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- Seating accuracy of implant immediate provisional prostheses fabricated by digital workflow prior to implant placement by fully-guided static computer-assisted implant surgery: An in vitro study

Short running title: Accuracy of immediate prostheses on sCAIS-placed implants

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Author Contribution Statement:

Jaafar Abduo: Concept/Design, Funding sourcing, Data Collection, Data analysis/interpretation, Drafting article, Statistics, Approval of article

Douglas Lau: Design, Data interpretation, Critical revision and editing of article, Approval of article

Seating accuracy of implant immediate provisional prostheses fabricated by digital workflow prior to implant placement by fully-guided static computer-assisted implant surgery: An in vitro study

Abstract

Objectives: Evaluation of seating accuracy of implant immediate provisional prostheses fabricated prior to fully-guided static computer-assisted implant surgery (sCAIS).

Materials and Methods: Two maxillary training models were used to plan for single anterior (S-Ant) and single posterior (S-Post) implant prostheses, and a bridge (B) spanning from an anterior implant (B-Ant) to a posterior implant (B-Post). A commercial software was used to plan the implants location, design the surgical guides and design the provisional prostheses. The master models with the provisional prostheses were scanned to generate virtual master models. For each maxillary model, a total of 10 guides and 10 surgical models were produced. Following implant placements in each surgical model, the provisional prostheses were attached to the implants and were scanned to produce virtual surgical models. The virtual master and surgical models were superimposed to measure the vertical error, the proximal contact error and the proximal contact quality.

Results: The vertical error was greatest for the S-Post (0.41 mm), followed by B-Post (0.29 mm), B-Ant (0.26 mm), and S-Ant (0.21 mm). There was no significant difference in vertical errors among the prostheses. For the proximal contact, the S-Ant had significantly greater
error (0.45 mm - 0.46 mm) than S-Post (0.15 mm) and B (0.09 mm - 0.15 mm). A similar pattern was observed for proximal contact quality.

**Conclusions:** All prostheses were associated with errors vertically and at the proximal contacts. Therefore, the clinicians who plan to use this workflow should be prepared to adjust the prosthesis after implant insertion.

**Keywords:** milling; proximal contact; surgical guide; crown; bridge

**INTRODUCTION**

The recent developments in implant dentistry have improved the treatment workflow, surgical and restorative outcomes, and patient experience. From the surgical perspective, there is a considerable interest in reducing the surgical invasiveness and the healing time of oral implants. For example, controlled surgical procedure in the form of static computer-assisted implant surgery (sCAIS), where all the steps of bone drilling and implant placement are executed through a surgical guide, allows for more accurate implant placement, reduces the surgery duration, reduces the necessity of flap raising and minimizes post-surgical patient discomfort (Derksen, Wismeijer, Flugge, Hassan, & Tahmaseb, 2019; Fang, An, Jeong, & Choi, 2019; Vermeulen, 2017; Younes et al., 2018). Other surgical aspects that received lots of attention are the implant placement and loading protocols. Several studies indicated that immediate implant loading can be a viable option for selected cases to reduce the whole treatment duration (Hall et al., 2007; Khzam et al., 2015). On the other hand, major advancements in implant prosthesis design and fabrication had occurred with the incorporation of digital dentistry (Abduo & Lyons, 2013; Schubert, Beuer, Schweiger, & Guth, 2019). Currently, it is possible to digitally design a whole implant prosthesis and produce it via milling. This approach was proven to exhibit good accuracy in comparison to conventional methods of prosthesis fabrication (Abduo & Lyons, 2013).

Today, it is feasible to combine the sCAIS, with digital prosthesis fabrication in a single workflow to immediately load the implants. In this workflow, the prosthesis is fabricated according to the digital implant planning prior to the actual implant placement.
(Lanis, Alvarez Del Canto, Barriga, Polido, & Morton, 2019; Leite et al., 2020; Venezia, Torsello, Santomauro, Dibello, & Cavalcanti, 2019). Subsequently, at the time of implant surgery, the implants are placed via sCAIS, followed by immediate restoration by the premade digital prosthesis (Johansson, Friberg, & Nilson, 2009; Komiyama, Klinge, & Hultin, 2008). This workflow has the clear advantage of being a complete protocol that controls all the steps from implant placement until provisional prosthesis fitting, which increases the reliability of the treatment and reduces the clinical time. In addition, this workflow is more convenient to the patient, and allows for immediate function, aesthetic restoration, and soft tissue contouring. However, the amount of evidence on the practicality and applicability of this workflow is limited (Johansson et al., 2009; Komiyama et al., 2008). Specifically, it is not clear how accurate and applicable the digital workflow is in immediately restoring single implants or multiple implants.

Several studies have indicated that implants placed by sCAIS exhibit some deviation from the planned implant position in the range of 1 mm - 2 mm in the horizontal and the vertical dimensions (Derksen et al., 2019; Fang et al., 2019; Schneider et al., 2019; Vermeulen, 2017; Younes et al., 2018). Subsequently, the errors in implant placement and prosthesis fabrication will manifest in clinical inaccuracy in the form of a lack of connection between the implant and the prosthesis, alternation in prosthesis position, occlusal errors and proximal contact errors. Therefore, this laboratory study aimed to evaluate the seating accuracy of implant immediate provisional prostheses fabricated prior to fully-guided sCAIS implant placement. The evaluated variables were vertical errors, proximal contact errors and proximal contact quality. These variables were considered because they determine the position and clinical seating of a prosthesis. Three forms of prostheses were included: (1) single anterior (S-Ant), (2) single posterior (S-Post), and bridge (B) spanning from an anterior implant (B-Ant) to a posterior implant (B-Post). The null hypothesis is that the different forms of implant immediate provisional prostheses will exhibit a similar level of seating accuracy.

MATERIALS AND METHODS

Implant planning and surgical guides fabrication

Ethics approval was not required for this laboratory study. Two maxillary training models (Nissin Dental Products Inc., Kyoto, Japan) were used to simulate 2 partially edentulous arches. One model was modified by removing the first incisor and first molar teeth. The other model was modified by removing the canine, first premolar, second premolar and first molar of the same quadrant. After removal of the teeth, the sockets of the teeth were sealed with
wax and the soft tissue silicone formers were trimmed around the sockets. Further, the ridge contour was modified to simulate a healed ridge of 6.5 mm at the anterior region and 8.0 mm at the posterior region. The modified models were scanned with a surface scanner (Identica T300, Medit Identica, DT Technologies, Davenport, IA) to generate virtual models of partially edentulous maxillary arches (Figure 1a). In addition, the modified models were duplicated in resin casts mixed with barium sulfate for scanning by a CBCT unit. The generated DICOM images outlined the available bone volume for the placement of implants. Four implants were planned to be inserted and restored by a single anterior crown (S-Ant), a single posterior crown (S-Post) and 4-unit bridge (B) supported by 1 anterior implant (B-Ant) and 1 posterior implant (B-Post). An intact model with a full set of teeth was scanned by the surface scanner to generate a virtual model to plan for ideal implant positions and design the implant provisional prostheses accordingly.

The DICOM images along with the virtual intact model and modified partially edentulous models were imported to a commercial implant planning software package (coDiagnostiX, Dental Wings, Montreal, Canada). All the images were merged together in which the DICOM images outlined the bone contour, the virtual modified models provided the surfaces on which the surgical guides were designed, and the intact model determined the ideal implant placement in relation to the planned prostheses. Bone level Straumann implants (Straumann AG, Basel, Switzerland) with a 4.1 mm diameter and 10 mm length were planned to be inserted in the location of 1st incisor, canine and 1st molars of the edentulous areas. For the anterior region, the implants were planned to be inserted 2 mm sub-crestal, and for the posterior region, the implants were planned to be placed 1 mm sub-crestal. All the implants were planned to receive screw-retained prostheses.

According to the planned implants, surgical guides for fully-guided sCAIS implant placement were designed to fit on the partially edentulous models. The 2 surgical guide designs covered all the remaining teeth and had windows to confirm the seating (Figure 1b). A total of 10 guides were produced for each model by a 5-axis milling unit (DWX-51D, Roland, Sydney, NSW, Australia) from a commercial milling centre. Fully-guided metal sleeves of 5 mm diameter (Straumann AG, Basel, Switzerland) were fitted in each guide at the locations of the implants. These sleeves were provided by the implant manufacturer to accommodate for all the drills, tapping tools and the implants. None of the guides were modified after receiving them from the milling centre.

**Provisional prostheses fabrication**

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According to the virtual location of the planned implants, the screw-retained immediate provisional prostheses were virtually designed by coDiagnostix software (Figure 1c). The prostheses were planned to be attached to prefabricated abutments, and were fabricated by a milling system (DWX-51D, Roland, Sydney, NSW, Australia). All of them were produced from composite resin and attached on prefabricated titanium abutments by composite resin cement (Variolink, Ivoclar Vivadent, Schaan, Liechtenstein) (Figure 2). Stock components (Straumann Variobase) were chosen from the same manufacturer to ensure the most ideal adaptation between the prostheses and the implant platform. Engaging abutments were chosen for the single crowns, and non-engaging abutments were selected for the bridge. The prostheses were provided by the manufacturer attached to printed master models with implant replicas representing the ideal implants and prostheses positions. The master models with the prostheses were scanned with the laboratory scanner to generate a virtual master model representing the benchmark prostheses positions.

**Implant placement**

According to the virtual partially edentulous casts, physical surgical models were produced by 3D printing (ProJet, 3510 DP Pro, 3D systems, Rock Hill, SC, USA). A total of 10 surgical models were produced for each edentulous situation. For each guide and surgical model, a different clinician inserted 1 implant per site (S-Ant, S-Post, B-Ant and B-Post). The clinicians were introduced to the fully-guided surgical protocol provided by the commercial implant company. Once the guides were fitted on the surgical models, all the drilling steps and implant placement took place without removing the guide. The sequence provided by coDiagnostix software was followed through the implant placement. This involved sequential preparation of the osteotomy and the use of different drill handles. With the aid of stop key engaging the implant transfer mount, the implant was inserted through the guide at the determined height. The final implant vertical position was achieved by the physical stop provided by the stop key. As per manufacturer’s recommendation, the final implant rotational position was reached by ensuring the dimples of the implant transfer mount were placed in the middle of the buccal aspect of the edentulous area. The location of the dimples on the transfer corresponded to the location of the protrusions of the internal connection that was used for provisional prostheses fabrication. To simulate a clinical situation, the models were attached on training manikin heads with opposing mandibular arches.
Accuracy evaluation

The fabricated provisional prostheses were used for accuracy evaluation. Each prosthesis was attached on the inserted implant in the surgical model using clinical measures. This involved the complete seating of the prosthesis interface on the implant platform without interferences from the proximal contact area (Figure 3). If interferences in seating the prosthesis were noticed, the surgical model was adjusted accordingly. This included peri-implant resin reduction to allow direct visualization and confirmation of the connection between the prosthesis and the implant, and the reduction of proximal contacts. Whenever the proximal contact interfered with the seating, it was minimally adjusted on the surgical model until the prosthesis was completely seated. The tightness of the proximal contact and the location of any binding spot were evaluated by shimstock foil (Coltene/Whaledent, Langenau, Germany). All the adjustments of the surgical models were reported to assist with the qualitative evaluation of the seating accuracy of the different prostheses. In addition, any resistance to tightening the retaining screws of the bridge prosthesis was reported as an indication of clinical misfit. After the seating of each prosthesis, the retaining screws were tightened initially by hand, followed by tightening to a torque of 35 Ncm by the torque wrench. None of the prostheses were adjusted in any way.

Following the complete seating of the prosthesis, the surgical model was scanned by the laboratory scanner to generate a virtual image of the surgical model with the attached prosthesis. Each virtual surgical model was superimposed against the virtual master model with the provisional prosthesis to measure the deviation of the attached prosthesis. The superimposition was executed through 3D rendering software (Geomagic Studio, Raindrop, Geomagic Inc., Research Triangle Park, NC, USA), by locating 3 widely distributed points on the teeth of each model. This was followed by automated global registration to align the models in the most common 3D position.

On the superimposed models, 3 accuracy variables were measured: vertical error, proximal contact error, and proximal contact quality. These variables were considered because they are clinically relevant following implant placement, and can influence the seating, occlusion, position and aesthetic of the prosthesis, and subsequently, the amount of adjustments required clinically. For the vertical error, 2 similar points were selected on the provisional prostheses on the master model and the surgical model (Figure 4). For the incisors and canines, the middle of the incisal edges and the canine tips were selected. For the molars, the central fossae were selected for the vertical measurement. In addition, the direction of the vertical error was determined (supra-occlusal or infra-occlusal). Proximal...
contact error was measured at the mesial and distal proximal surfaces. Opening of contacts was detected if the proximal surfaces of the provisional prosthesis and adjacent tooth were not contacting, and was reported as positive error. Overlap of proximal surfaces is indicative of tight contact and was reported as negative error. All the measurements were recorded in mm.

For the proximal contact quality, the virtual master model and the virtual surgical models were reconstructed to produce intact proximal surfaces. This was achieved by superimposing the virtual partially edentulous arch on the dentitions of each virtual model, and superimposing the designed virtual prostheses on the scanned implant prostheses of the master and surgical models. The proximal contact regions were extracted at the mesial and distal surfaces of the prosthesis along with the adjacent tooth. In this study, 1.5 mm of the axial surfaces of each side of the proximal contact were extracted for the master and surgical models. This was followed by automated overlapping and calculation of the deviation between the proximal contact at the master model and the proximal contact at the surgical model. The software (Geomagic) calculated the average deviation in the form of root mean square (RMS) value between 2 superimposed surfaces using the following equation:

\[ \text{RMS} = \sqrt{\frac{\sum (R_i - C_i)^2}{n}} \]

where \( R_i \) is a point of the original STL image, \( C_i \) is the same point of the scanned guide, and \( n \) is the full number of points. This test aimed to qualitatively evaluate the deviation of proximal surfaces of each contact area, where less RMS is indicative of greater accuracy and vice versa.

**Statistics**

The means and standard deviations were calculated for the vertical error, proximal contact error, and proximal contact quality. The normality of the data was confirmed by the Shapiro Wilk test. One-way ANOVA was implemented to evaluate the significance of the difference for each variable among the different groups, followed by post hoc tests. The SPSS software package (SPSS for Windows, version 23, SPSS Inc., Chicago, IL, USA) was used and the level of significance was set at 0.05. For all statistical tests, absolute values were measured. In addition, the data were presented in box plot diagrams. For the vertical error and proximal contact quality, the comparisons were for S-Ant, S-Post, B-Ant, and B-Post. For the qualitative evaluation of the proximal contacts, no differentiation was done for mesial or distal proximal contacts. For the proximal contact error, mesial and distal contacts were
reported separately, and the analyses were conducted among S-Ant, S-Post and B. The mesial and distal proximal contact errors were plotted in a scatter diagram.

RESULTS

Table 1 summarized the outcome of vertical error, proximal contact accuracy and proximal contact quality of the different implant prostheses. The proximal surfaces had to be adjusted for 8 S-Ant and 1 S-Post prostheses. Seven of the S-Ant proximal surface adjustments were performed on the mesial surface and 1 on the distal surface. One of them required considerable adjustment of more than 1 mm, 4 required adjustment of more than 0.5 mm, and 3 were adjusted for less than 0.5 mm. The S-Post adjustment was less than 0.5 mm on the mesial surface. None of the B proximal surfaces required any adjustment. On 2 models, the bridge prosthesis was fitted with minimal resistance to tightening, where the final tightening involved less than a half turn of each retaining screw. For 4 models, the final tightening required a full turn of the torque wrench of 1 or 2 retaining screws. On 4 models, the fit of the prosthesis appeared compromised, and the final tightening involved more than a full turn of the torque wrench to a maximum of 2 turns of the retaining screws.

Vertical error

All prostheses revealed vertical errors of positive magnitude, where the placed prosthesis was at the supra-occlusal position (Figure 6). The vertical error was more noticeable on the posterior implants than the anterior implants. Specifically, the discrepancy was greatest for the S-Post (0.41 mm ± 0.16 mm), followed by B-Post (0.29 mm ± 0.20 mm), B-Ant (0.26 mm ± 0.24 mm), and S-Ant (0.21 mm ± 0.10 mm) respectively. However, the difference among the groups was not significant ($p = .09$).

Proximal contact error

For the mesial proximal contact error, a significant difference among the groups was observed ($p < .01$), where the S-Ant had a significantly greater absolute error (0.46 mm ± 0.25 mm) than S-Post (0.15 mm ± 0.07 mm) ($p < .01$) and B (0.09 mm ± 0.06 mm) ($p < .01$) respectively (Figure 7a). However, there was no significant difference between S-Post and B ($p = .74$). In general, a similar pattern was observed for the distal proximal contact (Figure 7b), where the S-Ant proximal contact error (0.45 mm ± 0.25 mm) was greater than S-Post (0.15 mm ± 0.10 mm) and B (0.15 mm ± 0.06 mm). Significant differences were detected.
among all of them ($p < .01$), and between S-Ant and S-Post ($p < .01$), and S-Ant and B ($p < .01$). No significant difference was found between S-Post and B ($p = .90$). The distal proximal contacts for all the prostheses were generally light (open contact), that was more obvious for the S-Ant than other prostheses. The scatter diagram (Figure 8) relating the mesial and distal proximal contact errors for the 3 prostheses indicated that the B proximal contacts were more centred in the middle of the graph, followed by S-Post. The S-Ant suffered from greater error, especially in the form of tighter mesial contacts and open distal contacts. The S-Post proximal contacts were slightly tighter for the mesial surfaces, and open for the distal surfaces. Figure 9 illustrates some examples of seated crowns and the observed proximal contact errors.

**Proximal contact quality**

The qualitative evaluation of the proximal contacts revealed significant differences among the groups ($p < .01$), where the S-Ant proximal contact (0.15 mm ± 0.03 mm) was significantly more inferior than S-Post (0.12 mm ± 0.02 mm), B-Ant (0.12 mm ± 0.01 mm) and B-Post (0.11 mm ± 0.01 mm) proximal contacts ($p < .01$). There was no significant difference between the proximal contacts of S-Post and the B-Ant ($p = .74$), S-Post and B-Post ($p = .92$), and B-Ant and B-Post ($p = .49$). In addition, according to Figure 10, the S-Ant was clearly associated with greater errors in the quality of proximal contacts.

**DISCUSSION**

This study provides information on the seating accuracy of implant immediate provisional prostheses fabricated prior to implant placement via sCAIS. To the knowledge of the authors, this study is the first on the accuracy quantification of implant immediate provisional prosthesis produced by full digital workflow. Since the interface of the prosthesis is machined and prefabricated by the manufacturer (Abduo & Lyons, 2013; Schubert et al., 2019), the interface accuracy between the prostheses and the implants was not expected to be affected. Instead, any deviation in implant placement may prevent the seating of prostheses due to binding with the proximal surfaces of the adjacent teeth. The single crowns will eventually have complete seating following the adjustments of the proximal surfaces. The use of non-engaging conical abutments for bridge prosthesis and the application of the recommended manufacturer torque might have ensured complete seating on the implants via deformation of the prosthesis, which was noticed from resistance to the tightening of the retaining screws. Since all the prostheses were eventually seated on the implants, it can be...
assumed that this clinical protocol is feasible (Lanis et al., 2019; Leite et al., 2020; Schubert et al., 2019; Venezia et al., 2019). However, the study revealed that all the prostheses were associated with measurable errors in the vertical position and proximal contact regions that may have a clinical impact. Thus, the clinicians interested in inserting prostheses fabricated prior to sCAIS implant placement should be prepared to manage these errors clinically. As the provisional prostheses were produced by composite resin, the adjustments in the form of clinical reduction or addition are feasible. Therefore, since the proximal contact errors differed significantly among the different prostheses, the null hypothesis that the different provisional prostheses will exhibit a similar level of seating accuracy was rejected.

The observed inaccuracies in provisional prostheses seating can be attributed to deviations in implant placements via the fully-guided sCAIS protocol that was reported to be up to 0.2 mm vertically (Fang et al., 2019; Schneider et al., 2019) and 1.2 mm horizontally (Derksen et al., 2019; Fang et al., 2019; Vermeulen, 2017; Younes et al., 2018). Despite being accurate, the fully-guided implant placement is still prone to accumulated errors from every step of implant planning and placement (Bover-Ramos, Vina-Almunia, Cervera-Ballester, Penarrocha-Diago, & Garcia-Mira, 2018; El Kholy, Janner, Schimmel, & Buser, 2019; Hammerle et al., 2015; Tahmaseb, Wu, Wismeijer, Coucke, & Evans, 2018). The CBCT visualization and 3D segmentation of the different tissues prior to implant was reported to exhibit deviation from the actual anatomy, which may influence the virtual implant placement. All the digital surgical guide fabrication techniques, such as 3D printing and milling, were reported to have surface and dimensional errors (Sommacal, Savic, Filippi, Kuhl, & Thieringer, 2018) that can influence the seating and distortion of the guide. Further, studies on technical accuracy of surgical guides reported that guide drilling access can deviate in the range of 0.2 mm – 0.6 mm horizontally and vertically (Kernen et al., 2016; Kuhl, Payer, Zitzmann, Lambrecht, & Filippi, 2015). During the surgical procedure, the tolerance between the drills and the guide sleeves will further increase the horizontal errors (Koop, Verbruggen, Vermeulen, & Quirynen, 2013). In addition, implant placement deviation can further be accentuated by inconsistency of bone density or even a lack of primary stability (Derksen et al., 2019). Clinically, more errors can occur from patient-related factors such as movement, limited visibility, and limited access (Bover-Ramos et al., 2018).

In the present study, the occlusal surfaces of the implant prostheses were higher than the occlusal surfaces of the planned prostheses, which is most likely related to implant placement. The magnitude of vertical error reported in the study (range of 0.2 mm - 0.4 mm) is consistent with previously published reports on vertical error of implants placed by the fully-guided approach (up to 0.2 mm vertical errors) (Fang et al., 2019; Schneider et al., 2019). The supra-occlusal implant position can be associated with error and friction of the
guide on the teeth leading to incomplete seating of the guide (Al-Imam, Gram, Benetti, & Gottfredsen, 2018; Kernen et al., 2016; Park et al., 2014; Sommacal et al., 2018). Part of the challenges in seating surgical guides is the complexity of the teeth anatomy (fissures, cusp tips and grooves), and the large guide dimensions that cover the whole arch. In addition, presence of debris within the osteotomy of surgical plastic models may interfere with the complete placement of the implant, leading to supra-occlusal prostheses. The posterior single crown seems to be more affected than the other units. This can be due to difficulties in drilling and placing the implants in the posterior region of the mouth. The posterior single implant of this study was placed in a manikin head in an edentulous area bounded by 2 adjacent teeth, which further reduced the access available for the placement of drills and implant. On the contrary, the single incisor implant placement is much more accessible for the operators. Likewise, for the bridge situation, the wider edentulous span ensures more access for drilling and implant placement.

The provisional prostheses had proximal errors in the range of 0.1 mm - 0.5 mm. This magnitude of error required adjustment to ensure complete seating. The proximal errors occur due to angulation and horizontal errors of the placed implants that were reported to be in the range of 0.4 mm – 1.2 mm (Derksen et al., 2019; Fang et al., 2019; Schneider et al., 2019; Younes et al., 2018). There was a clear tendency for the anterior single crown to suffer from more proximal errors than the other prostheses. The anterior implant of the present study was inserted 2 mm sub-crestal, and the anterior edentulous span was narrowest in the mesiodistal direction and bounded by relatively long teeth with large proximal surfaces. Therefore, the drill will move in a longer distance through the guide which will further accentuate the effect error of guide seating and tolerance within the sleeves (Schneider et al., 2019). In a clinical situation, the seating of a single anterior provisional prosthesis will further be affected by over contouring of the emergence profile. On the contrary, the posterior single implant had shallower implant placement, with more mesiodistal dimension and less height, that may reduce the impact on the posterior proximal contacts.

Clinically, the feasibility of this workflow is dependent on the precision of each planning stage and implant surgery. Complications during surgery such as guide misfit, fracture and compromised implant primary stability (Tahmaseb et al., 2018), will reduce the reliability of this workflow. This has been observed by clinical studies on whole arch prefabricated prostheses prior to sCAIS (Johansson et al., 2009; Komiyama et al., 2008). Johansson et al found that from 52 immediate whole arch prefabricated prostheses produced prior to sCAIS, 2 prostheses did not fit, 10 prostheses had major connection problems between the prostheses and the abutments, and 3 prostheses required major
occlusal corrections (Johansson et al., 2009). Similarly, for 31 immediate whole arch prefabricated prostheses, Komiyama et al reported that 5 prostheses had misfit on the abutments, and 3 prostheses needed extensive occlusal adjustments (Komiyama et al., 2008). These technical complications were primarily attributed to the discrepancies between the planned implant position and the final implant position. As a result, the 2 studies recommended caution prior to routine application of this treatment workflow (Johansson et al., 2009; Komiyama et al., 2008). On the other hand, as the partially edentulous cases involve less implants, they may be associated with less misfit-related complications. However, the clinician should be prepared to perform certain adjustments occlusally and proximally. The occlusal errors are generally simple and are a routinely executed procedure for immediately restored implants. Clinical adjustments of proximal contacts are more challenging and may require trimming of proximal surfaces of one side of the prosthesis, and addition of composite resin on the other side, which can be time consuming following implant surgery. Alternatively, the implant crown with screw access can be fabricated to fit on a prefabricated abutment, which can be luted on the abutment intraorally following implant placement to compensate for the errors in placement (Schubert et al., 2019). Although the evaluated bridge prosthesis of the present study was eventually attached to the implants of all the models, errors in seating on the 2 implants were noticed in the form of resistance to tightening of the retaining screws to the final torque. Considering the prosthesis was fabricated from composite resin material and the implants were inserted in a 3D printed model, accurate seating of bridge prosthesis might be perceived following the elastic deformation of the prosthesis and the model as the screws were torqued. In the clinic, this may lead to peri-implant bone strain. It is not yet clear if this level of misfit will lead to biological or mechanical complications, especially that several in vivo studies indicated bone adaptation to implants restored with frameworks with vertical misfit in the range of 0.5 mm – 1.0 mm (Duyck et al., 2005; Jemt & Lekholm, 1998; Jemt, Lekholm, & Johansson, 2000).

While the study followed a clinical approach, it differs from an actual clinical set-up, which is further challenged by patient-related factors (Bover-Ramos et al., 2018). In this study, virtual evaluation was implemented and has the advantage of visualizing the errors of prosthesis seating accuracy and the simultaneous calculation of the deviation. However, the accuracy of virtual evaluation relies on the scanning accuracy, and the rendering software precision and visualization. While in this study only the vertical and proximal contact errors were relevant, clinically, buccolingual deviation requires evaluation as it is significant and may influence the soft tissue contour around the provisional prosthesis. In addition, the fit of bridge prosthesis needs accurate quantitative evaluation. Further, the clinical cost effectiveness and practicality of this workflow requires investigation in a clinical study.
CONCLUSION

Within the limitations of the present study, it can be concluded that regardless of the implant provisional prosthesis design, all the prostheses were eventually seated on the implants. However, all them were associated with measurable errors vertically and at the proximal contacts. The recorded errors were clinically measurable, and the clinicians using the full digital workflow for implant placement and immediate restoration should be prepared to manage these errors. All the prostheses had similar vertical accuracies, however, the single anterior crown had greater errors at the proximal contacts. The presented protocol requires further validation in a clinical set-up.

References


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Table legend

**TABLE 1** Summary of vertical error, proximal contact error and proximal contact quality

Figure Legends

**FIGURE 1** (a) Virtual images representing the different partially edentulous presentations. (b) The designed surgical guides. (c) The designed implant immediate provisional prostheses

**FIGURE 2** The virtually designed prostheses and the produced immediate provisional composite prostheses. (a) Single implant crowns. (b) Implant bridge

**FIGURE 3** The attached screw-retained immediate provisional prostheses on the implants. (a) Single implant crowns. (b) Implant bridge

**FIGURE 4** (a) Vertical error measurements on superimposed images by determining the vertical difference between the planned prosthesis and the attached prosthesis. (b) Proximal contact error was measured between the inserted prosthesis and the adjacent teeth of the master model. In this illustration open distal contact was observed, and the overlap at the mesial surface indicated tight mesial contact

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FIGURE 5 (a) Reconstructed master model and provisional prosthesis showing intact proximal surfaces. (b) A scanned surgical model after fitting the prosthesis showing lost proximal surfaces due to scanning limitations. (c) Reconstructed scanned surgical model after superimposition of virtual partially edentulous arch and the virtually designed prosthesis. (d) Extracted mesial and distal proximal contacts. (e) Superimposition result of extracted proximal contacts between the master model and surgical model.

FIGURE 6 Box plot diagram of the vertical errors of the different prostheses.

FIGURE 7 Box plot diagrams of the proximal contact errors of the different prostheses. (a) Mesial contact. (b) Distal contact.

FIGURE 8 Scatter diagram outlining the direction and the relation between the mesial and distal proximal contact errors of the different prostheses.

FIGURE 9 Examples of seated S-Ant on different models showing different outcome. (a) Relatively accurate contacts. (b) Example of tight distal contact and open mesial contact. (c) Example of open distal contact and tight mesial contact.

FIGURE 10 Box plot diagrams of the proximal contact quality of the different prostheses.
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<th>Single crown</th>
<th>Bridge</th>
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<td>S-Ant</td>
<td>S-Post</td>
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<td>S-Ant vs B-Ant = &lt; .01</td>
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B-Ant vs B-Post = .49
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Author/s:
Abduo, J; Lau, D

Title:
Seating accuracy of implant immediate provisional prostheses fabricated by digital workflow prior to implant placement by fully guided static computer-assisted implant surgery: An in vitro study

Date:
2021-03-08

Citation:

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