EFFECT OF DIFFERENT SCANNING TECHNIQUES AND IMPLANT ABUTMENT ANGULATIONS ON THE ACCURACY OF INTRAORAL FULL-ARCH ABUTMENT LEVEL DIGITAL IMPRESSION FOR MANDIBULAR FULL-ARCH IMPLANT-SUPPORTED FIXED PROSTHESES

A Thesis

by

MUNA S. KORO

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Chair of Committee,	Seok-Hwan Cho
Committee Members,	Jenn-Hwan Chen
	Mathew Kesterke
Head of Department,	Madhu K Nair

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ABSTRACT

Statement of Problem. Studies evaluating the effect of different abutment angulation and scanning techniques on the accuracy of completely edentulous arch digital impression is lacking. Purpose. The purpose of this in vitro study was to evaluate the effect of four different scanning techniques and three different abutment angulations on the accuracy of intra-oral scanning of fully edentulous mandible.

Material and methods. Three master models with four implants were 3D printed. For Model P all implants were parallelly placed with 4 straight multi-unit abutments. For Model S and T, the anterior implants were parallelly placed, while the posterior implants were tilted distally at 45 degrees. Model S received two anterior straight multiunit abutments and two17-degree multiunit abutments over the posterior implants. model T received two anterior straight multiunit abut and two 30-degree abutment over the posterior implants. Four different scanning techniques were tested with SBs: unmodified group (UM), floss tied between SBs (F), resin dots added on the ridge (R), scan guide connecting between the SBs (SG). Master models were scanned by a lab scanner to obtain the master scans. Each model with each technique was scanned 10 times (n=10). The scans were superimposed on the master scans, to measure distance and angular deviations were measured. A two-way ANOVA test followed by post-hoc Tukey test were used to analyze the effect of the technique and abutment angulation on accuracy of the intraoral scanning. Intraclass Correlation Coefficient was used to measure reliability.

Results. In regard to the distance deviation, there was no statistically significant difference between the model (P =.393), while, there was statistically significant difference between different scan techniques (P<.001). Group R and SG techniques showed less distance deviations (*P*<.001), in comparison with group UM and F. In terms for the angular deviation, there was a statistically significant difference between the different scanning technique and different models (*P*<.001).) Model T showed significant higher angular deviation compared with Model P and S (*P*<.001). However, there was no significant difference between Model P and S (*P*=.093). In terms of scan technique, Group R and SG had significantly less angular deviation compared with Group UM and F (*P*<.001). The reliability of the scans was 0.862.

Conclusions. The accuracy of complete edentulous arch intra-oral scanning at the abutment level was affected by the different scanning techniques and different abutment angulation. Adding more anatomy or texture in between the scan bodies resulted in significantly improved accuracy. Group R and SG had less angular and distance deviation, while group UM and F shower higher deviation values.

Clinical implication. The evidence from this study suggests the use of additional texture or devices for scan bodies to improve the accuracy of abutment level digital impression on mandibular edentulous arch.

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The statistical analysis was conducted in part by Dr. Mathew Kesterke. All work for the thesis was completed by the student independently.

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1. INTRODUCTION

In complete arch implant supported fixed prostheses fabrication, it is of significant importance to have passive fit of the framework.[1-6] Therefore, it is essential to register and transfer the three-dimensional position of the implants, including angulation, depth and position relative to the other implants or teeth with high accuracy and precision to the master cast.[6] The passive fit of the prostheses will result in long term success and avoidance of mechanical and biological complications such as bone loss, screw loosening and prosthesis fracture.[1-8] There are multiple factors that might affect the accuracy of the implant master cast such as the stone properties, the impression materials, impression techniques and more.[3-5] However, the first and most significant step is to make accurate implant impression.[1-7]

Accuracy has been defined as a combination of trueness and precision of system, device or method. Trueness describes how close the measurements are to the actual dimension of the measured object, whereas precision describe the deviation of repeated measurements of the same object from each other.[5-7,10,12,15,27,28] Over the past decades researchers have studied the effect of several factors and techniques on the accuracy of convictional implant impressions for edentulous patients.[1-5,7,16,10,28] Papaspyridakos et al. concluded that for a conventional full arch implant impression an open tray, splinted impression technique will result in more accurate definitive cast compared to the non-splinted or closed-tray impressions.[7] However, with the advancements of digital dentistry, CAD/CAM systems, and innovation of scan bodies, the interest in using intra-oral scanners to acquire digital impression has largely increased. CAD/CAM systems simplify the workflow, can improve patients' acceptance and comfort, reduce the possible distortion of the impression material and master cast, and increase efficiency.[1-5,7,11,25] Studies investigating the accuracy of intraoral digital scanning using scan body, found for a single implant, a bridge or even up to a quadrant it is as good as or even better than the accuracy of conventional impressions.[1,9,12-14,10] In regard to the edentulous full-arch implant scanning accuracy, the results are still inconsistent.[5,6,11,12] Several in-vitro studies compared the accuracy of the full-arch digital implant scans verses conventional impression techniques concluded that digital scanning is comparable and sometimes better than the conventional impressions.[1,3,4,11,14,28] A recent systematic review reported that most of those studies were in-vitro,[5] and these studies have used different master models, with variable implant numbers and angulations. The calibrate the master models was done using different systems such as lab scanners and coordinated measuring machines. As for the accuracy analysis results were conveyed with either linear and angular deviation, root mean square error, average measurement error or chromatic scales.[6,9,11]Therefore, the use of digital scanning for full-arch implant impression still needs to be validated with more clinical data,[11] and the conventional open-tray splinted full arch impression technique is still the standard of care.[14]

The challenge of obtaining accurate scans for edentulous arches is due to the scanning of large area of mobile moist soft tissue, that lack unique points or anatomical reference landmarks. In this situation the images would be improperly stitched together with accumulated errors.[2,11,13,18,19] Furthermore, the identical geometry of the scan bodies can lead the scanner to interpretation errors resulting in reading multiple scan bodies as one.[2,11,13] In general, the opaque, smooth and dull surfaces are easier to scan than the translucent, rough and shiny surfaces.[2,29] Also, the more landmarks or reference surfaces to be scanned the more accurate the virtual reconstruction of that surface.[2,29] Therefore, multiple clinical reports and techniques have been described to increase the surface anatomy of the edentulous ridge. In a recent clinical study, the test group scan bodies were splinted prior to scanning,[16] while others have added multiple dots of flowable composite resin which were secured by applying Histoacryl glue.[24] Similar to that is the use of fiducial markers and artificial markers.[14,17,18] Variable forms of custom Auxiliary Geometric Device and scanning guides have been also used. However, the scanning was done twice, with and without the device.[13,19,22,23,26] Recently, the scan bodies were modified by designing a rigid extension pointing toward the inter-implant region to create more characteristic reference points.[10] Only one study has compared the effect of four different techniques on the accuracy of scanning upper edentulous arches with four parallel implants, using five different implant level scan bodies.[15]

There is increased necessity for fixed mandibular prostheses, as the mandibular bone resorbs four times faster than maxillary bone,[21] and the stability of mandibular removable prosthesis is usually compromised. Therefore, the design concept of placing the implants in 15-45 degree distally to avoid anatomical structure, the need for bone augmentations surgeries and to decrease the length of posterior cantilever, was first described for atrophic edentulous mandible. It has been reported that this design has been widely used in the mandible.[20] However, most of previous studies have used the maxillary arch instead of the mandibular arch.[11] Furthermore, almost all in-vitro studies have used intra-oral scan bodies at implant level and few were concerned about digital impression accuracy on multi-unit abutments level.[1,11,26]

Therefore, the purpose of this in-vitro study was to compare the effects of four different scanning techniques (unmodified, floss splint, resin dots, custom scan guide) and three different abutment angulations (0^o, 17^o, 30^o) on the accuracy of intraoral full-arch abutment level digital impressions for mandibular complete-arch implant-supported fixed prostheses. The null hypotheses are that no significant difference will be found in the accuracy of edentulous full-arch scans among different scanning techniques and different abutment angulation.

2. MATERIAL AND METHODS

A mandibular fully edentulous stone model was scanned by lab scanner (R100; 3shape), to acquire a Standard Tessellation Language (STL) file which was exported to computer-aided design (CAD) software (Blue sky plan; Blue Sky Bio and Meshmixer; Autodesk Inc) to design the implants positions and create uniform thickness of the soft tissue. First design had four parallel implants; two placed anteriorly at the canine area and two placed posteriorly as the first Design. However, the posterior implants for the second design were placed at 45-degree distally, where the platform will emerge at the first molar area. A total of 3 master models of mandibular fully edentulous arch with soft tissue replica were 3D were printed (DPR 10 and Dreve FotoDent Gingiva Parts; Carbon Inc).

In each model, four implant replicas (Implant Replica CC RP; Nobel BioCare) were placed and secured in their planned location. The first model (Model P), the four parallel implants (Implant Replica CC RP; Nobel BioCare) received four straight multi-unit abutment (Multi-Unit Abutment Plus Conical Connection RP 3.5 mm; Nobel BioCare). For the second model (Model S) and the third model (Model T) the anterior implants received two straight multi-unit abutment (Multi-Unit Abutment Plus Conical Connection RP 3.5 mm; Nobel BioCare). The posterior implants for Model S received receive 17-degree multi-unit abutment (Multi-Unit Abutment Plus CC RP 3.5 mm Nobel BioCare), while the posterior implants for Model T received 30-degree multi-unit abutment (Multi-Unit Abutment Plus CC RP 3.5 mm; Nobel BioCare). All abutments were torqued according to the manufacture's instruction. Multiunit abutment scan body (Elos Accurate Scan Body; Elos) (SB) with a scanning area made of PEEK and titanium seating was inserted and tightened over each multiunit abutment according to the manufacturer recommended guidelines. After the SB's were placed they were not removed to eliminate positional errors (Fig.1). The three master models (S, P and T) were scanned and saved as standard tessellation language (STL) files by using lab scanner (E4; 3shape) as the master reference scans.

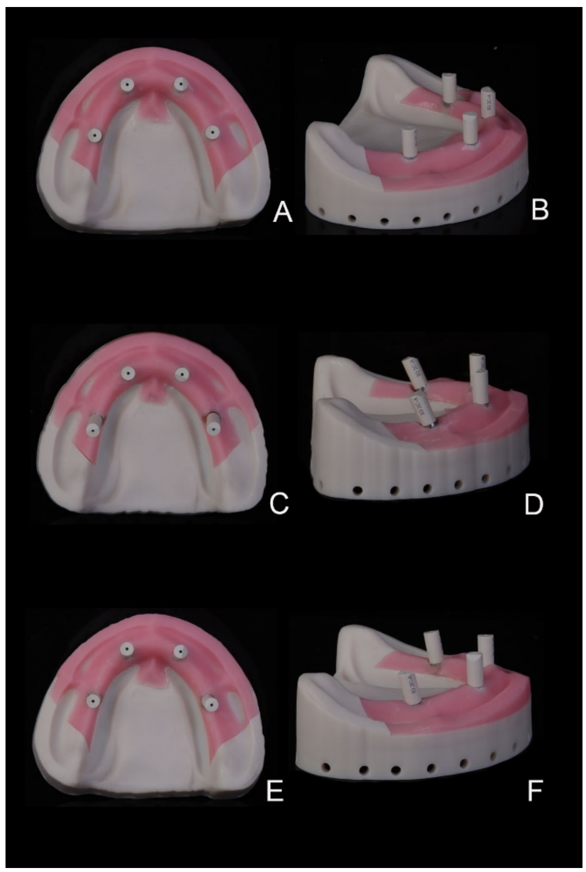

Fig 1. Different master models A, Occlusal view of Model P. B, Side view of Model P. C, Occlusal view of Models D, Side view of Model S. E, Occlusal view of Model T F, Side view of model T

Four different scanning techniques were tested: First, the Unmodified Group (UM) where the master model was used only with individual SBs. Second, the Floss Group (F): dental floss was used to tie among the SBs' (Fig. 2A). Third, the Resin Group (R): flowable resin composite (Filtek Supreme Plus; 3MESPS) was injected into a 3mm in diameter half spheres mold, cured then added on the ridge between each SBs, and they were secured with tissue adhesive (PeriAcryl; GlueStitch Inc) (Fig. 2B). Fourth the Scan Guide Group (SG): geometric scan guides, which consisted of rings slightly larger than the SB diameter, connected with bars were designed by CAD software (Blue sky plan; Blue Sky Bio and Meshmixer; Autodesk Inc), then 3D-printed by a 3D printer (Form 2; Formlab) with white resin (White; Formlab). They were secured in position by applying tissue adhesive (PeriAcryl; GlueStitch Inc) (Fig. 2C and 2D). The designs were based on the concepts of connecting the scan bodies passively, increasing the scanning reference points as well as to eliminating the need to double scan the arch.[10,13,16,19,22,23,26]

Intra-oral scanner (TRIOS3;3Shape) was used to scan each model with each technique, ten consecutive times. The scanning procedure was done in a temperature and humidity-controlled environment according to the manufacturer's instructions. Scanning were considered completed once the SB surface was completely scanned with no holes. The scans were imported and analyzed by the 3D inspection and metrology software (Geomagic Control X; 3D System) by using the best-fit algorithm between master reference scan and test scans. The body of each SB was defined as a cylinder region, while the top was defined as a plane region (Fig. 3A). To measure angular and distance deviation each cylinder central axes was identified as vector and the point of intersection of the vector and the plane was identified as the central point. The master scan vector and central point were considered to be at zero angle and zero millimeter.

The software then compared the test scans vectors and central points in X, Y and Z directions with the master and calculated the distance and angular deviations for each scan body in three dimensions (Fig. 3B).

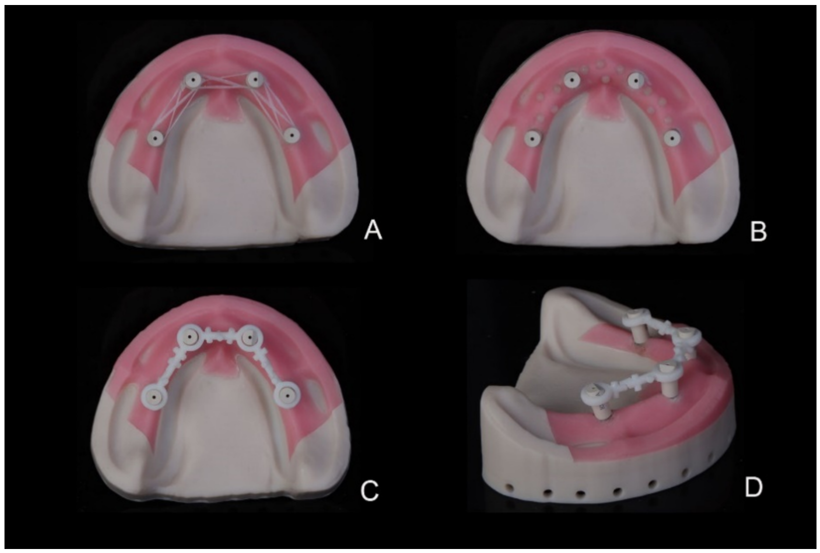

Figure 2. A, Occlusal view if Group F. B, Occlusal view of Group R. C, occlusal view of Group SG D. G, Side view of group SG.

Trueness is to measure how close tests scans are to the actual dimension of the master scan, therefore the effects of different scanning techniques and the implant angulations on distance and angular deviations were analyzed with two-way ANOVA test. For pairwise comparison and to resolve where the statistically significant differences lie, Post-hoc Tukey test was performed. As for precision, to evaluate the homogeneity of the intraoral scans, Cronbach's Alpha reliability analysis test was used. The level of significance was accepted at α = .05. SPSS software (IBM SPSS Statistics; IBM Corp) was used to perform the statistical analysis.

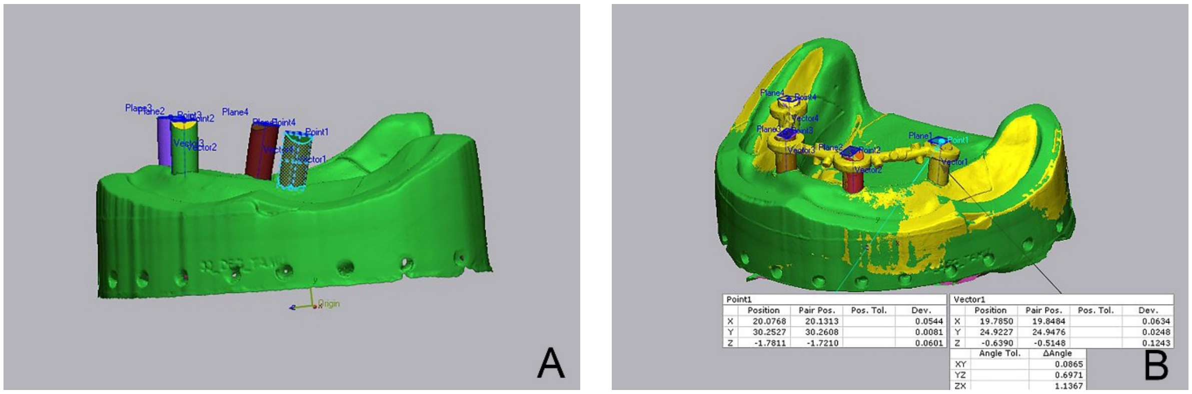

Figure 3. A. Vector, plane and points B. Calculated angle and distance deviation

RESULTS

Each model with each technique was scanned 10 times. Therefore, a total number of 120 scans with 480 points and 480 angles were obtained. Figure 4 shows the mean and standard deviation values (mm) of distance deviations for each group and model. Figure 5 demonstrates the mean and standard deviation values (degree) of angular deviations for each group and model.

Table 1 shows the effect of different techniques and angulation on accuracy by two-way ANOVA test. In terms of distance deviation, there was no statistically significant difference regarding the model (abutment angulation) (P =.393), while there was statistically significant difference in the scanning technique(P<.001). In terms for the angular deviation (Table.1), two-way ANOVA test shows that there was a statistically significant difference in regard to both scanning technique and model (abutment angulation) (P<.001).

According to the Post-hoc Tukey test shown in figure 6, group R and SG show less distance deviations (P<.001), compared with group UM and F (P=.330). However, the distance deviations between group R and SG were not significant (P=.988). In terms of angular deviation among the groups, Group R and SG has less angular deviation (P<.001) compared with Group UM and F. There was significant difference between group R and SG as well (P<.001). There was no significant difference between group UM and F (P=.970). For the scan technique comparison, the greatest deviations were shown for group UM (0.26 mm and 0.9 degree) and lowest were for group SG (0.17 mm and 0.52 degree).

Figure 7 showed the Post-hoc Tukey test among different Models. For distance deviation, Model T showed statically significant difference compared with Model P and S (P<.001), while Model P and S had no significant difference between each other

(P=.093). However, in terms of angular deviation, there was no significant difference among all different models. For the model comparison, the greatest deviations were shown for the Model T (0.22 mm and 0.87 degree) and the lowest for model P (0.21 mm and 0.65 degree).

The reliability (precision) of the scans was tested by using Intraclass Correlation coefficient. The average measure was .862 and with 95% confidence interval the lower bound was .691 and upper bound was .960.

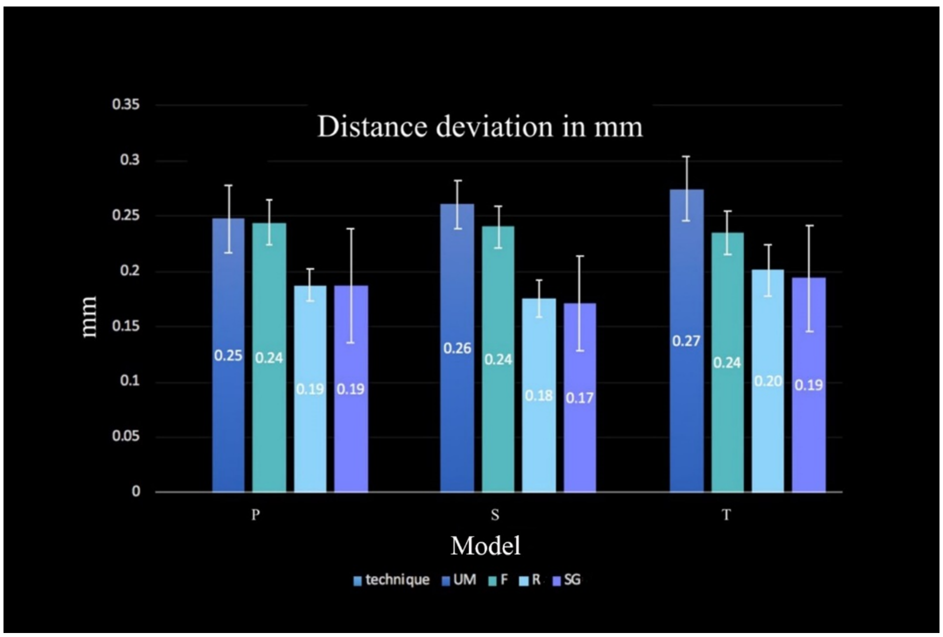

Figure 4. Graph indicating mean and standard values of distance deviation (mm) of different models and different scan techniques. UM, unmodified group. F, floss tied between scan bodies. R, resin dots added on the ridge. SG, scan guide connecting between scan bodies.

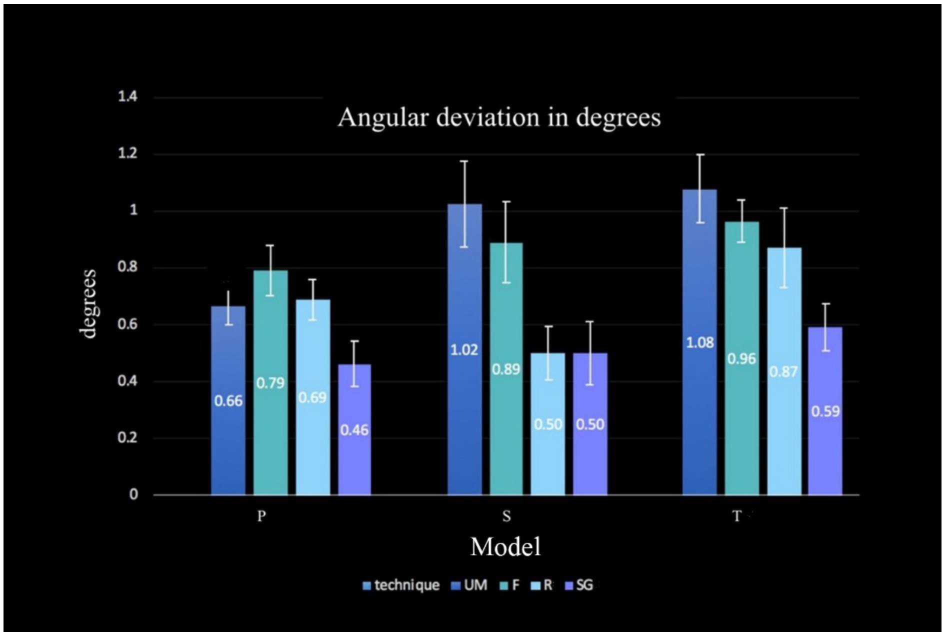

Figure 5. Graph mean and standard values of angular deviation (degree) of different models and different scan techniques. Model P, parallel abutments. Model S, seventeen-degree abutments. Model T, thirteen-degree abutments.

Category	Effect	***P*-value**	***df***	***F***
Distance deviation (mm)	Scan Technique	<.001	3	24.74
	Model	.393	2	1.46
	Technique *X* Model	.874	6	.49
Angular deviation (degrees)	Scan Technique	<.001	3	38.47
	Model	<.001	2	21.25
	Technique *X* Model	<.001	6	5.02

Table 1. ANOVA results comparing effects of both the scan technique and SB angulation on distance and angular deviation

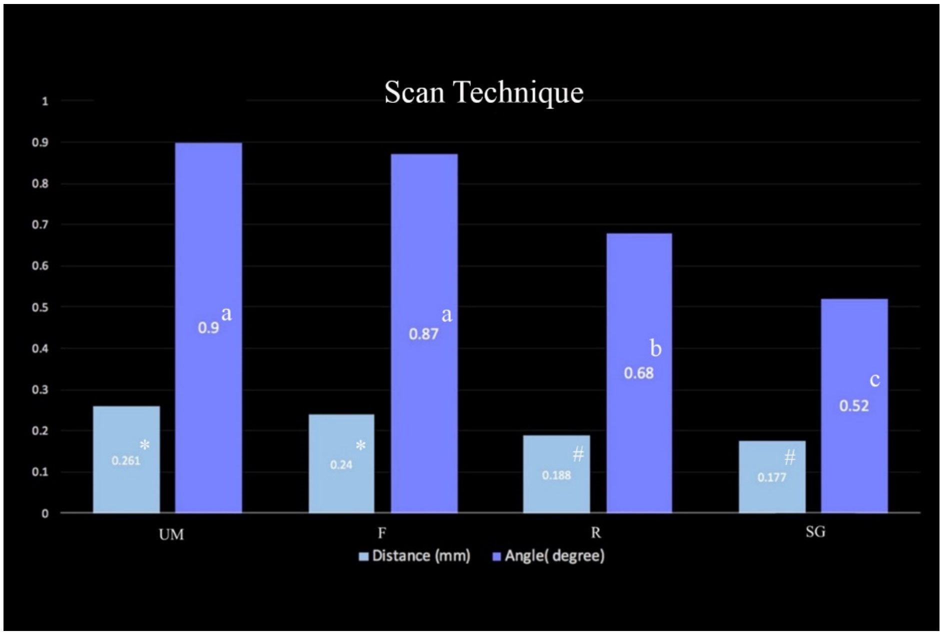

Figure 6. Bar graph showing distance (mm) and angular deviation (angular) among scan technique groups. UM, unmodified group. F, floss tied between scan bodies. R, resin dots added on the ridge. SG, scan guide connecting between scan bodies.
Note. Different alphabets show significant difference between the groups in angular deviation.
* and # marks indicate there is significant differences between the groups in distance deviation.

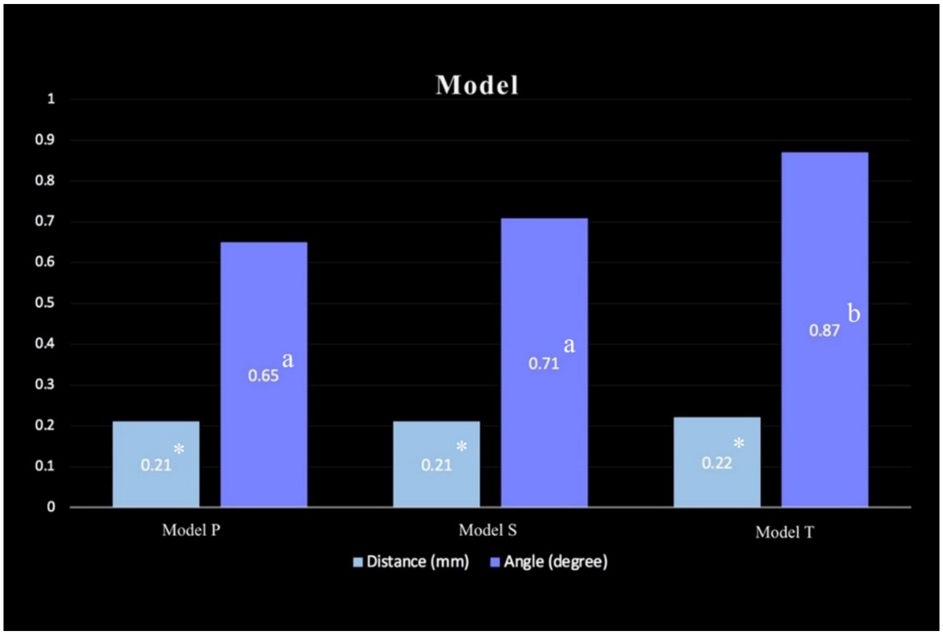

Figure 7. Bar graph showing distance (mm) and angular deviation (angular) among for different models. Model P, parallel abutments. Model S, seventeen-degree abutments. Model T, thirteen-degree abutments.
Note. Different alphabets show significant difference between the groups in angular deviation.
* marks indicate there is no significant differences among the groups in distance deviation.

DISCUSSION

This in-vitro study was designed to investigate the accuracy of intra-oral scanning of edentulous full-arch at abutment level by using four different scanning techniques and three different abutment angulations. The casts were fabricated to simulate real clinical situation for making digital impression of implants placed in edentulous mandible. The null hypotheses were rejected as the results demonstrated that there were statistically significant differences in the accuracy among different scanning techniques and different abutment angulations.

The scanned surface morphology and characteristics play a major part in the accuracy outcomes.[2] Therefore, scanning edentulous arches which are covered with saliva and lack unique reference points will result in improperly stitched and inaccurate images.[2,18,29] To overcome this challenge and improve the accuracy, several studies have introduced different techniques to increase mucosa surface data points and modified the scan bodies. [8,10,13-15-19,23,26] Iturrate et al [13,22] have designed and used auxiliary geometric device, based on complete denture replica. Their device was placed on maxillary stainless-steel model with four SB's. Scanning was performed twice with and without the device, concluding that the use of the auxiliary geometric device had improved both trueness and precision values. Bertta et al[19] designed a scan guide with geometric figures, confirming the enhanced accuracy of scans by superimposition, especially at the distal implants. Another study reported the use of the patient's maxillary denture.[26] Haung et al[10] have improved the scanning accuracy by CAD/CAM modified scan bodies with extensions to the edentulous areas. Meanwhile, in the present study, Group SG showed significant improvement of the scanning accuracy for both distance and angular deviations therefore, confirming the findings of the previous studies.

Mizumoto et al[15] was the first study that compared different scanning technique of 4 parallel implants placed in edentulous maxilla by using five different SBs. Their surface modifications were the splinting with floss, adding glass beads and pressure indicating past (PIP). They concluded that the surface modifications did not enhance the distance deviations and the type of the scan body had more effects on the accuracy. When comparing their study results with the present study results, similar conclusion in for the unmodified and floss group can be reached, because no statistically significant differences were obtained between them. However, the present study, the accuracy of the intra oral scanning was improved for group R. The difference in the results can be explained by the different surface of bead material used. The resin composite of the present study had colored dull surface instead of shiny surface of the glass beads.[2,29] Kim et al,[18] demonstrated that the trueness and precision of the intra oral scanners were improved with adding resin composite dots on the edentulous ridge. In addition, multiple clinical reports have used markers in the palate to improve the scanning accuracy and alignments of the intra oral scans.[8,14,17]

Chochlidakis et al[14] is one of the few clinical studies that compared the accuracy of the intra-oral scanning for the upper arch with fiducial markers in the palate with the scanned cast that was fabricated from splinted open tray impressions. It was concluded that accuracy of the digital scanning is acceptable, indicating that full digital work flow is achievable. A recent clinical study by Cppare et al[16] compared the accuracy between digital and conventional impression by evaluating the marginal bone loss after analysis of the definitive prosthesis fabricated from each technique on the marginal bone loss of the implants. They splinted scan bodies in similar technique used to splint the open tray impression coping before making the digital impression. They concluded that accuracy and predictability of full arch digital impression were clinically acceptable for implant supported fixed prosthesis.

Accuracy of different abutments angulations were analyzed in present study, to simulate clinical scenario where the implants being placed in the posterior with 15-45 degrees distal tilt.[20] The present study showed that Model T which had the 30-degree multi-unit abutment showed significant difference with an average angular deviation 0.88 degrees, compared with the parallel model (0.65 degree) and 17-degree models (0.75 degree). As of the distance deviations there was no significant differences among three different abutment angle models. However, Gimenez et al [(30)] reported that implant angulation had no effect on the accuracy. Papaspyridakos et al[4] concluded the implant angulation had effect on the conventional impression rather than the digital impression. A recent systematic review by Larisse et al[25] concluded that most of the studies reported no influence of the implant angulation on the accuracy. However, due to the different factors and techniques for accuracy measurements further clinical studies are needed. It is important to note that the most previous studies have scanned the edentulous arches with implant level SBs. In contrast, the present study investigated the accuracy of the scanning by abutment level SBs that is connected on the multi-unit abutments, instead of the implant platform.

With the advancement of CAD/CAM, several studies have compared the accuracy of full-arch digital impression with the conventional impressions[1,3-5,8,11,12,28] Amin et al [2] compared the accuracy of digital impression by using implant level scan bodies with the conventional impressions made with splinted open tray implant level impression coping for edentulous mandible with five parallel implants, while Papaspyridakos et al[3] used angulated distal implants. They both reported that the digital implant impression for full edentulous arch was as accurate as the open-tray splinted conventional impression. Similar conclusion was reached by Alikhasi et al,[11] as their results showed that digital impression accuracy was even superior to the conventional impression. However, Wulfman et al[11] in a recent systematic review reported that there are inadequate number of clinical studies to validate the results of the in-vitro studies. This analysis noted that even though the conventional impressions is still the standard of care, the digital impression was reported to be as accurate as the conventions, because there are several factors that might affect the accuracy therefore, more clinical data and standardization of accuracy measurements are required.

The passive fit of implant supported fixed prosthesis framework has been defined as the framework that does not apply any pressure on the implants in the preload condition. Unfortunately, there are few studies that evaluated the fit of the framework fabricated from digital scans.[1,14,16] Furthermore, there is no research that clearly defines or set a value for the error in angular and distance deviations to be clinically adequate. Jemt and Lie's[8] study on casted frame over the master cast reported the misfit should be mostly less than 150 by evaluating the marginal bone loss after analysis of the definitive prosthesis fabricated from each technique on the marginal bone loss of the implants μm. While Chochlidakis et al[14] reported a range between 65-200 μm as acceptable value. Abduo et al [2] showed that a misfit that ranged from 30 to 500 μm can be eliminated when the retaining screws were tightened. As for the present, the results have shown that the lowest distance and angular deviations in all three models were for the scan guide group (180 μm and 0.52 degrees). Even though 180 μm value is within the acceptable range based on the previous studies, they would not necessarily imply clinical validity. Therefore, a clinical research with fabrication of final prosthesis should be conducted to provide more scientific evidence especially with promising results of the techniques of the scan guide and the resin dots. In addition, the present study did not include conventional impression methods as one of the groups. Furthermore, the effect of different scan body types, inter-implant distances and different scanning protocols should be taken into consideration for further investigation. To the knowledge of the authors, this is the first study looked into improving the accuracy of intra oral mandibular full arch implant scans at abutment level, using different scanning techniques and different abutment angulations. Further studies should be directed toward investigating the effect of different implant numbers, different scan bodies on the accuracy as well as to compare it with conventions impression technique.

CONCLUSIONS

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

1. The accuracy of complete edentulous arch intra-oral scanning at the abutment level was affected by the different scanning techniques and different abutment angulation.
2. Adding more anatomy or texture in between the scan bodies resulted in significantly improved accuracy. Group R and SG had less angular and distance deviation, while group UM and F shower higher deviation values.
3. Abutment angulation on distal implants on mandibular edentulous arch might affect the accuracy, as Model T showed significant angular deviation compared with Model P and Model S.

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