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ACCURACY OF IMPLANT SUPPORTED OVERDENTURE DIGITAL IMPRESSION UTILIZING SCAN BODIES AND DIFFERENT SCANNING TECHNIQUES: AN IN-VITRO AND IN-SILICO STUDY

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ABSTRACT

Introduction: The accuracy of different scanning techniques and intra-oral scan bodies (ISBs) in allocating the position of dental implants in complete overdenture digital impression has been questioned, this work compared it to conventional impression in situation where 4 parallel implants were used to simulate implant-supported overdenture situations in an in-vitro setting.

Materials and methods: A conventional and digital impressions using ISBs and 5 different scanning techniques were made of a study model having 4 parallel implants at teeth sites 36, 33, 43, and 46 which were designated as A, B, C, and D respectively. The resulting stone cast and digital impressions virtual casts were compared for linear deviations between the implant sites using a digital caliper versus computerized measurements, and for surface mismatching using a computerized superimposition process of the stone model scan and virtual models. The linear deviations measurements were statistically analyzed using the paired t test, and the horizontal deviations were statistically analyzed using the Kruskal Wallis test.

Results: Comparison of the linear measurements on the stone cast and virtual models detected significant differences in the second and third sextants of the dental arch with techniques I and IV, while superimposition horizontal deviations detected significant differences at implant positions C and D also in techniques I and IV.

Conclusions: Virtual models generated from full arch digital impressions using scan bodies and scanning techniques II, III, and V had similar accuracy to stone models developed from conventional elastomeric impressions.

KEY WORDS: Intra-oral scan bodies (ISBs), digital impression, intra-oral scanner (IOS), in-silico superimposition, implant supported overdenture.

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INTRODUCTION

Intra-oral scan bodies (ISBs) are devices that transfer the implant position from the patients mouth through the digital impressions to the digital dental models, the ISBs therefore delete the need of impression copings and implant analogues used in the conventional stone casts.[1] in such situation, several factors affect the accuracy of the digital impression, such as the technique in which the intra-oral scanners (IOS) used,[2] the digitization and surface reconstruction of the ISBs, the distance between the ISBs, their visible amount, vertical shifts, and angular deviation from one quadrant of the dental arch to the other.[3-7] However, operators experience in using certain IOS protocols was thought to overcome such technical difficulties in long spans and full arch impressions as compared to conventional impressions in both in-vitro and in clinical studies.[8-12]

Nevertheless, there is no consensus on a certain intra-oral scanning protocol or technology, where most of the tested IOS were found to be affected by the scanning strategies, specifically in long span impressions.[13-16] But when considering the advantages of the digital impressions, the ISBs were found to improve the precession of digital impressions using different scanning strategies with or without stitching, which yielded virtual models that were more durable than the plaster casts, and allowed a full digital work flow that permitted checking of the prostheses occlusal relationships and fit before try-in in the patient mouth.[17-22]

Hence, it can be concluded that the digital impression scanning protocol used can affect the accuracy of the successively scanned and superimposed full arch segments, [23] and that further research is needed to standardize and validate the use of optical impressions, [24] which might have inherent inaccuracies at the impressions border in completely edentulous arches, [25] but might fall within clinically acceptable margins when dental implants were used to assist the prostheses, and ISBs used to improve the quality of the scanning process. Accordingly, the aim of this work was to evaluate the use of different scanning techniques and ISBs in implant supported overdenture digital impressions as compared to the use of closed top tray impression copings and implant analogues with conventional elastomeric impression.

MATERIALS AND METHODS

A polyurethane edentulous ridge was invested in a base of dental stone (type III model hard stone, Enrst Hirnichs Dental GmbH, Germany), and 4 parallel dental implants (Nobel BioCare Active 4.3 mm diameter) were placed in this ridge to provide the study model of this research. The implants were positioned at the locations of teeth 36, 33, 43, and 46, and were named A, B, C, and D respectively.

A closed top tray impression copings were secured to the implants with a 10 N/cm torque ratchet, as seen in figure 1, and a polyvinyl siloxane impression (Aquasil, Dentsply, Sirona) was made, the impressions copings were removed from the implants, secured in the impression, and the implants analogues were attached to them, then the impression was poured in dental stone (type III model hard stone, Enrst Hirnichs Dental GmbH, Germany), and the abutments were attached to the implant fixtures analogues to check for parallelism of the implants as seen in figure 2.

The scan bodies (Elos Accurate Scan Body IO 2B-B SA, Nobel Biocare, Denmark) were then attached to the implants in the study model which was scanned with the Trios IOS (3 Shape Dental Systems, Copenhagen, Denmark) using 5 different scanning techniques, as seen in figure 3, around implants positions A, B, C, and D as follows:

Technique I: Full arch straight motion, using a straight sweeping motion on the buccal surface of the cast and ISBs from implant position A to D, then going back to implant position A passing over the

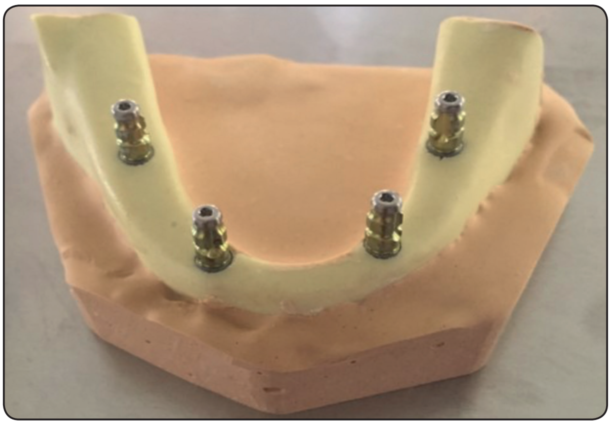

Fig. (1): The study model with 4 implants and impression transfer copings.

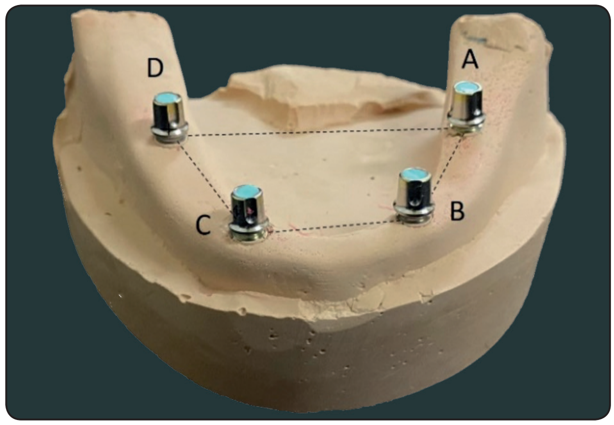

Fig. (2): The stone cast with 4 implants analogues and abutments

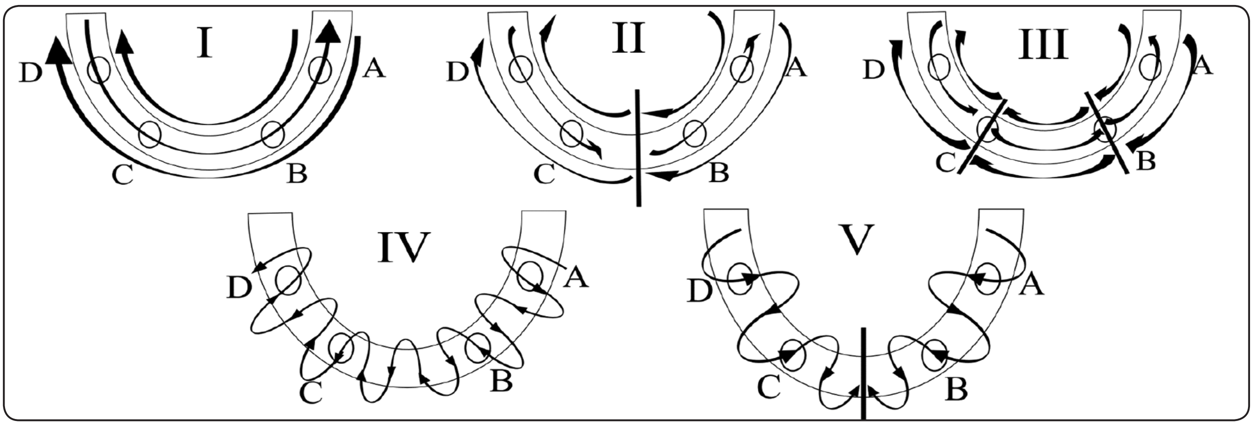

Fig. (3): Different scanning techniques used around implants positions A, B, C, and D. (I) full arch straight motion, (II) half arch straight motion, (III) sextant straight motion, (IV) full arch zigzag motion, (V) half arch zigzag motion.

occlusal surface of the cast, then finally going from there to implant position D on the lingual surface of the implants ISBs.

Technique II: Half arch straight motion, similar to technique I but dividing the scanning process into 2 halves, where the first half began at the most distal implant position, and the second half continued from the anterior part of the arch to its other distal end.

Technique III: Sextant straight motion, similar to technique I but dividing the scanning process into 3 thirds.

Technique IV: Full arch zigzag motion, using a zigzag in-and -out motion covering the buccal, occlusal and lingual aspects of the arch from implant position A to D.

Technique V: Half arch zigzag motion. Similar to technique IV but dividing the arch into 2 halves, with each half starting from the most distal implant location and proceeding forward.

The resulting virtual models, seen in figure 4, were saved in Standard Tessellation Language (STL) format. Using the 3 Shape CAD/CAM software and library (3 Shape Dental Systems, Copenhagen, Denmark; software version 1.4.5.3), the scan bodies were used to orient the implant fixtures in the virtual model as seen in figures 5.

To compare the accuracy of the digital models obtained from each digital impression scanning

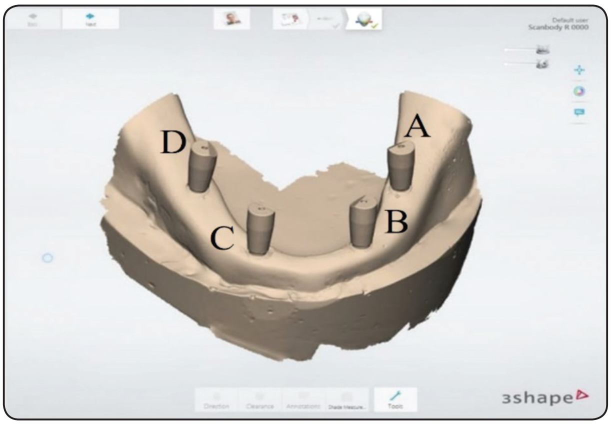

Fig. (4): One of the virtual casts with the scan bodies at implants positions A, B, C, and D.

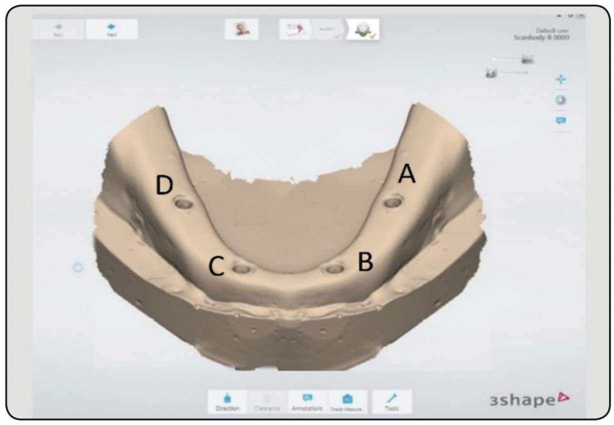

Fig. (5): The scan bodies removed after orienting the virtual implants in position in the virtual cast.

technique, in relation to the stone model, two methods were used, first an in-vitro study where the linear distances between the implants, A-B, B-C, C-D, and D-A were measured on the stone cast, seen in figure 2, using a digital caliber (Mcmaster RS PRO 150mm Digital Caliper Metric) which is considered as control or gold standard to which virtual measurements comparisons were made.[26-29] Then, the ImageJ software was used to measure the same linear distances between the implants on the virtual models as seen in figure 6. The known implant diameter was used to set scale in the ImageJ software, then from the Analyze command, the measure option was used from the drop menu to measure linear distances. The virtual models' measurements were compared to the digital caliper measurements, where the readings of the linear measurements were collected, tabulated and statistically analyzed using the paired sample *T* test, with a level of significance of $P < .05$

Second, using an in-silico method to compare the position of the implants in the virtual models to those in the stone cast, where the stone cast and its embedded implant analogues were scanned using the bench top scanner (Kavo ARCTICA AutoScan), and their resulting virtual model was saved in STL format, as seen in figure 7, then this virtual model was superimposed to the virtual models obtained from each scanning technique using the Geomagic software (Geomagic Qualify 2013, Geomagic, Morrisville, NC, USA). The best-fit feature of the Geomagic software was used to superimpose the stone cast scan and the virtual models, the implants orifices were used as assembly points, then the 3D compare feature of the software was used to detect the horizontal deviations of the scans from each other at 8 points around the implants' orifices. In addition, to simulate situations where full arch bars are used to support overdentures, vertical cylindrical projections, of 4.3 mm diameter and 6 mm height, were superimposed at each implant orifice in the virtual models, to simulate screw-retained abutments that support full arch bars, and were also examined for horizontal deviations from each other at their middle and top cross sections. Then, the detected deviations were presented as surface color maps, with each color representing a 0.1 mm positive or negative deviation as seen in figure 8. The Geomagic software "tabular view-3D compare" was used to provide the value for each of these superimpositions at the 8 selected points around each implant orifice and at the superimposed cylinders. The average reading from each implant position was calculated, then the readings from the 4 implants positions were tabulated for statistical analysis using the Kruskal-Wallis test of the Statistics Package for the Social Sciences Software (SPSS version 23.0, SPSS Inc., Chicago, IL, USA) to compare the horizontal surface matching deviations, with $P < .05$ indicating statistical significance.

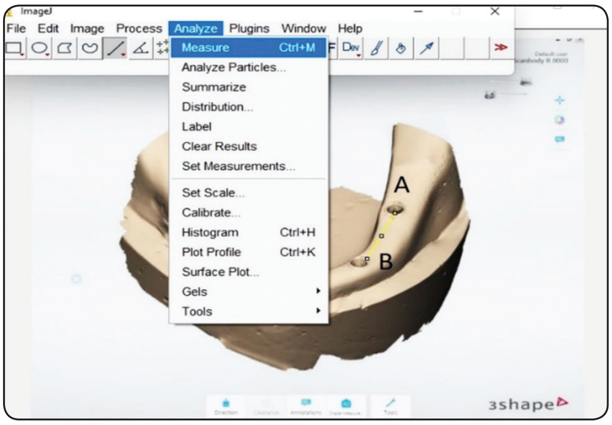

Fig. (6): The ImageJ software used to measure the linear distance between the virtual implants in the virtual model

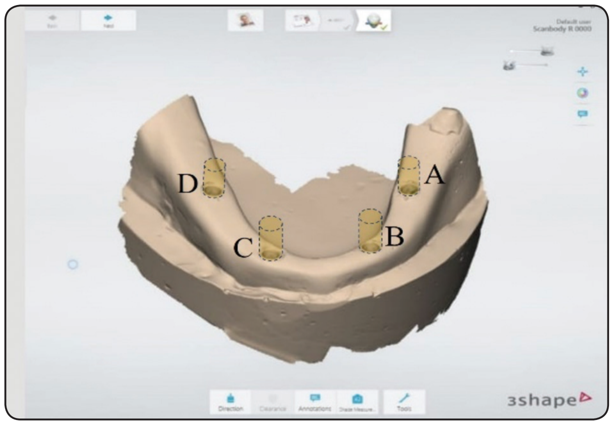

Fig. (7): A scan of the stone cast and its embedded implant analogues with sites of the cylindrical projections over each implant site.

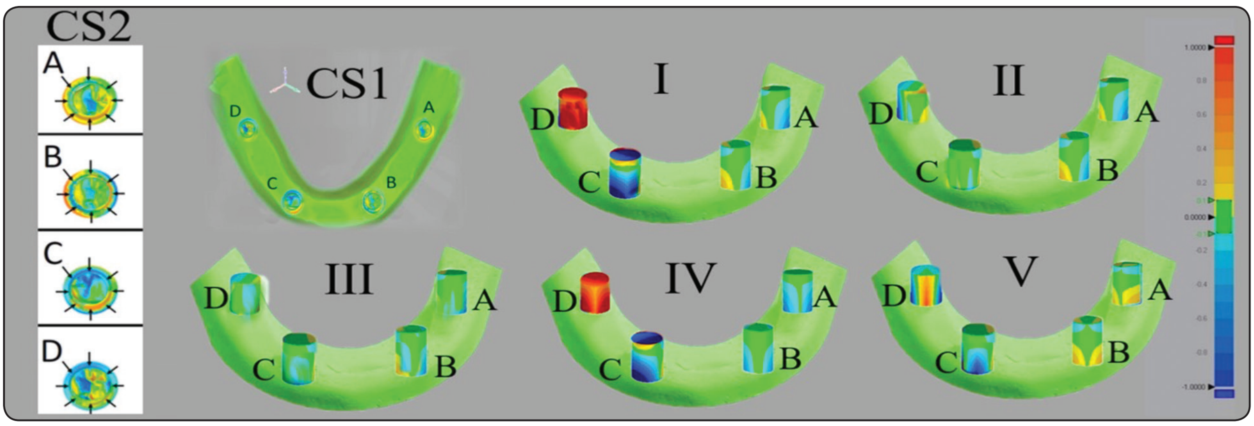

Fig. (8): Superimposition of the stone cast scan and the virtual models generated from each scanning technique I, II, II, IV, and V. The implant positions are named A, B, C, and D, and CS1 represents a cross section in each virtual model at the orifice of the implant fixtures or the base of the cylindrical projections, CS2 represents one of the cross section studied at each implant position, and the black arrows represent the 8 points at which horizontal deviations readings were recorded, where green areas represented minimal displacements ranging from -0.1 to + 0.1 mm, red areas represented +1mm as maximum positive deviations, and blue areas represented -1 mm as maximum negative deviations.

RESULTS

Table 1, 2 and figure 9 show the comparison between the linear measurements made from one implant site to its successive on the stone cast and on the virtual models generated from the digital impressions. Only techniques I and IV had statistically significant differences from the measurements made on the stone model in relations the distances between implant sites B-C, C-D, and D-A, where there was a decrease in the distance between implants B-C and increase in the distance between implants C-D and D-A.

Table 3 and 4 and figure 10 show the average horizontal deviations at each implant site as detected from the superimposition of the stone cast scan and the virtual models. Where there were no statistically significant differences between the cylindrical projections over the implant sites except at implant sites C and D in scanning techniques I and IV, this result came in agreement with the linear distances measurements with negative horizontal deviations at implant site C, and positive horizontal deviations at implant site D at the base cross sections of each cylindrical projection.

TABLE (1): Descriptive statistics, comparison between the linear distance measurements (mean in mm) on the stone cast and virtual model generated from the digital impression

	A-B	B-C	C-D	D-A
Stone cast	2.63	2.23	2.72	4.82
Technique I virtual cast	2.62	1.98	2.86	5.25
Technique II virtual cast	2.63	2.24	2.73	4.83
Technique III virtual cast	2.62	2.23	2.74	4.85
Technique IV virtual cast	2.63	1.99	2.89	5.32
Technique V virtual cast	2.63	2.25	2.73	4.84

TABLE (2): Statistical analysis of the linear distance measurements on the virtual models, generated from each digital impression scanning technique, versus linear measurements on the stone cast. (p significant when < .05)

	A-B	B-C	C-D	D-A
Technique I virtual cast	0.06	0.01	0.02	0.00
Technique II virtual cast	0.07	0.08	0.05	0.05
Technique III virtual cast	0.08	0.1	0.09	0.08
Technique IV virtual cast	0.06	0.02	0.03	0.02
Technique V virtual cast	0.05	0.07	0.09	0.08

TABLE (3): Descriptive statistics (mean + standard deviation) of the horizontal deviation from superimposition of the stone cast scan and the virtual models at 8 points of cylindrical projections cross sections at implant positions A, B, C and D.

Implant position	Cross section location	Scanning techniques virtual models				
		I	II	III	IV	V
A	Base	-0.01	-0.02	+0.01	-0.01	+0.02
	Middle	-0.02	-0.01	+0.01	-0.01	+0.01
	Top	+0.01	+0.01	-0.01	+0.02	-0.01
	Total	0.00	0.00	0.00	0.00	0.00
B	Base	-0.01	-0.01	-0.01	-0.01	+0.02
	Middle	+0.01	+0.01	+0.01	+0.01	+0.01
	Top	+0.01	+0.01	+0.01	+0.01	-0.01
	Total	+0.01	+0.01	+0.01	+0.01	0.02
C	Base	-0.08	+0.01	+0.01	-0.04	-0.02
	Middle	-0.06	+0.01	+0.01	-0.06	+0.01
	Top	-0.06	-0.01	-0.01	-0.03	+0.01
	Total	-0.06	+0.01	+0.01	-0.05	+0.01
D	Base	+0.06	+0.01	+0.01	+0.07	+0.02
	Middle	+0.08	+0.02	+0.01	+0.06	-0.01
	Top	+0.09	+0.01	+0.02	+0.08	-0.01
	Total	+0.09	+0.02	+0.02	+0.06	+0.02

TABLE (4): Statistical analysis of the horizontal deviation of the virtual models from the stone cast scan at cylindrical projections and their base, middle, and top cross sections at implant positions A, B, C and D. (p significant when < .05)

Implant position	Cross section location	Scanning techniques virtual models				
		I	II	III	IV	V
A	Base	0.05	0.06	0.08	0.06	0.05
	Middle	0.06	0.05	0.06	0.07	0.07
	Top	0.05	0.07	0.07	0.05	0.06
	Total	0.05	0.05	0.05	0.05	0.05
B	Base	0.07	0.08	0.06	0.08	0.07
	Middle	0.08	0.09	0.07	0.06	0.09
	Top	0.05	0.05	0.05	0.05	0.1
	Total	0.05	0.05	0.05	0.05	0.05
C	Base	0.00	0.09	0.08	0.03	0.06
	Middle	0.00	0.06	0.06	0.00	0.09
	Top	0.00	0.08	0.05	0.01	0.05
	Total	0.00	0.1	0.05	0.04	0.05
D	Base	0.01	0.05	0.06	0.00	0.07
	Middle	0.00	0.08	0.07	0.01	0.06
	Top	0.00	0.06	0.08	0.00	0.05
	Total	0.00	0.05	0.05	0.00	0.05

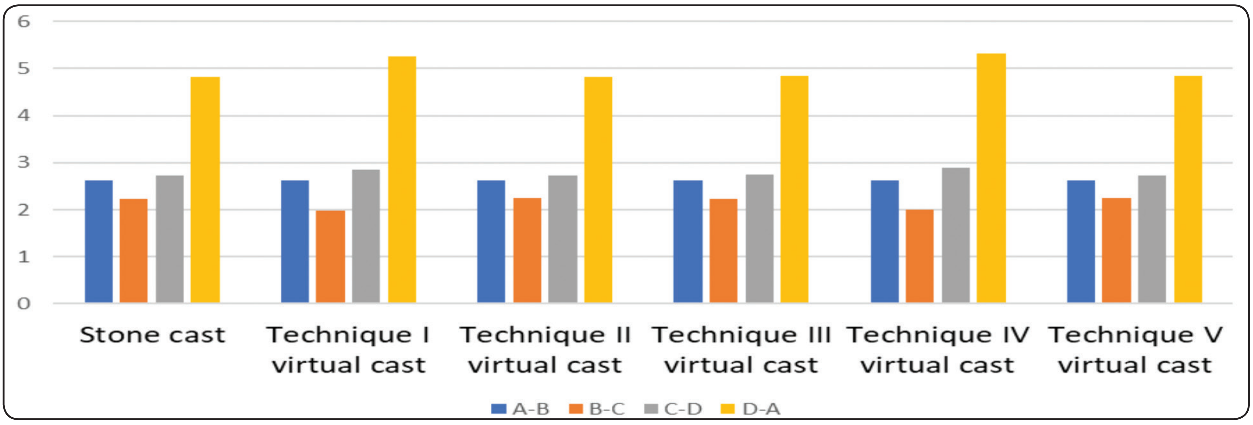

Fig. (9): comparison between the linear measurements made from one implant site to its successive on the stone cast and on the virtual models generated from the digital impressions.

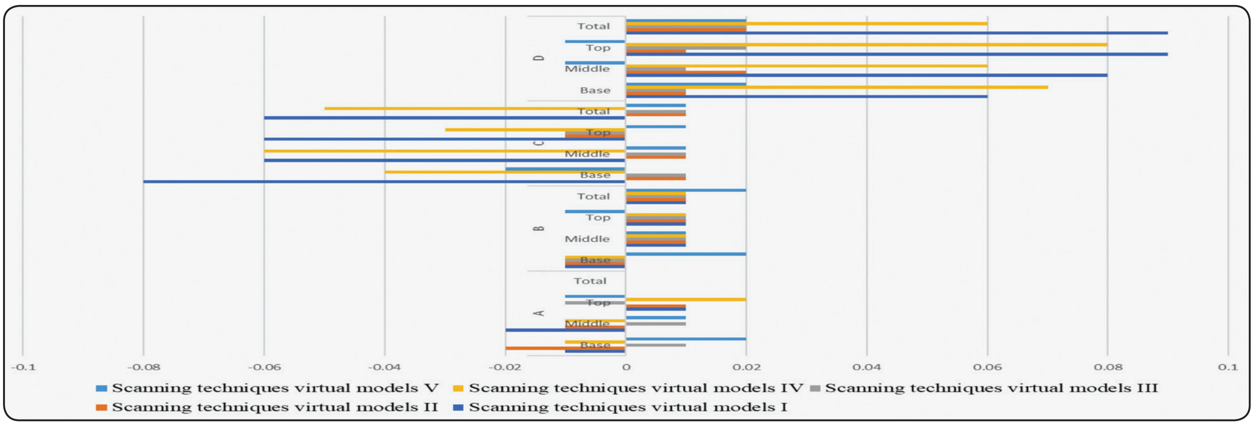

Fig. (10): Average horizontal deviations of the base, middle, top and whole of the cylinders superimposed on each implant sites A, B, C, and D as detected from the superimposition of the stone cast scan and the virtual models.

DISCUSSION

According to Mangano et al[8] optical impressions have several advantages over conventional impressions in being more comfortable to both patients and operators, time-efficient, and able to eliminate conventional plaster models. In addition, Mizumoto et al[1] stated that the use of ISBs with optical impressions appeared to be promising for the making of long span restorations as they can accurately transfer the implant positions from the patients mouths to the virtual models, although their digitalization and interaction with the IOS is not well understood, and are affected by the scanning protocol as suggested by Flügge et al.[2] However, in the reviews by Richert et al[13] and Sanda et al[24] no single scanning technique or technology could be unanimously considered more accurate than any other due to the heterogeneity in the research methodology. Also, the questions by Joda et al[3] about the ability of the ISBs to duplicate the dental implant emergence profile, and by Fluegge et al[4] about their ability to provide accurate data as the inter-scan body distance and geometries differed were answered by Motel et al[10] who found that Elos scan bodies, similar to these used in this study, were able to provide high accuracy and acceptable clinical results. Also, the scanner used in this study, Trios, was proved by Kim et al[15] and Scanners[18] to have high degree of trueness and precision as compared to other IOS although long-term follow-up studies were needed to confirm these positive results.

In a similar design to this study, Ribeiro et al[9] studied the accuracy of implant casts generated with conventional and digital impressions and found that for a model with four parallel implants, the deviations of the digital impressions were smaller than those associated with the conventional techniques. And in another study on the accuracy of digital impressions versus conventional impressions, Cappare et al[11] and Amin et al[12] found that digital full-arch implant impressions could be a reliable alternative to conventional impressions, however, these results came in contrast to the results of this study which detected significant differences between the linear measurements on the stone model and virtual models generated from the full arch continuous scanning techniques I and IV in the second and third sextants of the dental arch, which were thought to be due to defects in the long scanning and superimposition process of such edentulous areas by the used IOS, Also, the Geomagic superimposition study of the same casts revealed progressively larger horizontal deviations at implant positions C and D.

Similar to the results of this study, Rech-Ortega et al[6] reported differences between conventional and digital impressions in relations to the two most distal implant analogues, however, with the errors found in both impressions falling within the acceptable clinical range of 30 to 150 µm, Kim et al[15] also found that the deviations of digital impressions increased as the ISBs were further located from the reference origin. However, in comparison to the study of Arcuri et al[16] who detected extreme deviations of linear accuracy up to 520 µm with angulated implants, it seemed that the parallel placement of the implants guarantees minimal deviations and better passivity of final full arch restorations as also proved by AlTuwaijri[21] who found that 45-degree placement of the dental implants affected the accuracy of both polyvinyl siloxane and digital impressions captured by Trios IOS.

On the other hand, when the full arch digital impression scanning process was broken into 2 halves or 3 sextants, the results of this study were in agreement with the findings of ABDALLA and Dohiem[20] who found that ISBs could be accurate only in partially edentulous patients restorations, in agreement with Gimenez-Gonzalez et al[5] who concluded that the accuracy of the first scanned quadrant is always better than the second quadrants.

In conclusion, and in contrast to the findings of Alkhodary[25] that optical impressions could not replace conventional impressions of completely edentulous arches, and in contrast to the review by Mangano et al[8] that literature does not support optical impressions using IOS for the making of full arch restorations supported by implants or natural teeth, the results of this study found that the use of ISBs with IOS scanning techniques II, III, and V were able to regenerate virtual models with non-statistically significant deviations from the conventional stone model that were in the acceptable clinical range, and that the accuracy of such digital work flow could be improved if the IOS were used in consequent separate scans, not a full arch one continuous scan, as recommended by Mandelli et al,[19] that help minimize the deviations as the scanner moved from one quadrant to the other, and help control the saliva and tongue movement in clinical situations, in addition, due to the different available IOS technologies, Revell et al[23] thought that the increased experience of the operator using a certain IOS would help increase the accuracy of optical impressions that could be further improved by the use of ISBs. Finally, it is worth mentioning that this study had its limitations, as only one type of IOS was used, in only one scanning technique, and in an in-vitro and in in-silico settings.

CONCLUSIONS

Within the limitations of this study, the followings were concluded:

Virtual models generated from full arch digital impressions using intra-oral scan bodies and scanning techniques II, III, and V had no significant linear or horizontal plane deviations from stone models developed from conventional elastomeric impressions.

Recommendations

Clinical examination of the effects of different scanning techniques and intra-oral scan bodies on the passivity of full arch titanium, cobalt-chromium, and zirconia bars.

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