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CLINICAL RESEARCH

A modified protocol for restorative implant abutment selection by using computer-aided design and computer-aided manufacturing technology

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ABSTRACT

Statement of problem. Implant abutment selection is complex because of the numerous factors involved. Computer-aided design (CAD) technology allows for the virtual selection and placement of abutments after all parameters have been precisely measured. The outcome of this new protocol should be validated.

Purpose. The purpose of this in vitro study was to validate a new digital protocol in which abutment selection is made through CAD software, the abutments are virtually placed, and the restoration is then designed based on the virtual abutments to fit the actual abutments when delivered to the implants intraorally.

Material and methods. A cast with 2 parallel implants was scanned 10 times. Then, 2 abutments were placed and scanned 10 times. Twenty identical superstructures were designed and manufactured to simulate the clinical situation of a 3-unit fixed partial denture, screw-retained to 2 implants. These were divided into 2 groups—A, real abutment and B, virtual abutment—and then compared by means of digital and optical measurements.

Results. No significant differences were detected for the measurements between the control and test groups in either the x-axis or y-axis; significant differences were found for the median value of the measurements obtained from both groups regarding the z-axis (P=.046). The mean gap in the virtual abutment group was 50 μm and 35 μm in the real abutment group.

Conclusions. Superstructures produced after the virtual selection and placement of intermediate restorative abutments compared favorably with those produced after the digitalization of actual abutments and placement in the implant model, thus validating the proposed digital protocol for virtual abutment selection and placement. (J Prosthet Dent 2020;■:■-■)

Passive fit is a theoretical parameter, because in practice, absolute passivity cannot be achieved when an implant superstructure is seated on an implant abutment or directly on implant bodies. Nevertheless, the accuracy and fit of implant frameworks have been determined with different measuring methods[1-5] and have provided values for an acceptable fit. The biological consequences of misfits,[6-8] the possible mechanical complications,[9,10] and the long-term performance of restorations and their relationship with fit have been evaluated.[11] Acceptable figures for vertical misfit range from 30 to 150 μm,[12] with 120 μm suggested as an acceptable value.[13,14] However, as suggested by Jemt and Hjalmarsson,[3] figures of acceptable fit must be regarded with caution and assumed only as a clinical guideline.

The fit of an implant-supported restoration depends on various factors, including the precise transfer from the intraoral 3D position of the implant to a definitive cast (conventional or digital). Intraoral scanners offer a high level of accuracy[15-22] and have the advantages of increased time efficiency,[23] the elimination of dimensional changes in the impression and pouring materials and manipulation errors, less risk of a gag reflex, and the ability to keep files for future correction or reuse.

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Clinical Implications

The implementation of this protocol would lead to more precise and efficient abutment selection in a digital workflow, with acceptable accuracy of fit of the produced implant superstructures.

However, the performance of intraoral scanners for large restorations on multiple implants has been questioned, particularly in completely edentulous patients.[24]

The fit of an implant-supported restoration depends on the precise manufacturing of the implant-supported superstructure. Whether frameworks designed and produced through computer-aided design and computer-aided manufacturing (CAD-CAM) can reach the accuracy of fit standards of conventionally made frameworks is unclear. However, available scientific research suggests that CAD-CAM will provide a similar if not better fit than conventional techniques.[25,26]

The design of implant superstructures with a direct connection to the implant, particularly when an internal connection is present, is problematic. Producing different geometries to be inserted and precisely fit and, at the same time, simultaneously seal the internal connection of more than 1 implant is challenging. When attempted, the conventional laboratory or milling center may solve this problem by eliminating the internal connection. This leaves the system with a joint that is not mechanically stable and likely lacks a biological seal. This may be of particular concern when a bone level implant with platform switching is used,[27-29] and more so, when there are multiple component connections and reconnections.[30,31] Consequently, in these clinical situations, it may be advisable to use restorative or transmucosal abutments.

Originally, abutment selection was an intraoral decision during second-phase surgery (implant uncovering) or with the definitive impression after the healing period when a 1-phase protocol was selected. In the past, implant systems offered few abutments selections, but this has increased, making abutment selection complex. Making the impression directly from the implant improved the situation, as abutments could then be selected on the definitive cast controlling all parameters. Nevertheless, abutment selection often becomes a complex task with the numerous factors involved. Discrepancies between the surgical and restorative axes (implant angulation), the depth of the implant in the mucosal sulcus, axis divergence between multiple implants, the vertical and mesiodistal restorative space, and component compatibility with the restorative materials are some of these factors.

CAD-CAM is now routinely applied in the design and production of definitive restorations. Digital files can be obtained from a digital scan on the implant or abutment level. If from an implant-level impression, the restoration must be designed with a direct connection to the implants, as this would be the only information available to the CAD software. If abutments are used to connect the implants to the superstructure, these must be ordered and placed in the definitive cast, rescanned, and a new CAD project initiated. This is not an efficient protocol and is a setback to a straightforward digital workflow.

The purpose of the present study was to validate a modification of the digital protocol in which abutment selection is made with CAD software, the abutments are virtually placed in the implant on the screen, and the restoration is then designed from the virtual abutments to fit the actual abutments when placed in the implants intraorally. The selected abutments are then ready at the clinician's office for superstructure evaluation. The null hypothesis was that the fit of the superstructures made through the virtual selection of abutments would compare with that of superstructures made after a direct scan of real abutments placed into implants or implant replicas.

MATERIAL AND METHODS

An experimental model with 2 implants was prepared for this in vitro study. Implant 3D position was captured 10 times by means of a laboratory digital scanning system. Then, restorative abutments were placed into the implants and also scanned 10 times with the same system. Virtual abutment placement was implemented in the implant group. A superstructure was designed to fit the abutments (virtual or actual), and 20 frameworks were produced, 10 for each group. Finally, the fit of the test (virtual abutment) group of frameworks was compared with that of the control (actual abutment) group.

A Type IV stone cast (Desert Sand; Zhermack) with 2 implants was produced (Klockner Vega RN; Soadco). An effort was made to position the implants parallel to each other. The implants were fixed upside down with cyanoacrylate adhesive material to a horizontal flat surface. Then, the cervical areas were blocked with wax, and the compound was boxed and poured in stone. The distance between the centers of the implants was 17 mm. This was based on the average anatomic dimensions of the 3 dental units (mandibular first molar, second premolar, and first premolar) that were designed over the implants, considering that the implants were aligned to the center of the occlusal surfaces of the abutment teeth.

A digital model was obtained by scanning with a desktop laboratory scanner (IScan L1; IMetric 4D). The implants were scanned 10 times with the corresponding direct-to-implant files to record the 3D positions of the implants. The scan bodies were hand tightened.

Figure 1. Experimental model: 2 implants parallel to each other, 2-mm abutment placed in first molar position, and 3-mm abutment placed in first premolar position. CAD-CAM superstructure tightened to both abutments. CAD-CAM, computer-aided design and computer-aided manufacturing.

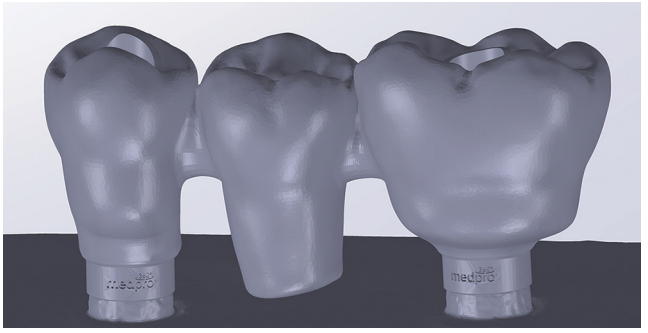

Figure 2. Computer-aided design of 3-unit implant-supported fixed dental prosthesis.

Next, 2 prosthetic abutments of 2 mm and 3 mm in height (Klockner Vega RV Permanent; Soadco) were placed onto the implants. The 2-mm abutment was placed on implant number 46, and the 3-mm abutment was placed on implant number 44 (Fig. 1). Different abutment heights were used to further recreate a common clinical scenario wherein an implant in the first premolar area will often be located deeper in the soft tissue. Although no difference in the measurements between the 2 implant-abutment units was expected in the present experimental setting, previous reports have suggested that deeper implants could be involved in increased fit errors, likely because of the impression-making protocol[32] and machining tolerances.[33,34] Then, a 30-Ncm torque was applied to both abutments. To ensure the accuracy of this step, a calibrated torque wrench, reference number JDTWKL (Klockner), was used to tighten the abutments to the implants, as would be done in a standard clinical

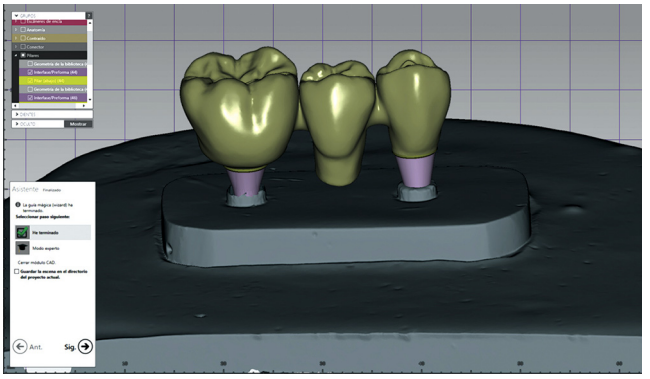

Figure 3. Virtual abutments placed with computer-aided design software into virtual implant replicas. Designed digital superstructure then placed on virtual abutments

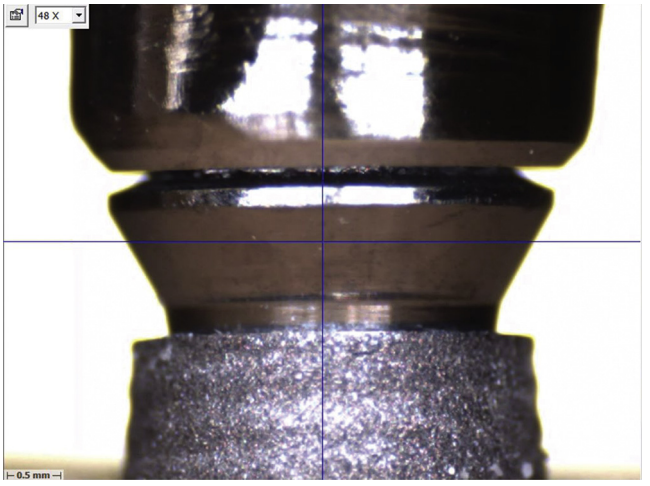

Figure 4. Photomicrographs from direct optical measuring method (original magnification ×48).

Table 1. Statistics of 98 541 axis measurement deviations (μm) of analog and digital groups (x-, y-, and z-deviations) and their comparison

Measurement/ Axis	*n*	Average (SD)	Median (Q1; Q3)	Min; Max	*P*
X-deviation	98 541	-2.9 (64.5)	0.4 (-18.1; 20.6)	-940.5; 692.2	.529
Y-deviation	98 541	0 (53.5)	1.3 (-11.9; 21.6)	-518.4; 872.2	.941
Z-deviation	98 541	16.6 (124.6)	**0.9** (-18.6; 22.5)	-410.5; 777.7	**.046**

Bold values are significant ($P<.05$)

environment. The torque wrench was previously calibrated with a Tohnichi torque meter (model BTGE50CN-G). Once the abutments were in place, they were scanned with the corresponding scan abutments according to the manufacturer instructions. The scan bodies were hand tightened. This procedure was performed 10 times to generate another 10 different .stl files, this time by recording the 3D positions of the abutments. Then, 10 superstructures for group A were

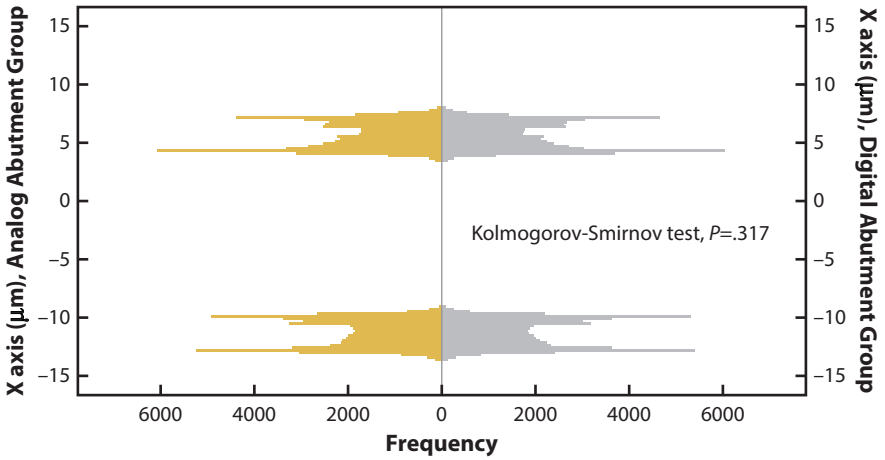

Figure 5. Comparison of overall frequency distributions of x-axis measurements of analog and digital abutment groups.

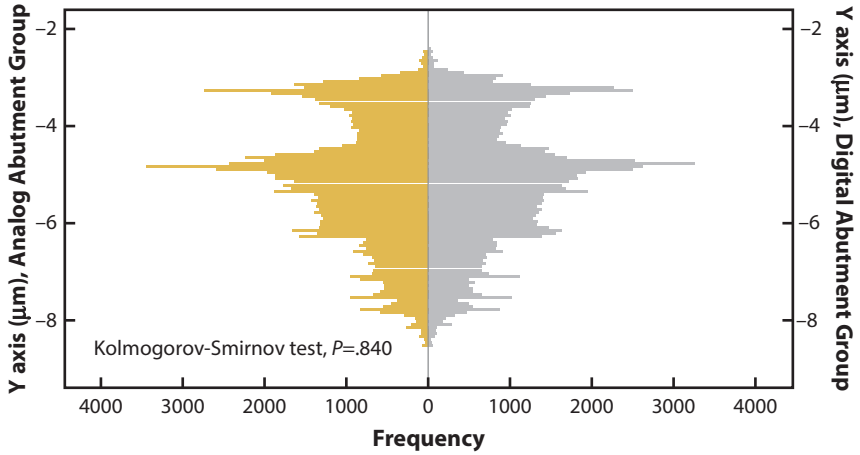

Figure 6. Comparison of overall frequency distributions of y-axis measurements of analog and digital abutment groups.

designed to simulate a 3-unit fixed partial denture (mandibular right molar to mandibular right first premolar) with a screw retained to the 2 implants (Fig. 2).

In the CAD phase, with the appropriate software (Exocad v 6136; Exocad), 2 prosthetic abutments of corresponding type and height were selected from the digital library and virtually placed onto the implants (Fig. 3). This was repeated for the 10 digital projects generated from the files obtained by direct scanning of the implants. Ten superstructures for group B, identical to those of group A were digitally placed on the virtual abutments.

The resulting 20 digital projects were divided into 2 groups: Group A—control, real abutment (RA). Group B—test, virtual abutment (VA). Each project was numbered in each group from 1 to 10 and posteriorly paired consecutively for comparison: RA 1 versus VA 1 up to RA 10 versus VA 10. Subsequently, all 20 superstructures from groups A and B were produced by using CAD selective laser melting in Cr-Co (Mlab cusing; Concept Laser and Ultrasonic 10; DMG MORI).

Two measuring systems were applied. First, the exact 3D positions along the x-axis, y-axis, and z-axis were compared for each pair of digital.stl files with specific analysis software (Geomagic Compare/3D; 3D Systems). Second, all 20 manufactured structures were placed on the reference model, screwed in, and tightened to 15 Ncm in 1 of the abutments, and no screw was placed in the second implant, ad modum 1-screw test.[1,35] This clinical method described by Jemt in 1991[1] allows for a very precise quantification of the misfit by very simple means. The resulting gap between the structure and abutment in the second implant was quantified. Direct optical measurements were performed with a profile projector (SOL 161; M2220111; Micro-Vu) at 192× in millimeters (Fig. 4). The projector was aligned to what would be the vestibular side of the gap, and 180 degree was captured. Next, 6 measurements were performed every 30 degrees, and the highest (most unfavorable) measured value was selected as the sample. This procedure was repeated for every specimen in both

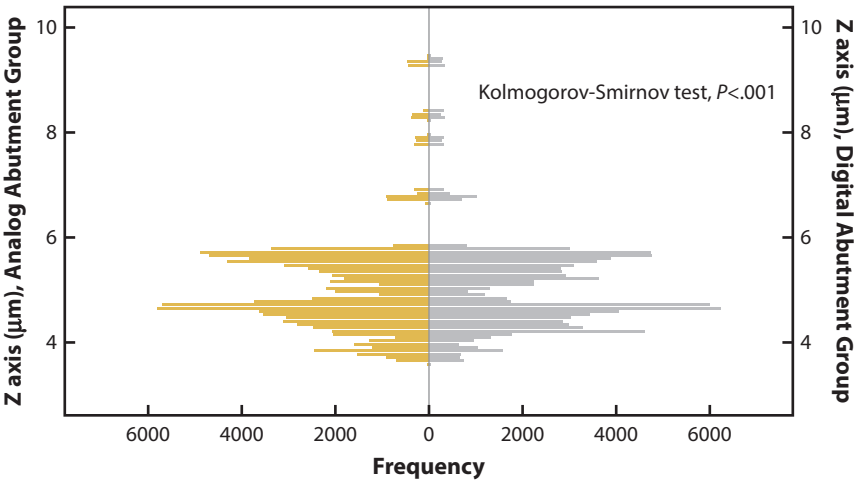

Figure 7. Comparison of overall frequency distributions of z-axis measurements of analog and digital abutment groups.

abutments for both groups, giving a total of 240 measured points, of which only the highest 40 are presented in the results.

For each of the 20 projects (a total of 40 implant positions in pairs), the x-axis, y-axis, and z-axis measurements (μm) were obtained for both the analog and digital abutments 98 541 times. The statistical unit *n* (implant) was 10, and the statistical replicate measure accounted for a size of 98 541. The specimens obtained from the scanning of real (physical) abutments were the control group, whereas those obtained directly from the implants for placing virtual abutments in the CAD software were the test group. The data were analyzed with statistical software (IBM SPSS Statistics for Windows, v25.0; IBM Corp).

The 98 541 deviations in the x-, y-, and z-axis data produced by the real and virtual abutment protocols in the impressions were not normally distributed, as determined with the Kolmogorov–Smirnov tests, and symmetry was absent. For these reasons, the differences in the x-axis, y-axis, and z-axis measurements of both groups (control to analog and test to digital groups) were described by using the median and corresponding interquartile range (although the mean and standard deviation were also computed and is presented in the results) to allow for comparisons with the results of other studies, as well as the range (minimum and maximum). For the same reasons, significant differences were assessed by a nonparametric comparison of median values between both groups by using the Mann–Whitney *U* test. Additionally, the overall frequency distribution of the x-axis, y-axis, and z-axis measurements of both groups was compared by using the Kolmogorov–Smirnov test (α=.05 for all tests).

RESULTS

No significant measurement differences were detected between the control and test groups in either the x-axis (*P*=.529) or y-axis (*P*=.941). However, significant differences were found for the median values of the measurements obtained from both groups regarding the z-axis (*P*=.046), where the z-median measurement value of the digital group (4.87 μm) was significantly higher than that of the analog (4.82 μm) (Table 1).

Likewise, when comparing the overall frequency distributions of the measurements of both groups (control/analog and test/digital groups), no significant differences were detected for the x-axis (Fig. 5, Kolmogorov–Smirnov test, *P*=.317) or y-axis (Fig. 6, Kolmogorov–Smirnov test, *P*=.840), but significant

Table 2. Values after screw tightening and resulting gaps of first premolar and first molar

LOT	Tightened to First Premolar (N)	Gap in First Molar (μm)	Tightened to First Molar (N)	Gap in First Premolar (μm)
A10118(PR2)	15	20	15	49
A10108(PV2)	15	60	15	30
A10621(PF4)	15	72	15	44
A10624(PF6)	15	18	15	39
A10613(PV6)	15	99	15	102
A10609(PV4)	15	44	15	0
A10622(PF5)	15	36	15	30.8
A10618(PV9)	15	69	15	30
A10615(PV8)	15	51	15	0
A10614(PV7)	15	31	15	22
A10610(PV5)	15	15	15	71
A10629(PV3)	15	61	15	20
A10619(PV10)	15	49	15	31
A10626(PF8)	15	100	15	30
A10620(PF3)	15	34	15	33
A10625(PF7)	15	26	15	68
A10628(PF10)	15	36	15	55
A10627(PF9)	15	31	15	26
A06740..(V1)	15	22	15	101
A06740..(R1)	15	74	15	48

Table 3. Average contralateral gaps first premolar and first molar

RA vs VA	Average Contralateral gap (μm)	DS (μm)	Minimum-Maximum (μm)
VA screwed to 44	50	24	15-99
VA screwed to 46	30	38	0-102
RA screwed to 44	35	27	18-100
RA screwed to 46	42	13	26-68

Abbreviations: RA, real abutment; VA, virtual abutment.

differences in the frequency distributions were detected for the z-axis (Fig. 7, Kolmogorov-Smirnov test, $P<.001$).

The results of the direct optical measurements are presented in Tables 2 and 3. The average contralateral gap was 37 μm for the control group (RA) and 40 μm for the test group (VA). The measured differences in the x-axis, y-axis, and z-axis are shown in Figure 8.

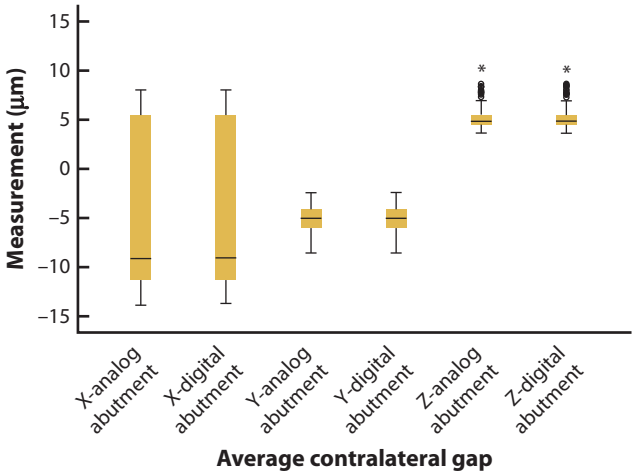

Figure 8. Analysis of generated spaces between superstructures and abutments. *$P<.05$.

DISCUSSION

The null hypothesis was accepted as the fit of the superstructures made through the virtual selection of abutments was no different from and comparable with that of those made after a direct scan of real abutments placed into the implants, suggesting clinicians and dental laboratory technicians can implement this modification of the digital protocol in which abutment selection is made through CAD software.

The advantages of restorative abutments have been reported with some researchers reporting an improved biological seal (both within the implant and in the soft tissues around the implant cervical area), particularly when a bone level implant is involved and platform switching is incorporated into the design,[27-29] even more so when the abutment is placed at the time of surgery and not removed subsequently.[30,31] Other potential advantages include the ease of tray removal and consequently the improved accuracy of the definitive cast at the time of definitive impression, as the tolerance of the abutments to implant axis divergence is much larger, particularly when dealing with an internal implant connection. The use of abutments facilitates the clinical procedures because evaluation and restoration delivery occur at a more coronal level in the peri-implant mucosa. This is relevant when dealing with extensive and complex clinical situations, including edentulous patients.

A first approach for measuring the accuracy of the protocol was made with a virtual comparison between frameworks designed from an RA or VA with software (Geomagic Deviation/3D Compare; 3D Systems), as described and used in previous studies both on natural teeth and implants.[18-22] The results of this measurement method found no difference between test and control superstructures in the x-axis or y-axis. However, a statistically significant difference was detected in the z-axis (vertical), suggesting a larger vertical gap between the framework and abutment. An explanation for this increased discrepancy in the z-axis might be that the overall dimensions are always greater in the vertical axis (the larger the measured object is, the greater the measuring deviations).[18] Additionally, the real abutment was tightened to 30 Ncm, whereas the abutment from the virtual library had to be virtually placed in the virtual implant body. The depth to which the virtual abutments are placed is based on engineering calculations on how much an internal connection with a 10-degree cone would intrude when a torque was applied to the abutment screw. In the present model, this was calculated as if a theoretical torque of 10 Ncm was applied to simulate a normal clinical and laboratory setting where hand tightening of the components was used for impressions, digitalization of the cast, and evaluation of the superstructure. This would produce a theoretical vertical displacement of the abutment of less than 10 μm. The vertical discrepancy observed with the Geomagic software was never greater than 60 μm, which is within the accepted tolerance of misfit.[12] Moreover, this scenario compares well with that of clinical practice, where components are generally placed and evaluated only by hand tightening then tightened to 30 Ncm at the definitive delivery.

A direct optical measuring device was used to determine the vertical gaps between the superstructures and abutments under a magnification of ×192. Following the 1-screw test,[1] all abutments were tightened to 30 Ncm, and all 20 frameworks were tightened in the test model to 15 Ncm to 1 of the implants to simulate a clinical setting. Then, the gap in the contralateral implant was measured as in previous studies.[34] As presented in the results (Tables 2 and 3), the mean gap was 37 μm for the

control group (RA) and 40 μm for the test group (VA). This suggests that the fit of these restorations was within accepted standards.[12] Moreover, this confirms that the CAD-CAM protocols led to an accuracy of fit similar to or better than that of conventional casting procedures.

An ideal implant position where the 2 implants were parallel to each other was used in the experimental setting. Although a 0-degree divergence is desirable but not likely or a realistic goal, it was chosen a good baseline for this pilot study. Future studies may determine the influence of implant divergence on the fit of the superstructure; however, because impressions were not made and the cast was scanned, implant divergence might not affect the accuracy.

The protocol was designed to provide a highly precise abutment selection method, because all parameters can be evaluated through the CAD software in the laboratory and to develop a smoother and time-effective and cost-effective workflow, as the number of procedures in the laboratory and office was reduced, stock of a component in the office was not needed, and the problems of incorrect abutment selection were eliminated. Overall, implementation of this protocol will save time for clinicians and technicians, because purchase orders for abutments can be placed, and components can be delivered at the same time as the superstructure is designed and manufactured and because redesigns or refabrications are less likely to occur. Further research is needed to validate this protocol in different clinical scenarios and its possible application in different steps of the digital production of dental prostheses.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Superstructures produced after the virtual selection and placement of intermediate restorative abutments compared favorably with those produced after the digitalization of real abutments placed in the implant model.
2. The proposed protocol is cost-effective as it reduces clinical time and improves the laboratory digital workflow, leading to a high precision final product.

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