Original Article

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Influence of model-less cementation on the accuracy of the implant-supported crown in a complete digital workflow

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Objectives: This study compared the accuracy of single-unit implant crowns using a model-less digital workflow versus a complete digital workflow with a 3D printed model, with implants adjacent to normal dentition and mesially tipped adjacent teeth.

Materials and Methods: Two master models with a single implant at the lower left second premolar were scanned fifteen times using an intraoral scanner. Crowns were divided into two groups: fifteen crowns underwent model-less digital workflow (test) and fifteen crowns were adjusted with a 3D printed model (control). Interproximal adjustments, angular deviation, and adjustment time were measured and analyzed ($p < 0.05$).

Results: All crowns in the control group fit without further adjustment after being adjusted in the printed model. Median angular deviations were 2.67° (test) vs 1.53° (control) for normal dentition and 2.53° (test) vs 1.68° (control) for mesially tipped dentition. Mean adjustment times were 1.50 ± 0.54 min (test) vs 2.12 ± 0.59 min (control) for normal dentition, and 1.43 ± 0.42 min (test) vs 1.50 ± 0.54 min (control) for mesially tipped dentition. Maximum adjustment depths were comparable between groups. Light contacts were noted in the control group (1 for normal dentition, 7 for mesially tipped dentition). Statistically significant differences were observed only in angular deviation.

Conclusions: The model-less digital workflow had greater angular deviation compared to the 3D printed model workflow, but both techniques showed comparable adjustment time and amount.

Keywords: cementation, dental abutments, dental implants/ workflow, dental prosthesis, implant-supported

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Introduction

The shift towards digitization has been reshaping dentistry for decades, especially in fixed prosthodontics where technology-driven methods introduce new clinical and production protocols. The advancement of CAD/CAM methods is crucial to these developments, and is further enhanced by the extensive use of intraoral scanners (IOS), which have significantly transformed dental clinical practices in recent years [1, 2]. These technologies, when used together, allow for complete digital workflows. This workflow can be used to fabricate the restoration in a virtual setting without the need for a working model, owing to the CAD software and digital manufacturing technologies (CAM) [3].

Recent clinical research has indicated that model-less digital workflow is advantageous for implant treatment. Single crowns and multi-unit restoration workflows seemed to have shorter fabrication times at lower costs and better patient satisfaction than conventional workflows, whereas precision and esthetic outcomes were similar [4-11]. The recent trend is toward complete digital workflows involving monolithic restorations and prefabricated titanium base abutments, which are widely used stock components in implant

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prosthodontics, offering standardized anti-rotation features that serve as a reliable reference for crown seating in digital workflows [12].

While single-implant crowns may not require physical models, they are crucial for multiple-unit implant prostheses [13]. These models enable the assessment of marginal fit, occlusal contact, and proximal contact. Moreover, working models or dies help technicians properly contour, finish, and polish the restorations. Nowadays, additive manufacturing processes or three-dimensional (3D) printing are increasingly used in dentistry. This enables a fully digital workflow with a 3D printed working model, as an alternative to conventional casts. A systematic review [13] revealed that additively manufactured casts also provided consistent and precise data that fell within an acceptable clinical range (<120 microns) [14]. Recent studies have reported that 3D printed resin models have better 3D accuracy and lower absolute angular distortions than conventional stone and virtual models [15-20]. The deviation of the 3D printed model is related to angulated implants [21-24] and implants with increased inter-implant distance [25, 26] which affect the digital scan accuracy. However, it remains unclear whether a 3D printed working model used during the cementation step can improve crown seating accuracy and reduce intraoral adjustment time, compared to a model-less approach.

Previous studies on model-less digital workflow have focused on time, cost, patient satisfaction, and accuracy of restoration evaluated from marginal gap, occlusal contact, and proximal contact. Meanwhile, studies on workflows with printed models were laboratory studies evaluating 3D model accuracy, linear measurement, angular deviation, and displacement of the implant analog position. There is a lack of evidence comparing crown accuracy between model-less complete digital workflow and complete digital workflow with 3D printed models for implant-supported fixed dental prostheses with prefabricated titanium base abutments. This is especially relevant when the adjacent tooth is tipped into the space, which reduces implant space and affects the path of insertion, increasing the need for crown adjustment. Having a working model may therefore help reduce intraoral adjustment in this situation.

This in vitro study analyzed the accuracy of monolithic single-unit implant restoration on a prefabricated titanium-base abutment using a model-less complete digital workflow and complete digital workflow with an additively manufactured model in two different scenarios: the implant adjacent to normal dentition and the implant with the mesially tipped adjacent tooth. The outcomes were angular deviation of the final crown position after cementation and fixation in the reference model compared with the designated crown position in the virtual planning software, maximum interproximal adjustment of the crown, and adjustment time. The null hypothesis of the in vitro study was that both model-less digital workflows and complete digital workflows with additively manufactured models and dentition scenarios for single-unit monolithic implant crowns were not different.

Materials and Methods

1. Reference Model Preparation

Master models were created using a stereolithographic partial-arch implant model of the second mandibular premolar under different tooth conditions adjacent to the dental implant space. Model A represented a scenario with normal dentition, whereas Model B depicted the mesial shift of the first left mandibular molar, characterized by a 20-degree angular

modification of the lower left first molar (Figure 1). CAD software (3Shape Dental System, 3Shape, Copenhagen, Denmark) was used to create an angular modification of the lower left first molar. The teeth adjacent to the dental implant were designed as zirconia crowns to ensure that the crown would not be abraded by the final implant crown during the try-in process.

2. Screw-retained Crown Design and Fabrication

An intraoral scanner (TRIOS, 3Shape, Copenhagen, Denmark) was used to digitize the reference models for the crown and printed model fabrication. Each reference model was scanned 15 times and the scanned data were exported in stereolithography (STL) file format. The screw-retained crown was designed individually for each STL data in computer-aided design (CAD) software (Dental System 2019, 3Shape, Copenhagen, Denmark) using a Ti-base abutment with a height of 5.5 mm and a gingival height of 1 mm (Variobase®, Straumann AG, Basel, Switzerland). The crown design featured proximal contact adjustments through an auto-adjustment function with an interproximal contact parameter of -0.1 mm. Furthermore, a 1 × 2 mm bar was integrated into the crown to serve as a reference for angular analysis, as depicted in Figure 2.

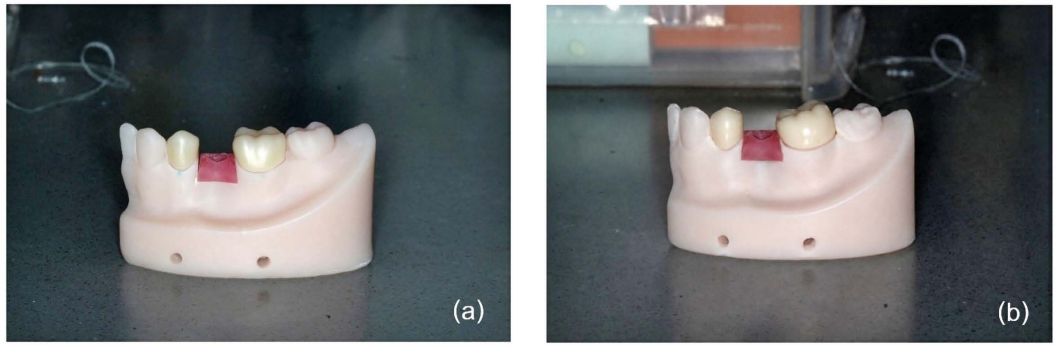


Figure 1 Model design representing normal dentition (a) and mesially tipped dentition (b) with the lower left first premolar and first molar prepared for monolithic crowns.

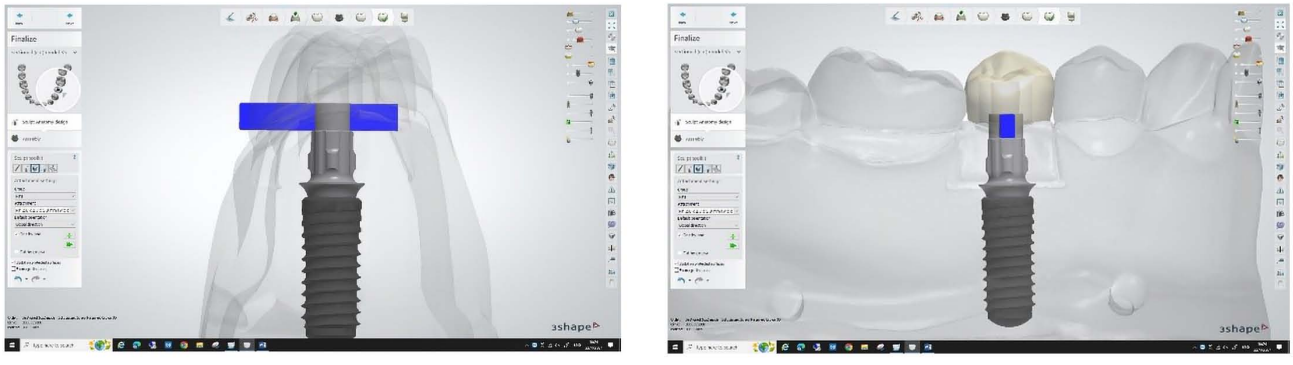


Figure 2 The designed bar integrated in the crown.

The printed model was constructed using Model CAD software (Model Builder, 3Shape, Copenhagen, Denmark), with the gingival portion separated from the model to facilitate the placement of the repositionable analog and crown. The designed STL files for both the crown and model were exported separately as computer-aided manufacturing (CAM) files for crown and model production and exported both crown and model together in visualization outputs, where the crown and model were in a coordinated position as the STL file for deviation analysis.

Monolithic zirconia crowns were milled using an Inlab MC X5 milling machine (Dentsply Sirona, Bensheim, Germany). The resin models were produced using a 3D printer (Form 3+ , Formlabs, USA), and an implant analog (repositionable analogs, Straumann AG, Basel, Switzerland) was inserted and fixed in the model using a eproxy resin. For each of reference model A and reference model B, a total of 30 crowns and 15 printed models were created, with 15 crowns assigned to the test group (model-less cementation) and 15 to the control group (cementation with printed model) in each reference model. Thus, 60 crowns were created in total. This setup resulted in 15 experimental pairs for each model. All the crowns were individually designed by the same operator. Thus, the experimental groups in this study were divided into four subgroups according to the workflow and dentition scenario: Test A (n=15) model-less complete digital workflow in reference model A; Control A (n=15) complete digital workflow with 3D printed model in reference model A; Test B (n = 15) model-less complete digital workflow in reference model B; and Control B (n=15) complete digital workflow with 3D printed model in reference model B.

The crowns underwent a try-in phase on prefabricated Ti-base abutments (Variobase®, Straumann AG, Basel, Switzerland) with internal surface adjustments made as necessary using an indicator marking spray (Occlude®, Pascal Inc., WA, USA) until the crown margin could be fully seated to the Ti-base abutment.

3. Crown-Abutment Cementation

For each reference model, the crowns were divided into two groups based on the cementation process: the test group (model-less cementation) and the control group (cementation with printed model).

In the Test group, each crown was scanned using an extraoral scanner (Ceramill Map 600, Amann Girrbach GmbH, Pforzheim, Germany) to obtain the STL file of the pre-adjustment crown for adjustment analysis. Subsequently, the crown was directly cemented onto the Ti-base abutment using resin cement (Multilink-N, Ivoclar Vivadent, Schaan, Liechtenstein), without any model for positional guidance. The crown was light-cured at the margin for 20 seconds and left for at least 8 minutes to complete the cement set. The cemented crown was tried-in on the reference model. The interproximal adjustment was performed utilizing 12 μm metallic articulating paper (Arti-Fol metallic Shimstock-film; Dr. Jean Bausch GmbH) and a zirconia adjustment kit (Luster Lab Kit HP, Meisinger, Hager & Meisinger GmbH, Düsseldorf, Germany) until the abutment could fully seat into the implant analog and the interproximal contact of the crown achieved a normal contact point when mint waxed floss could be passed with firm resistance. The adjusted crown was scanned for the post-adjustment crown STL file for adjustment analysis and the adjustment time was recorded.

Conversely, in the Control group, the crowns underwent a similar initial scanning process as the pre-adjustment crown STL file. The abutment was affixed to the repositionable analog with a hand-tight torque, and the crown was tried-in onto the abutment using a printed model. The adjusted crown was rescanned using an extraoral scanner,

and the adjustment duration was noted for the adjustment analysis. The crown was cemented onto the abutment with resin cement, using the printed model as a reference for positioning. The crown was tried-in on the reference model, and interproximal adjustment was performed until the abutment could be fully seated in the repositionable analog. The post-adjustment crown of the reference model was scanned for the adjustment analysis. The adjustment time of the crown in the control group was a combination of the adjustment time for both printed and reference models. The interproximal contact points were checked using dental floss.

1. Normal contact point occurs when it can pass through with a firm resistance.
2. Light contact point occurs when the floss can pass with slight resistance.
3. Loose contact point occurs when there is no contact point when the dental floss passes without any resistance.

After crown adjustment and scanning were completed, the dies of the first premolar and the first molar in the reference model were removed to ensure that there was no involvement of the proximal contact and the die holes were closed with the putty plug. The abutment-cemented crown was fixed to the reference model using hand-tight torque. The crown and reference model were scanned using an extraoral scanner for angular deviation analysis. (Figure 3)

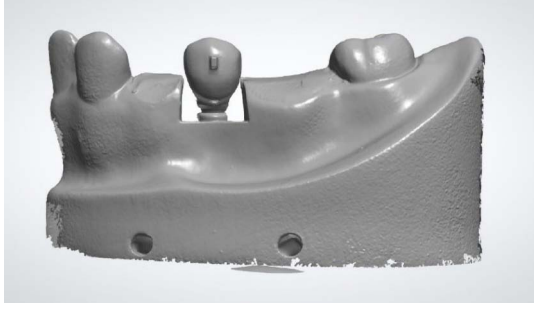


Figure 3 The STL file of the crown in the reference model for the angular deviation analysis.

4. Data Analysis

4.1 Adjustment time consumption

Adjustment time was recorded by a single operator using a digital timer, starting from the first try-in of the crown and stopping when firm floss resistance was achieved at the interproximal contact. Time spent on scanning and cementation was excluded. For the control group, total adjustment time included both the printed and reference model adjustments; for the test group, only the reference model adjustment was recorded.

4.2 Angular deviation

The STL files of the designed crown and reference model from the visualization output and the post-adjustment crown with the reference model were imported into Geomagic Control X software (3D Systems, Rock Hill, SC, USA) and superimposed together using the Best Fit Alignment function. Then, a vector was created on the middle of the top surface of the bar of the designed crown in the reference data and the post-adjustment cemented crown in the reference model according to the experimental groups. The angulation deviation between these crowns was determined by comparing the two vectors with an angular dimension function, and the angulation error was recorded (Figure 4).

4.3 Interproximal Adjustment Amount

The STL files of the pre- and post-adjustment crowns were imported into Geomagic Control X software and superimposed using the Best Fit Alignment function. 3D Compare task was performed separately for the mesial and distal segments. Deviation from superimposition was analyzed and displayed as a visual 3D color map. The maximum range of each experimental crown adjustment referring to the negative value of the minimum deviation was recorded.

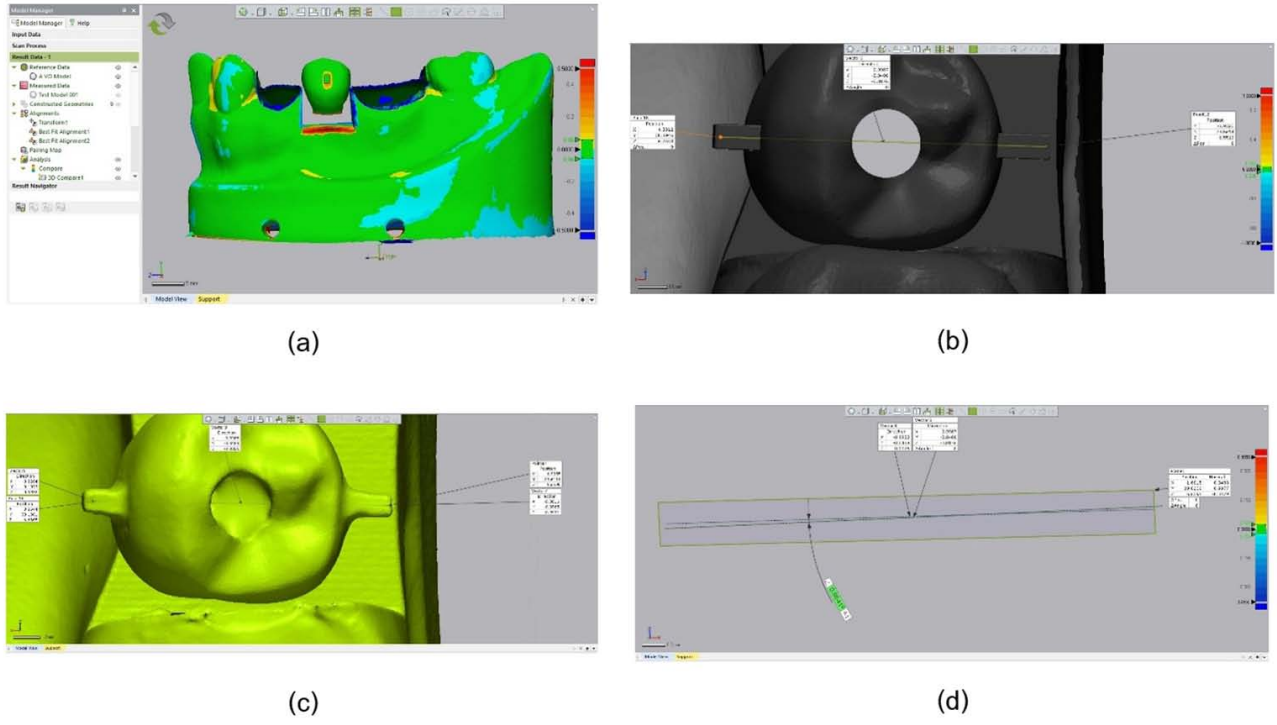


Figure 4 Angular deviation analysis: (a) The STL file of the post-adjustment crown with the reference model was superimposed with the designed crown and reference model from the visualization output using the Best Fit Alignment function, (b) The vector was created on the middle of the top surface of the bar of the pre-adjustment crown, (c) The vector was created on the middle of the top surface of the bar the post-adjustment crown, (d) The angulation deviation between the vector of the pre-adjustment crown and the vector of the post adjustment crown was calculated with Angular dimension function.

For the test group, only one adjustment was performed in the reference model, which compared the STL files of the pre-adjustment crown and post-adjustment of the reference model. Meanwhile, for the control group, the analysis was separated into the adjustment in the printed model comparing the STL files of the pre-adjustment and post-adjustment crowns of the printed model, and the adjustment in the reference model comparing the STL files between the post-adjustment crown of the printed model and post-adjustment of the reference model (Figure 5). Therefore, the adjustment for the control group was calculated as the sum of the adjustments made in the printed model and the adjustments made in the reference model.

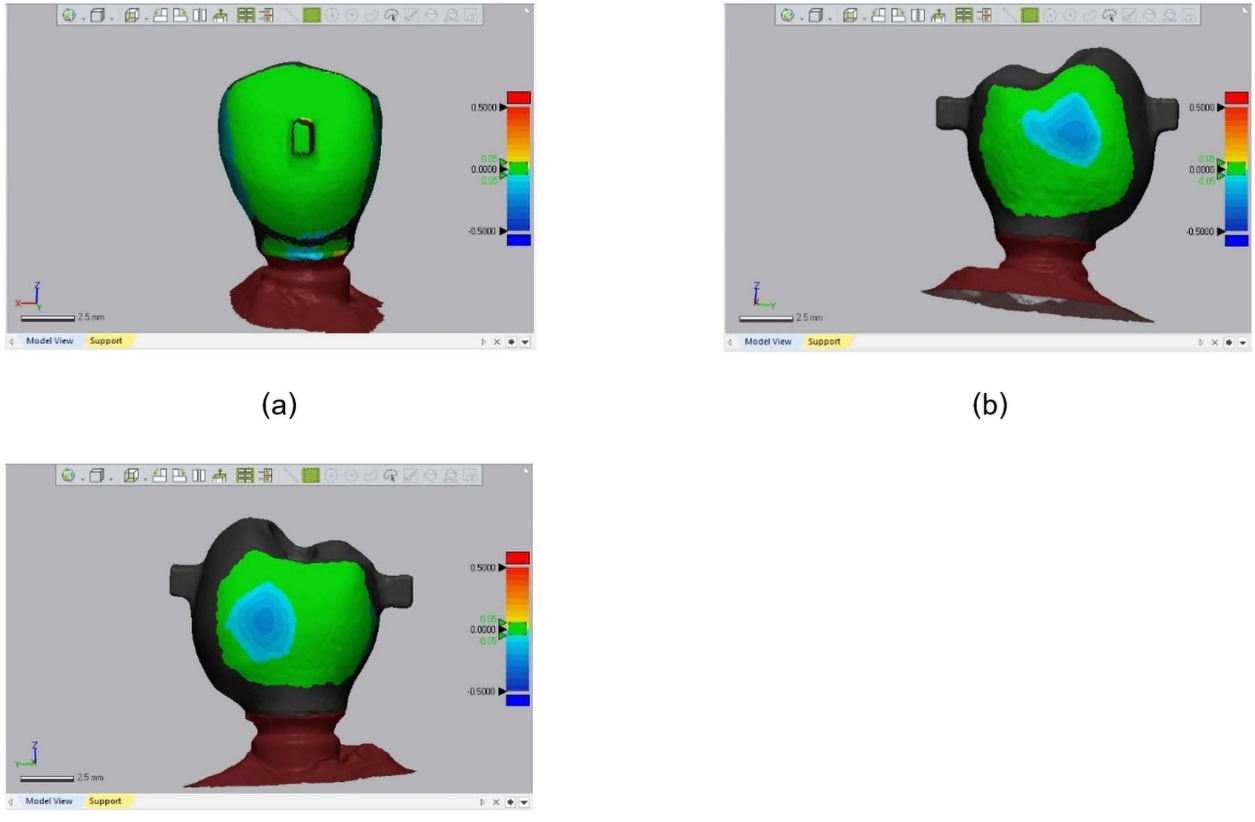


Figure 5 Interproximal Adjustment Amount analysis; (a) the pre- and post-adjustment STL files were superimposed by Best Fit Alignment function using the middle part of the crown as the reference area, (b) 3D compare task analyzed the interproximal adjustment amount on the mesial contact, (c) and the distal contact of the crown.

5. Statistical Analysis

The data obtained were statistically analyzed using SPSS statistic v28.0 (IBM SPSS Statistics for Windows Version 28.0. Armonk, NY IBM Corp.). Normality of data distribution was assessed using the Shapiro-Wilk test. Adjustment time and maximum proximal adjustment were normally distributed and analyzed using paired t-test. Angular deviation data were not normally distributed and were analyzed using the Wilcoxon signed-rank test to compare differences between the test and control groups.

Results

1. Maximum Interproximal Adjustment

In the normal dentition group, the amount of mesial contact adjustment in the test group was 147.54 ± 73.12 μm, while the control group had 172.40 ± 46.90 μm (p = 0.216). Distal contact adjustment was 135.49 ± 76.16 μm and 171.15 ± 53.80 μm for the test and control groups, respectively. Although the interproximal modifications were slightly lower in the test group, the difference was not statistically significant.

In mesially tipped dentition, the findings showed the maximum adjustment on the mesial

contact as 120.64 ± 65.72 μm and 147.26 ± 70.47 μm in the test and control groups, respectively and on the distal contact 135.52 ± 45.79 μm, and 150.57 ± 88.62 μm in the test and control groups, respectively. This showed a similar trend that the control group had greater adjustment compared to the test group. However, only mesial contact in the mesially tipped dentition showed statistically significant difference between the two groups (Table 1).

2. Crown adjustment time

The time taken for crown adjustment in the test and control groups was 1.50 ± 0.54 and 2.12 ± 0.59 minutes, respectively for the normal dentition and 1.43 ± 0.42 and 1.50 ± 0.54 minutes, respectively for the mesially tipped dentition. The adjustment time used in control group was higher than the test group, but the differences were not statistically significant (Table 2).

3. Angular deviation

The test and control groups showed different median angular deviations for both normal and mesially tipped dentitions. For normal dentition, the test group had a median angular deviation of 2.67 degrees, whereas the control group had a median deviation of 1.53 degrees. For mesially tipped dentition, the test group had a median angular deviation of 2.53 degrees, whereas the control group had a median deviation of 1.68 degrees. The test group had a higher median angular deviation than the control group for both types of dentitions. The Wilcoxon signed-rank test revealed a statistically significant difference between the two groups for both types of dentitions. ($p < 0.05$) (Table 3).

4. Number of light-contacted screw-retained crowns

In the control group, all crowns could fit in

Table 1 Maximum interproximal crown adjustments comparing model-less digital workflow and digital workflow with 3D printed model.

	Mean ± SD (μm)		*p*-value
	Test Group [Model-less]	Control Group [Printed model]	
Normal dentition			
- Mesial contact	147.54 ± 73.12	172.40 ± 46.90	0.216
- Distal contact	135.49 ± 76.16	171.15 ± 53.80	0.057
Mesially tipped dentition			
- Mesial contact	120.64 ± 65.72	147.26 ± 70.47	0.019*
- Distal contact	135.52 ± 45.79	150.57 ± 88.62	0.469

*$p < 0.05$

Table 2 Mean adjustment time comparing model-less digital workflow and digital workflow with 3D printed model.

	Mean ± SD		*p*-value
Mean adjustment time (min)	Test Group [Model-less]	Control Group [Printed model]	
Normal dentition	1.50 ± 0.54	2.12 ± 0.59	0.122
Mesially tipped dentition	1.43 ± 0.42	1.50 ± 0.54	0.272

Table 3 Angular deviation comparing model-less digital workflow and digital workflow with 3D printed model.

	Median (P_{25}, P_{75})		*p*-value
	Test Group [Model-less]	Control Group [Printed model]	
Normal dentition	2.67 (0.86, 7.38)	1.53 (0.60, 2.05)	0.020*
Mesially tipped dentition	2.53 (1.51, 4.63)	1.68 (1.07, 3.02)	0.023*

*$p < 0.05$

Table 4 Screw-retained crowns which had light contact comparing model-less digital workflow and digital workflow with 3D printed model.

	Test Group [Model-less]	Control Group [Printed model]
Normal dentition		
- Mesial contact	0	1
- Distal contact	0	0
Mesially tipped dentition		
- Mesial contact	0	3
- Distal contact	0	4

the reference model without additional adjustment. One screw-retained crown had light contact in the control group for normal dentition. While for mesially tipped dentition, seven crowns in the control group had light contact-three crowns on mesial contact and four crowns on distal contact. However, no loose contact crown was found. Normal contacts were found in all test groups (Table 4).

Discussion

The purpose of this in vitro study was to compare the crown accuracy of screw-retained single-implant crowns on prefabricated abutments between a model-less complete digital workflow and a complete digital workflow with an additively manufactured model in terms of angular deviation and interproximal crown adjustment. The null hypothesis was partially confirmed for the adjustment time and maximum adjustment amount, whereas it was rejected for the angular deviation.

This study evaluated the angular deviation resulting from the rotational error from the cementation in the complete digital workflow between the model-less method and the 3D printed model approach. Comparing the results to those of previous studies has to be done carefully because of the differences in the experimental objectives and methodologies. Previous studies [10, 11, 27, 28] have employed quantitative methods to evaluate the necessary adjustments for screw-retained crowns, using software to superimpose the resultant STL data onto the planned STL data for accuracy analysis. One of our objectives was to evaluate three-dimensional alterations in crown adjustment using a similar approach. In the studies by Zhang *et al.* in 2019 [11] and Ren's 2021 study [10], the chairside model-less digital workflow was found to be more

precise and required fewer adjustments than a hybrid workflow involving conventional impressions. In a study by Zhang *et al*., the maximum adjustment amount for occlusal contact was reported as 237 ± 112 μm in the model-less group compared to 485 ± 195 μm in the hybrid group. Additionally, the clinical adjustment time consumption was 8.4 ± 3.5 minutes and 12.3 ± 3.7 minutes, respectively. Ren's study in 2021 also found better precision with the complete digital workflow over the conventional workflow, with maximum crown adjustments on the occlusal surface measuring 212.7 ± 150.5 μm and 330.7 ± 192.5 μm, respectively. The maximum mesial adjustments were 33.0 ± 96.2 μm and 3.7 ± 66.7 μm, and the maximum distal adjustment was 48.6 ± 70.5 μm and 11.4 ± 106.7 μm, respectively. Although interproximal modifications were slightly greater in the complete digital workflow, the difference was not statistically significant. Moreover, the complete digital workflow required less time for crown adjustment (6.45 ± 2.21 minutes) compared to the conventional workflow (13.15 ± 3.84 minutes). In line with the findings of the present study, the model-less workflow required less time than the method with the implant cast, while the adjustment effort was not different. In 2016, Joda [29] found that the model-less workflow had a higher accuracy of the single implant crown and better time efficiency over the workflow with the milled model from the intraoral scan, with a total adjustment time of 0 minutes and 3.3 minutes, respectively. Graf *et al.* [30] investigated the CAD/CAM Enamic implant crown on the titanium-base abutment in the digital model-less workflow and the approach with the printed model in terms of the occlusal and interproximal adjustment. They found that the clinical adjustment time of the model-less workflow (2.44 min) was longer than that of the printed model (1.46 min). However, when the laboratory adjustment time was included, the total adjustment time of the model-less group was shorter than that of the printed model group (4.25 min). The quantity of adjustment also followed this trend: the root mean square of the clinical adjustment of the model-less group (45 ± 7 μm) was greater than that of the printed model group (34 ± 6 μm), while the total adjustment for the printed model group was greater (61 ± 11 μm). The authors concluded that double adjustment using 3D printed model for laboratory adjustment, preliminary to the clinical adjustment, could cause an extensive but inessential modification. These results were in accordance with the findings of the present study, although there was no statistically significant difference, the time effort and the maximum amount of adjustment for the model-less group were slightly lower than the 3D printed model group. This trend was consistent across both normal and mesially tipped dentition, with the maximum adjustment of the mesial contact in the mesially tipped dentition being the only parameter that showed a statistically significant difference.

Graf *et al.* [30]. cemented the crown to the abutment freehand and mentioned the potential rotational discrepancy between the internal crown surface and the titanium-base abutment that contributed to occlusal and interproximal inaccuracies. The present study evaluated the effect of the printed model on the rotational deviation of the model-less approach during cementation. The use of the printed model during the cementation procedure had a lower rotational discrepancy than model-less cementation, although the difference was not statistically significant. To standardize crown fabrication and internal adjustment, the experiments were performed by one operator, and internal adjustment was performed using an articulation marking spray. Specimen preparation was strictly conducted according to the manufacturer's specifications in compliance with the clinical

workflow.

While the accuracy of 3D printed models and implant analog positions is critical for creating precise prostheses, clinical validation of 3D-printed model accuracy has been limited to in vitro studies. Despite this limitation, various studies [15-20] have reported different accuracies of 3D-printed models using diverse technologies and analytical methods, with reported deviations ranging from 21.57 to 108.09 μm, all of which fall within clinically acceptable ranges. In this study, a 3D-printed model was produced using stereolithography (SLA) 3D printing technology, with reported accuracies of 59 μm by Papaspyridakos (2020) [18], 88 μm by Kim (2018) [31], and 65.7 μm by Abdeen (2022) [15]. No additional corrections were required for the crowns on the reference model in both normal and mesially tipped dentitions, following adjustments made to the 3D printed model.

When the path of insertion for the implant crown is not parallel to the adjacent teeth, often due to the tipping of these teeth, it leads to altered proximal contact positions which can complicate restorative adjustments. The dentist had the option to adjust the mesial or distal side based on the resistance of the dental floss during the try-in process when encountering the last molar tipping. However, while there was no statistically significant difference in adjustment amount and time, the study found that this molar tipping effect could result in excessive, unnecessary crown adjustment, as evidenced by the larger number of crowns with light proximal contact compared to implant crowns in regular dentition. Adjusting the proximal contact on tipping adjacent teeth prior to the digital scan may be necessary to improve proper contact between the implant restoration and adjacent teeth.

Light contact was observed, with one contact in the normal dentition and seven contacts in the mesially tipped dentition. Although these contacts were not loose, they posed a risk of clinical food impaction, necessitating crown replacement. Despite greater angular deviation in the model-less group, the printed model group demonstrated more light contacts. The maximum adjustment of crowns in the printed model group also exceeded that of the model-less group. This discrepancy may be attributed to accumulated errors in the 3D-printed model arising from polymerization, implant analog deviation, and crown-abutment cementation. Another factor is the use of different try-in and cementation methods. In the test group, in which the crown was cemented onto the abutment before fitting it onto the master model, the CrossFit connection of the abutment helped establish the path of insertion, which enhanced the accuracy and efficiency of crown adjustments. This method typically requires precise adjustments. In contrast, in the control group, after fixing the abutment onto the analog, the crown could rotate slightly during the try-in process, leading to overadjustment during interproximal checking with the metallic articulating paper.

The evaluation of crown accuracy in previous studies has often included occlusal adjustment as a common parameter. Angular deviation may have an impact on occlusal adjustment because the position of contact on the occlusal surface could be influenced by the rotational offset and the distance from the center of rotation. However, it is important to note that the occlusal adjustment analysis was not conducted in the present study.

Despite these findings, several limitations of this study remain to be acknowledged. This study focused on a specific brand of dental implant system and 3D printing technology. Design variations of titanium-based abutments can affect their anti-rotational effectiveness. Similarly, various implant analog designs and arrays of 3D printer

technologies can yield different results. Future studies should expand this analysis to gain a more comprehensive understanding. Moreover, the current investigation examined a single-implant scenario in an in vitro setup, and all adjustments were performed by a single operator, which may limit the applicability of the results to other clinical settings where greater variability and complexity are encountered.

Conclusions

Within the limits of this in vitro study, model-less complete digital workflow for single-unit screw-retained implant-supported restorations had greater angular deviation compared to the complete digital workflow with the additively manufactured model. The clinical outcome in terms of adjustment amount and time used were not different. The complete digital workflow with the 3D-printed model increased the possibility of having light contact of the implant crown. The tipping of the tooth adjacent to the dental implant could affect the path of insertion, causing unnecessary overadjustment, but had no influence on the model-less complete digital workflow. However, based on the results, the model-less cementation technique was comparable to the approach with the printed model for the single implant crown in a complete digital workflow.

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Ethical approval

Not applicable. This study involved the analysis of commercially available products and did not include human or animal subjects.

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