–50	78.80 ± 14.26 ^{ac}	1.46 ± 0.45 ^a
Group 55	0	85.39 ± 14.89 ^a	1.61 ± 0.48 ^a
	1–10	83.29 ± 4.55 ^a	2.13 ± 0.04 ^c
	11–20	81.61 ± 11.84 ^a	2.04 ± 0.09 ^{bc}
	21–30	80.72 ± 8.28 ^a	1.88 ± 0.08 ^{ab}

^{abc} Different superscript letters indicate statistically significant differences ($P < 0.05$)

Table 3. Details for printing

Groups	Support structure configuration				
	Touch-point size (mm)	Number of support attachment	Volume (cm ³)	Resin consumption (mL/one-denture)	Printing time (h)
40	0.80	40	57.02	5.42	1.45
55	0.80	55	57.56	5.64	1.45
70	0.80	70	58.07	5.95	2.00

the 1–10 range. In Group 55, supports with mismatches between 21–30 exhibited the least thickness, which significantly differed from mismatches in the 1–10 range ($P < 0.05$).

4. Discussion

The strategic use of supports is necessary for denture printing to ensure optimal precision, contributing to an efficient printing process. This study aimed to investigate how the accuracy of printing dentures changes depending on the arrangement of supports and explore methods of support placement to achieve precise and efficient printing. To investigate an efficient support placement method for printing dentures, we created three denture models with different numbers of supports (Groups 40, 55, and 70) and investigated the effect of adding supports at certain locations on the accuracy of denture printing. A comparison of the printing results of each group with those of the original STL design file revealed that printing was more accurate in Group 70 than in Groups 55 and 40. Therefore, the first hypothesis was rejected. When comparing the characteristics of supports in mismatched areas, the number of mismatches and angulation of the supports appeared to have little correlation. However, the supports positioned in the thinner areas exhibited more mismatches. Therefore, the second hypothesis was partially rejected.

The number of supports directly influences the total print volume, leading to an increased printing time and material usage, which can reduce the overall efficiency of the 3D printing process. Group 70 demonstrated the largest print volume in this study, followed by Groups 55 and 40 (**Table 3**). Consequently, the resin consumption was higher in groups with larger volumes, reflecting a proportional relationship between the support structures and material usage. This

observation is consistent with the findings of Namano *et al.*, who reported similar trends[25]. Interestingly, while the printing times were identical between Groups 40 and 55, Group 70 required significantly more time to complete (**Table 3**), highlighting the combined effect of increased volume and support complexity on print duration.

In this study, the RMSE values for trueness were lower in Groups 55 and 70 than in Group 40 (**Fig. 4**). The RMSE for precision was lower in Group 70 than in Groups 40 and 55 (**Fig. 5**). A comparison within the same group using micro-CT images revealed that Group 70 exhibited the smallest discrepancies, followed by Groups 55 and 40; this difference was statistically significant (**Table 1**). The results showed that Group 70 demonstrated the highest trueness and precision, whereas Group 40 exhibited the lowest values for both metrics, which is consistent with the findings of a previous study, suggesting that a greater number of supports enhances both accuracy and reproducibility[25]. Given that Group 55 was automatically configured using the CAD program, it could serve as a reference point. The results showed that when more supports were arranged rather than automatically determined, the precision increased without a corresponding increase in trueness. Conversely, arranging fewer supports than the automatic support design resulted in a decrease in trueness.

Compared to existing studies, the RMSE values in this study were lower. Yoshidome *et al.* evaluated trueness based on printing angulation, reporting an RMSE value of 108.88 μm for the same angulation used in this study[9]. Additionally, a previous study investigating the effect of support quantity on printing accuracy used a 45° printing angulation and found that the group with the highest number of supports achieved a trueness of 61.0 μm and precision of 40.8 μm [25]. In comparison, the Group 55 in this study, with standard support placement, showed trueness of 58 μm and precision of 37 μm (**Fig. 4**). The lower RMSE values observed in this study may be attributed to the downsized denture design used to facilitate the micro-CT analysis. A smaller overall size likely reduced the absolute magnitude of the deviations, even if the relative error rates remained similar.

Previous studies assessing the accuracy of 3D-printed dentures compared printed models with the original STL files after the removal of supports. This methodology makes it impossible to identify the specific areas of printed dentures that contribute to discrepancies in accuracy. In contrast, this study sought to identify specific areas where accuracy issues arose during the printing process by comparing models with the base and supports still attached during image superimposition. Overlapping the prototype of the printed object along the direction of 3D printing enables tracking of the error areas that occur during the printing process. Because the remaining supports obstruct the field of view of the scanner, capturing the complete geometry of the denture using conventional scanning methods is challenging. Consequently, micro-CT imaging was employed to obtain and analyze the models. Because the typical dimensions of dentures exceed the scanning range of micro-CT, the printed models were scaled down for analysis. Based on the trueness results from the STL file data, which showed that Group 70 had the highest printing accuracy, the mismatched sites in the other groups were evaluated relative to those in Group 70 using micro-CT images. **Figure 6** shows the mismatched areas and indicates no mismatched areas in the palatal region. These findings are consistent with those from previous studies, which demonstrate that removing support from the palatal area does not affect trueness[25]. In this study, most mismatched areas were located at the periphery of the denture.

Notably, in Group 40, the most frequent mismatch was found in regions identified as the initiation points of denture overhang (**Fig. 6**). These experimental results indicate that sufficient support should be placed on the edges of the denture rather than at the center for more accurate printing. In addition, more support is required in overhang areas because of the potential deformation caused by material sagging or separation forces, which may lead to distortion.

In this study, the mismatched areas observed between the two groups with differing numbers of supports were attributed to the presence or absence of supports. Analyzing the characteristics of the supports within these mismatched areas provides clues regarding the essential printing areas where support is necessary to enhance printing accuracy. As previously mentioned, the occurrence of mismatches is determined by whether the support is located on the palate or the border. By comparing the characterization of the supports according to the frequency of mismatches and excluding the areas without mismatches, thinner areas were associated with a higher number of mismatches, with the number of mismatches and angulation of the supports appearing to have little correlation (**Table 2**). The thinner parts of 3D printed structures are often less accurate, primarily because of the challenges in maintaining structural integrity. The limited amount of material deposited per layer can lead to difficulties in achieving precise layer adhesion and dimensional accuracy when printing thin features. A thinner structure implies that narrower layers are stacked on top of each other during printing. Stacking reduces structural stability, making thinner structures more susceptible to collapse. This can result in inconsistencies such as warping, curling, or even collapse during the printing process, especially if the part lacks adequate support structures. In addition, the mechanical strength of the thin sections may be compromised, affecting the overall durability and stability of the printed object. Therefore, supplemental support is necessary for the accurate printing of thin areas.

Most CAD programs offer automatic support generation based on predefined settings commonly used when printing dentures. This study conducted experiments by modifying automatically selected support arrangements to evaluate their impact on printing accuracy. The findings highlight that strategically placing supports—particularly around overhangs and thin sections—significantly enhances the accuracy—encompassing both the trueness and precision—of 3D-printed dentures. Manually adding support to the edges of dentures, particularly in thinner areas, improves manufacturing outcomes. These insights suggest that clinicians can enhance fit and patient comfort by tailoring support placement based on specific design requirements. However, since support arrangement algorithms differ across CAD programs[28]—and even within the same program based on the printing orientation[29]—further studies using various programs and orientations are required to validate these findings and ensure broader applicability.

In this study, three groups with different support arrangements were created by removing or adding 15 supports to the 55 supports automatically selected by the software. Designing a wider variety of support arrangements for different denture designs and testing them in future experiments is highly promising. In addition, future studies are needed to verify the effect of support structures on product accuracy using various printers and materials.

The support structure is another critical factor in 3D printing that affects both the accuracy and efficiency of the printing process.

The design of the supports, including factors such as area coverage and angulation, directly affects the stability and precision of the print[30]. The angle of the supports relative to the build platform determines how effectively they bear the weight of the overhangs, with steeper angles often providing better support, but requiring more material[31]. The surface areas of the supports in contact with the model must provide sufficient stabilization without leaving excess marks on the final product[30]. In addition, an efficient support design minimizes material usage and print time, reducing waste and the risk of print failure[32]. This optimization not only speeds up the overall printing process but also simplifies post-processing because well-designed supports are easier to remove and leave fewer surface imperfections[33]. Because a single support structure was used in this study, further studies considering different support structures are necessary. In addition, this study specifically examined the relationship between the support structures and morphological characteristics of dentures. However, the optimal use of supports may be influenced by multiple factors, including printing angle, post-curing conditions, and layer thickness. Furthermore, parameters such as printing speed, laser intensity, and rheological properties of the material, including viscosity and flowability, may affect the necessity, quantity, and configuration of the support structures. Future studies that systematically investigate the interplay between these variables would contribute to a more comprehensive understanding and optimization of the 3D printing process for denture fabrication.

5. Conclusions

While this study has limitations, our findings clearly demonstrate that placing supports specifically around overhangs and thin-walled areas, while minimizing or eliminating supports in non-critical regions, such as the palatal surface, leads to significantly improved accuracy of 3D-printed dentures. Therefore, we recommend this support configuration as an optimized strategy for enhancing the accuracy and efficiency in the additive manufacturing of dental prostheses. These insights provide practical guidance for CAM and support its application in clinical and laboratory settings.

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Conflict of interest statement

The authors declare no conflict of interest.

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