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Original Article

Accuracy of 3D Printed Implant-Supported Provisional Restorations Fabricated Prior to Fully Guided Computer- Assisted Implant Insertion an in Vitro Study

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Abstract

Aim of the study: This study aimed to evaluate the accuracy of vertical and proximal contacts in provisional 3D-printed, implant-supported restorations, following a complete digital workflow, once they were attached to implants.

Methods: In this study, a fully dentate maxillary model was modified twice to simulate partially edentulous arches, creating two reference models (R1 & R2). The first model had the right central incisor, and first molar removed (master model S), while the second had the left first and second premolars and first molar removed (master model F). These modified models were scanned, virtually designed, and 3D printed five times each. Cone-beam computed tomography and BlueSkyBio software were used for implant planning, surgical guide design, and provisional restoration creation. Dummy implants were inserted into the printed models using the surgical guides, and temporary restorations were attached. The models were then scanned and superimposed with the preplanned designs to measure vertical and proximal errors using MEDIT LINK and EXOCAD software, respectively.

Results: The study revealed a statistically significant vertical error between the preplanned and actual 3D-printed provisional restorations for the upper central incisor and fixed partial denture (FPD) (P= 0.035). In terms of proximal contact errors, the first molar restorations had the lowest frequency of errors compared to the upper central incisor and FPD.

Conclusions: The study found that most prostheses had vertical and proximal contact errors. Therefore, clinicians using a complete digital workflow should anticipate the need for adjustments to the prosthesis after implant insertion.

Keywords: 3D Printing, Provisional Restorations, Digital implant planning, CAD/CAM

I. INTRODUCTION:

Computer-aided design/computer-aided manufacturing, or CAD/CAM technology has been of a great use in the dental field. The CAD which incorporates the data acquisition, the software would be used for planning that reduce the chairside time of impression taking and designing and ensures that all the data records would be saved on the computer (**Bilgin et al., 2016)**.

The CAM which is the computer aided manufacturer which utilizes either the printing or milling technology. The printing or the additive technology would have several advantages; it is faster, more economic, and would be used to produce large restorations as partial framework or maxillofacial prosthesis (**Abdullah et al., 2018)**.

CAD/CAM technology have several uses in dentistry, it has also been used to fabricate surgical guides for implants installation. Fully guided stents would reduce the post operative complications of the conventional implant installation surgery and furthermore, the surgical guide would be used to fabricate provisional restoration, that could be used at the day of implant installation. Provisional restorations would improve patient satisfaction, when used with immediate implant insertion it would improve the soft tissue contour (**Davidowitz and Kotick 2011)**.

The accuracy of the surgical guide fabricated would be of great importance for fabrication of provisional restorations. Various factors can impact accuracy in imaging, ranging from data transformation into a guide to incorrect positioning during surgery. Among the various types of errors are those that arise during image acquisition and processing, surgical template production, template positioning and movement during drilling, and mechanical error resulting from surgical instrument tolerance. Despite being uncommon, all mistakes have the potential to compound (**Vercruyssen et al., 2014)**.

Various studies on the parameters influencing the accuracy of guided surgery have been conducted in the past several years, **(Behneke et al., 2012)** and systematic reviews (**Tahmaseb et al., 2014; Raico et al., 2017)** have evaluated these studies carefully, concentrating on computer-guided surgery's accuracy, clinical benefits, survival rates, complications, and the impact of utilizing various types of guides. However, not enough data were provided concerning clinical trials regarding the accuracy and influence of relevant clinical factors except for tissue of support (**Raico et al., 2017).** Since there are now no accepted guidelines for evaluating deviation, there is a lack of consistency in the results, making it difficult to use deviation as a useful indicator of how accurate guided surgery is.

The aim of this in-vitro study was to evaluate vertical and proximal contact accuracy of provisional 3D printed implant-supported restorations after being attached to implants using a complete digital workflow.

Null hypothesis: Implant supported 3D printed provisional restorations will not be differed from the virtual preplanning design in terms of accuracy.

II. MATERIALS AND METHODS:

Sample Size Calculation:

In a previous study the response within each subject group was normally distributed with standard deviation 2.06. If the true difference based on expert opinion is 1, we were needed to study 5 experimental subjects

and 5 intervention subjects to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) 0.8. The Type I error probability associated with this test of this null hypothesis is 0.05 (**Peroz et al., 2022)**.

Scanning of the models:

A fully dentate training model (El Banna model, Egypt) was used in this in vitro study (reference model) which was modified two times to mimic partially edentulous arches.

The model was modified two times separately to mimic partially edentulous arches. The first time modified by removal of the right central incisor and right first molar (for single tooth implant crowns, master model S). The second modification was done by removal of the left first and second premolars, as well as first molar (for implant supported FPD, master model F) then each modification was scanned by extra oral scanner (Extra oral scanner MEDIT T500, MEDIT corp., republic of Korea) to get the virtual design of the modification. The two modified models were printed to get the surgical models using 3D printer (Formlab 3D printer (form 3/3B) USA). Formlab3D printer using a liquid resin (Temporary CB resin, USA) which hardened into plastic to produce five printed models of each design (the one with missing right central incisor and right first molar, and the other with missing left first and second premolar, as well as first molar. After that, the printed models were washed for 10 minutes in isopropyl alcohol by Form Wash L unite (Form Wash L unite (formlabs, USA) to perfectly clean the models then raised and dried by air, finally cured in the Form Cure L curing unite (Form Cure L unite (formlabs, USA) for 10 minutes according to the manufacturer instructions. **Figure 1**

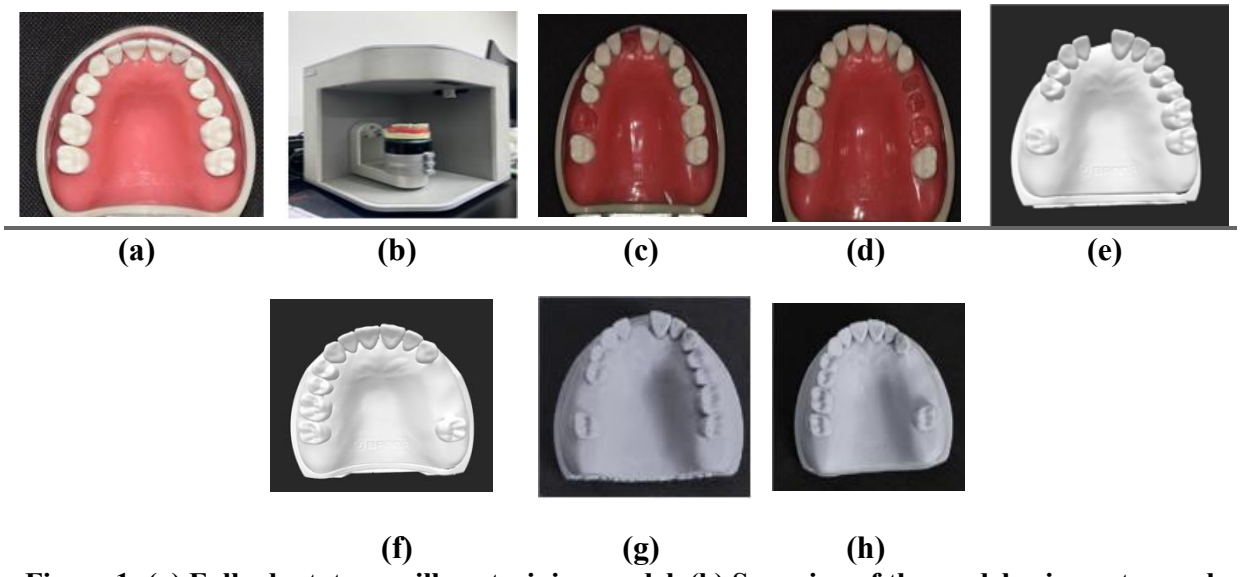

Figure 1: (a) Fully dentate maxillary training model, (b) Scanning of the model using extra oral Medit scanner T500, Occlusal view of master (c) model S, (d) model F, virtual master (e) model S, (f) model F, (g) Printed model with missing central and first molar, (h)Printed model with missing left 1st, 2nd premolar, and 1st molar.

Implant planning and surgical guide fabrication:

Each printed model was captured by CBCT x-ray machine (Planmeca, Finland) to get a DICOM file for each. By the aid of DICOM file, It was intended to place four implants and

restored by a single anterior crown (S-Ant), a single posterior crown (S-Post) and 3-unit FPD supported by 2 dummy implants (Dummy implants J Dental care Italy) at the sites of first premolar and first molar. The DICOM images were loaded into a commercial implant planning program together with the altered partially edentulous models and the virtual intact reference model. (BlueSky plan software, USA) and merged. The surfaces on which the surgical guides were designed were provided by the virtual modified models, and the optimal implant position in respect to the intended prostheses was established using intact models. Screw-retained prostheses were intended to be installed on all of the implants.

According to the implant planning, two surgical guides were designed on the partially edentulous virtual models for the placement of the four implants. One for placement of two single implants which received single tooth implant crowns, and the other for placement of two implants which received implant supported FPD. Then surgical guides were printed using surgical guide Draft Resin (Draft Resin (formlabs, USA) for each model by 3D printer (Formlab 3D printer). **Figure 2**

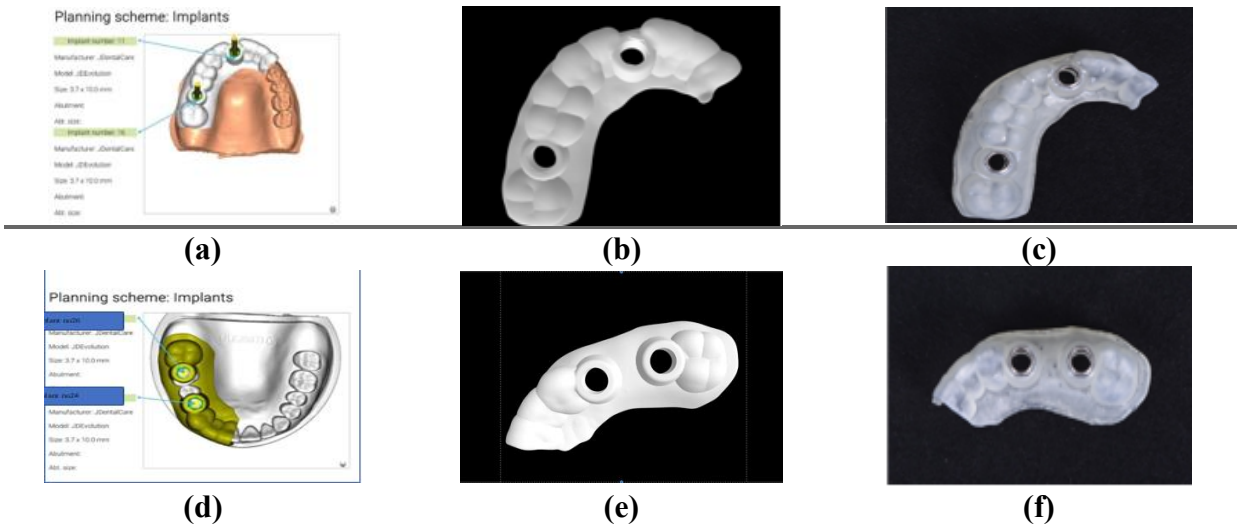

Figure 2: (a) planning scheme showing the position of the implants in central incisor and first molar sites with the surgical guide, (b) virtual design of the surgical guide of the central incisor and 1st molar, (c) 3D printed surgical guide with the metal tubes for placement of the single implants (central incisor and molar) (d) Planning scheme showing f1st premolar and 1st molar positions implants with the surgical guide, (e) virtual design of the surgical guide of 1st premolar and 1st molar, (f) 3D printed surgical guide with the metal tubes for placement of the single implants (upper left 1st premolar and 1st molar).

Designing and fabrication of provisional restorations:

The designing of the provisional restorations according to the virtual planning of the implants on the virtual partially edentulous models (S and F), provisional restorations for the single crowns and FPD were virtually designed by (Bluesky plan software,USA).

The provisional restorations were printed from a liquid resin material (Temporary CB resin, USA), using SLA 3D printing machine, after that the printed restorations were washed for 10 minutes in isopropyl alcohol to perfectly clean restorations, then raised them

to air dry once finished, then cured for 10 minutes according to the manufacturer instructions, Ti base (Ti base , J Dental, Italy) was first screwed to the implant analog and prepared for cementing by sandblasting to roughen the surface using micro etcher with 50 microns white aluminum oxide (Aluminium oxide powder, Zest Dental Solution, Germany), small cotton pellet was used to block the screw channel hole in the Ti base before sandblasting to protect the screw from sand particles, then a metal primer bond (Monobond plus, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the Ti base surface and left to dry for 60 seconds. Then, the provisional crown was lightly filled with the composite resin cement (Variolink, Ivoclar Vivadent, Schaan, Liechtenstein) and seated on the Ti base, excess cement was removed and cotton pellet inside the channel was removed with the excess cement entered the channel.

Drilling and dummy implant installation:

The printed surgical guides were checked to be seated accurately on each of the printed surgical models (S&F). Drilling of the implant osteotomy was completed in compliance with the manufacturer's guidelines. using the sequence of the drills till the final drill, starting with the initial drill followed by (2mm, 2.4mm, 2.8mm, 3.2mm, and finally 3.6mm) as the implant size was 3.7mm*10mm with the aid of the surgical guide kit (Surgical guided kit, J Dental care, Italy). Dummy implants size 3,7 * 10 (J dental care) were installed in the printed surgical model by the fully guided kit with the aid of the surgical guides. This step was repeated in the five printed models of each design. **Figure 3**

(a) **(b)** **(c)**

Figure 3: Surgical guide seated on (a) model (S), (b) model (F), (c) Drilling into 3D printed surgical model through surgical guide using surgical guided kit.

Screwing of provisional restorations

The provisional restorations were screwed to the inserted implants in the surgical models first by hand then by torque wrench at 20 Ncm as the manufacturer recommended, any interference with seating of the restoration was removed from the model around implant platform, then the models were scanned using lab scanner (Extra oral scanner MEDIT T500, MEDIT corp., republic of Korea) and superimposed with the preplanned designs to measure the vertical error using MEDIT LINK software, the proximal error was measured visually using EXOCADE software.

Vertical error measurement: three cross sectional buccolingual cuts were taken for every tooth and three points were detected on each cut (Buccal point on mesio-bucal cusp tip, mesio-palatal cusp tip, and in-between) for the molar. That makes nine measurements for each tooth. For the central the same was done, three cuts (mesial, middle, distal) labio-palatal with three points on each cut (labial, incisal edge, palatal). Two comparable spots were chosen on the interim restoration on master

virtual models and surgical models and the direction also determined if (supra-occlusal or infra-occlusal). For the vertical measurement of the FPD, three sectional buccopalatal cuts were taken for each tooth the 1st premolar, 2nd premolar, and 1st molar, for each cut three points were detected and for each point two similar points were selected on the provisional restoration on master virtual models and surgical model and the direction also determined if (supra-occlusal or infra-occlusal). **Figures (4-8)**

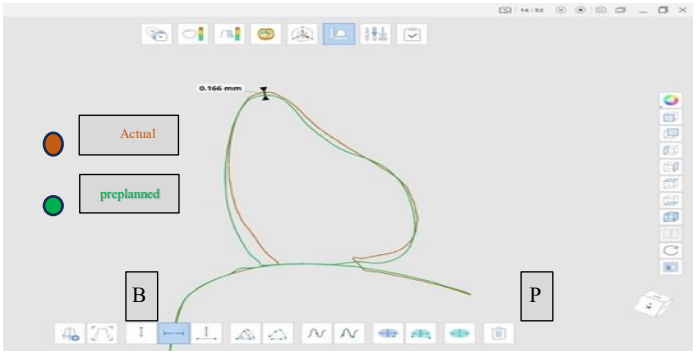

Figure (4**):** Labio-palatal section showing the vertical error measurements after superimposition of the surgical model with the preplanned model for the central incisor.

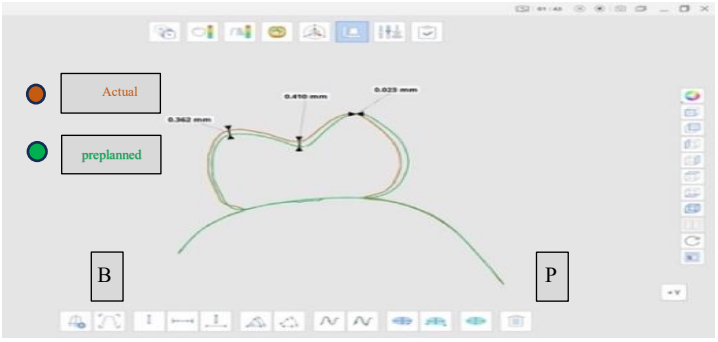

Figure (5**):** Sectional cut buccopalatally of the 1st molar showing the vertical error after superimposition of the surgical model with the preplanned model of the single molar.

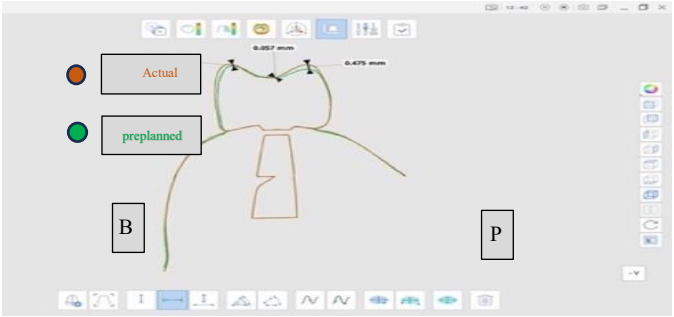

Figure (6): Sectional cut buccopalatally of the 1st premolar showing the vertical error after superimposition of the surgical model with the preplanned model of the FPD.

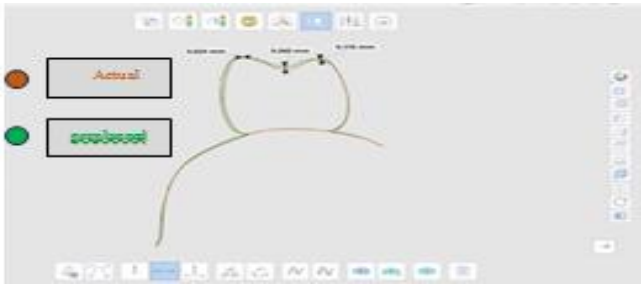

Figure (7**):** Sectional cut buccopalatally of the 2nd premolar showing the vertical error after superimposition of the surgical model with the preplanned model of the FPD.

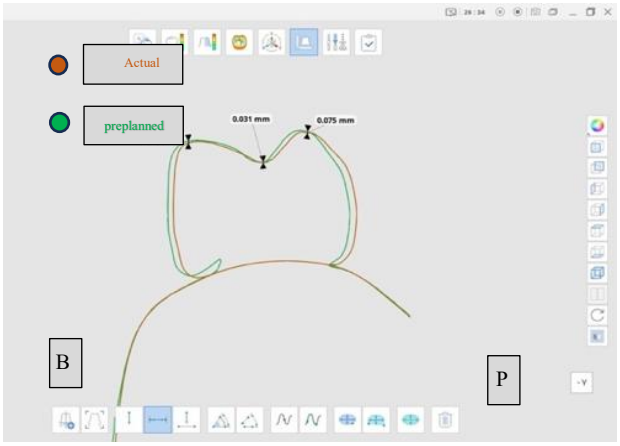

Figure (8**):** Sectional cut buccopalatally of the 1st molar showing the vertical error after superimposition of the surgical model with the preplanned model of the FPD.

proximal contact evaluation:

Proximal contact error was visually evaluated with the aid of Exocad software at the mesial and distal proximal surfaces. When the neighbouring tooth and the provisional prosthesis' proximal surfaces did not make contact, opening of contacts was identified and recorded as a positive error. A negative error was reported when there was overlap of the proximal surfaces, which indicates tight contact.

Statistical analysis:

The statistical study was carried out using Microsoft Excel 2016, Graph Pad Prism, and SPSS 20. The Shapiro-Wilk and Kolmogorov Normality Tests were used to examine the normality of the quantitative data, which were then displayed as means and standard deviations (SD). One Way ANOVA to compare between different groups, followed by Tukey`s Post Hoc test for multiple comparisons. Comparison between actual and planned was performed by using Paired t test. Exploration of the given data was performed using Shapiro-Wilk test and KolmogorovSmirnov test for normality. It was revealed that the significant level (P-value) was shown to be insignificant as P-value > 0.05, which indicated that data originated from normal distribution (parametric data) resembling normal Bell curve in all groups.

III. RESULTS:

There was a statistically significant difference between the planned and the actual 3D printed provisional restoration of the upper central incisor and FPD, the planned which was designed prior to implant installation and the actual which was the 3D printed provisional restoration seated after implant installation and superimposed to the actual (P= 0.035). No statistically significant variation was observed between the planned and the actual 3D printed provisional restoration of the upper first molar (P=0.15). **Table 1**

Table 1: Minimum, maximum, mean and standard deviation of actual and planned measurements of upper central incisor provisional crowns, upper molar and FPD difference between them (accuracy) and comparison between them using Paired t test

	Actual	Planned	Difference					
			MD	SD	SEM	95% CI		P
						Lower	Upper	
Central incisor	9.77±0.01	9.75± 0.00	0.020	0.011	0.005	0.002	0.030	**0.035***
First Molar	6.39±0.02	6.37±0.00	0.018	0.022	0.012	-0.013	0.046	0.15
FPD	7.71±0.01	7.69±0.00	0.016	0.011	0.005	0.002	0.030	**0.035***

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*Significant p value <0.05, SEM: standard error mean, CI: confidence interval, FPD: fixed partial denture.

There was no statistically significant difference between the actual 3D printed provisional central incisor, first molar and the FPD which seated after implants installation (p=0.07). **Table 2**

Table 2: Mean difference and standard deviation of accuracy regarding upper central, upper six and bridge and comparison between them

	Mean ± SD	P
FDP	0.016±0.011	0.07
Central Incisor	0.020±0.011	
First Molar	0.018±0.022	

Proximal contact results are illusterated in table (3), and figure (8-10).

Table 3: proximal contacts error of central incisors, upper first molar and FPD

	Mesial contact	Distal contact
Central Incisor 1	Open contact +ve	Overlap -ve
Central Incisor 2	Normal	Normal
Central Incisor 3	Overlap -ve	Open contact +ve
Central Incisor 4	Overlap -ve	Normal
Central Incisor 5	Normal	Normal
	Upper first molar	
First molar 1	Normal	Normal
First Molar 2	Open contact +ve	Normal
First Molar 3	Normal	Normal
First Molar 4	Normal	Overlap -ve
First Molar 5	Normal	Normal

	FPD	
FPD 1	Slight open +ve	Overlap -ve
FPD 2	Normal	Normal
FPD 3	Overlap -ve	Open contact +ve
FPD 4	Normal	Normal
FPD 5	Normal	Normal

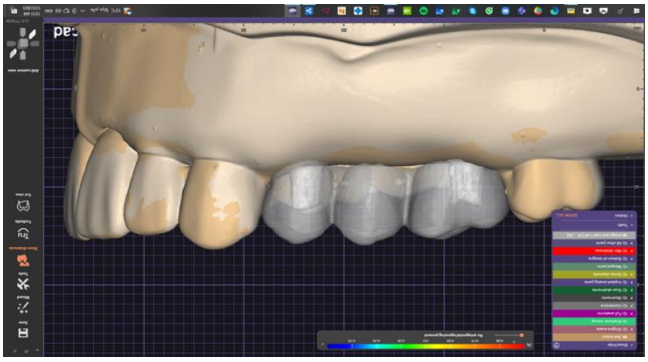

Figure (8): Illustrative sample showing proximal contact of the FPD restoration using Exocade software.

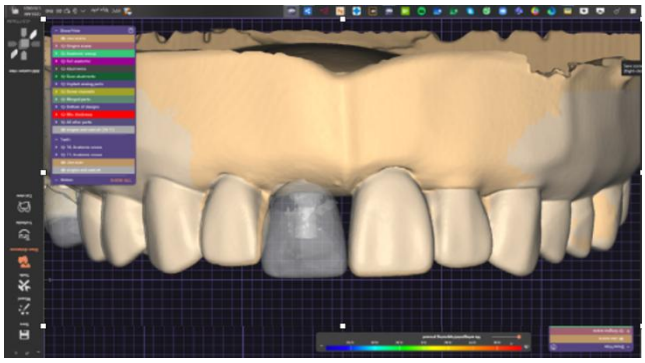

Figure (9): Illustrative sample showing proximal contact of the central incisor provisional restoration using Exocade software.

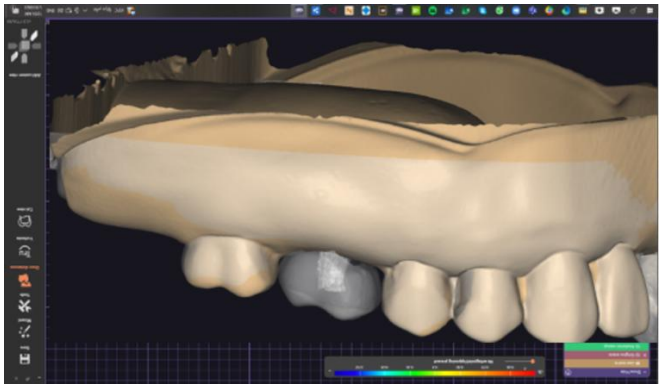

Figure (10): Illustrative sample showing proximal contact of the single molar using Exocade software.

IV. DISCUSSION:

3D printing technology was used in this study for printing of the casts, surgical guides, and provisional restorations because It is lighter, more durable, more wear resistant, less likely to damage most materials, and contains a larger percentage of digital data, to name a few of its benefits. Additionally, printing can be done with environmentally safe materials, further **Jeong et al. 2018** reported that 3D printed models proved to be more accurate when compared with milled models.

A provisional screw retained restorations was selected in the present study as screw retained provisional restorations would completely prevent the possibility of any excess temporary cement being present in the tissue around the implant, it also provides the advantage of being easily retrieved (**Priest 2006)**.

One benefit of employing a ti-base abutment as a temporary one is that, in contrast to prefabricated temporary abutments, these abutments are made with different gingival heights. Because ti-base abutments come in a range of gingival heights, they can be placed immediately after extraction and seated without requiring the removal of proximal crestal bone, which could lead to additional marginal bone loss during the healing process. Ti-base abutments are known to offer various advantages, one of which is the extraoral cementation of the prosthesis. These abutments are regarded a solid link between the implant and the crown and produce a positive esthetic outcome (**Yilmaz et al., 2015)**.

The provisional restorations were then carefully seated in the three tested situations (single anterior, single posterior, and the bridge) the surgical models were scanned by the laboratory scanner (Extra oral scanner MEDIT T500) to get virtual image of the surgical model with the attached provisional restoration. Dental extra oral laboratory scanners were used for obtaining STL files for the models. **Baumgarten 2009** reported that dental extra oral laboratory scanners have clinically acceptable accuracy. Extraoral scanners would provide several cameras and, more crucially, multi-axis motion movements, enabling more accurate full- and cross-arch scans. **Lee et al., 2017** declared that the digital dental models acquired using dental extra oral laboratory scanners proved to possess higher accuracy than intraoral scanners (**Asawa et al., 2015; Ayranciet al., 2015)**.

The virtual image of the surgical casts with the provisional restorations screwed to the implants (the cast with the single anterior and single posterior crown and the cast with the FPD), they were superimposed on the reference model by manually selecting common landmarks on each dataset as part of best-fit alignment approach to measure the vertical error and the proximal contact error using Medit Link software. One benefit of the Medit Link software is that it is available for free download, meaning there are no extra fees, unlike other soft wares like (Geomagic Control X (3D Systems) is not free and sold with a training course, because it is relatively complex and difficult to use.

O'Toole et al. 2019 evaluated various alignment strategies and discovered that best fit alignment produced much fewer alignment errors and more accurate measurements. Using of appropriate software to superimpose the 3D models produced with an intraoral device onto a reference model allows us to assess the actual trueness and precision.

The accuracy of provisional restoration would affect the seating accuracy especially in cases of immediate loading. The instant temporary restoration's seating accuracy which

is fabricated by complete digital workflow using fully guided computer stents would be affected by several factors such as the variation in the positioning of the implants that would prevent the seating of prostheses due to the need of adjustment with the proximal surfaces of the adjacent teeth. In the following in vitro study, all the 3D provisional restorations were seated with minute adjustments, so it is reasonable to believe that this clinical procedure of manufacturing immediate provisional using a complete digital workflow prior to implant installation is a reliable protocol (**Lanis et al., 2019; Leite et al., 2021; Schubert et al., 2019; Venezia et al., 2019)**.

In the present study, there was no statistically significant difference in the deviation between the actual and planned 3D printed provisional restorations in the molar but there was statistically significant difference in the central incisor and the FPD. **Abdou and Lau 2021** concluded that the vertical error did not differ significantly among the 3D milled provisional restorations.

The 3D segmentation of the various tissues and the visualization of CBCT before implant installation was reported to result in some divergence from the real anatomy, which could affect how the implant is installed virtually. During implant installation, the drills' and the guide sleeves' tolerance may result in an increase in the horizontal errors (**Koop et al., 2013)**.

In the following study, there was a higher statistically significant difference between the actual and planned 3D printed provisional restoration in the anterior central incisor of 0.02 mean difference , and the FPD with an anterior and posterior implant (FPD replacing 1st and 2nd premolar as well as 1st molar) of 0.01 mean difference (P=0.03), there was also deviations between the actual and the planned 3D provisional restoration in the first molar but this deviation was not significant of 0.01 mean difference.

An explanation of the present results would be that provisional restorations whether manufactured using the printed or milled technology would be subjected to proximal errors and the magnitude of this error would need to be adjusted to guarantee full seating. Proximal errors would mainly arise because of the placed implants' angulation and horizontal faults. that was reported to be in the range of 0.4–1.2 mm (**Derksen et al., 2019; Fang et al., 2019; Schneider et al., 2019; Younes et al., 2018)**. The anterior provisional 3D printed restoration showed a higher significant deviation mainly because the error will be highlighted much more when the drill travels farther through the guide resulting from incomplete seating of the guide and the tolerability within the sleeves (**Schneider et al., 2019)**. While for the posterior single implant would exhibit reduced height, more mesiodistal dimension, and shallower implant positioning, that would result in less horizontal errors that was the reason of the small deviations that wasn't of any significance.

This in vitro study has some limitations as the scanning steps may be harder intraorally also drilling for the implants differ from human bone. Additionally, the study not resembling the clinical situation as seating of the provisional restorations and rescanning may be affected by saliva and oral fluids. It would be recommended to carry out randomized clinical trials with larger sample size and different types of 3D printers and printing materials to precisely assess the accuracy of the implant-supported provisional restorations.

V. CONCLUSIONS:

Most of the prostheses were associated with errors vertically and at the proximal contacts,

therefore, the clinicians who plan to use the complete digital workflow should be prepared to adjust the prosthesis after implant insertion.

Financial support and sponsorship: Nil

Conflict of Interest: Nil

Ethics: This study protocol was approved by the ethical committee of the faculty of dentistry- Cairo university on: 20/12/2021, approval number 20/12/21

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