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Accuracy of Digital Models Obtained by Direct and Indirect Data Capturing of Multi-Implant Impressions

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ABSTRACT

Purpose: The present study was conducted both in-vivo and in-vitro. The aim was to evaluate the trueness and precision of three-dimensional datasets acquired from digital impressions by chair-side intraoral scanning, or extraoral scanning of the impressions and gypsum casts of completely edentulous patient with multiple implants (All-on-4 protocol). **Materials and Methods: Test groups of the in-vivo study: Group (I):** (IOS n=5) Direct digital scans using intraoral digital impression technique, **Group (II) :**(IMPR IL n=5) Digital scans of the conventional implant level impressions using extraoral scanner, **Group (III):**(CAST IL n=5) Digital scans of the stone casts - obtained from the conventional implant level impressions, **Group (IV):**(IMPR AL n=5) Digital scans of the conventional abutment level impressions using extraoral scanner and **Group(V):** (CAST AL n=5) Digital scans of the stone casts- obtained from the conventional abutment level impressions. **Test groups of the in-vitro study: Control group:** reference scan of the resin master models, **Group (I):** (IOS n=5) Direct digital scans of the master model using intraoral scanner, **Group (II):** (IMPR IL n=5) Digital scans of the conventional implant level impressions using extraoral scanner, **Group(III):**(CAST IL n=5) Digital scans of the stone casts - obtained from the conventional implant level impressions, **Group (IV):**(IMPR AL n=5) Digital scans of the conventional abutment level impressions, using extraoral scanner and **Group (V):** (CAST AL n=5) Digital scans of the stone casts- obtained from the conventional abutment level impressions. All STL datasets (IOS 1–5, IMPR 1–10 and CAST 1–10) for both in-vivo and invitro studies were imported into industrial reverse engineering software. The distance data were saved as an STL file and imported into a statistical program. The measurements were noted in tables and compared with the same measurements made with other scans. **Results:** The results of the in-vivo study revealed that the highest agreement (reliability-precision) between distance measurements was found with Group 1 (IOS), while the lowest agreement was found with Group 5 (CAST-AL) [insignificant difference] However; all Cronbach's alpha coefficients showed very good

KEYWORDS

All-on-4 implant concept, Trueness, precision, Intraoral scanner, Extraoral scanner, Implant level impression, Abutment level impression, Linear measurements.

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agreement (range between 0.812 - 1.000). As regards angle measurements; Group 2 (IMPR-IL) showed the highest agreement, while Group 5 (CAST-AL) showed the lowest agreement [insignificant difference]. Cronbach's alpha coefficients showed very good agreement (range between 0.912 – 0.988). Regarding the invitro study, the highest agreement (reliability-precision) between distance measurements was found with Group 1(IOS) , while the lowest agreement was found with Group 5 (CAST-AL) [insignificant difference]. However; all Cronbach's alpha coefficients showed very good agreement (range between 0.871 - 1.000). As regards angle measurements; Group 5 (CAST-AL) showed the highest agreement while Group 3 (CAST-IL) showed the lowest agreement [insignificant difference]. Cronbach's alpha coefficients showed very good agreement (range between 0.749 – 0.992). Overall comparison between errors in distance and angle measurements (In-vitro study) revealed that there were no statistically significant differences between overall dimensional changes in distance or angle measurements in all groups. **Conclusion:** It was concluded that the five digital impression techniques tested were comparable under all conditions, and the misfits were all within the clinically acceptable range.

INTRODUCTION

Passive fit of implant-fixed complete dental prosthesis depends on the accuracy of the implant cast. There are several clinical and laboratory variables that affect the accuracy of an implant cast, namely impression material properties, die stone properties, impression techniques, stone pouring techniques, implant angulation and depth, machining tolerance of implant impression components and the lengths of impression coping connections. However, the impression procedure still remains one of the most significant factor. Different implant impression techniques have been used to generate a definitive cast that will ensure the accurate clinical fit of implant-fixed complete dental prosthesis. [1-4] The misfit of frame work will generate stress on the implants, which may have a biological effect on the bone – implant interface. The passive fit of fixed dental prostheses on dental implants has been considered critical in decreasing the incidence of mechanical complications such as screw loosening, screw fracture, stripped threads, fractures of implants, and frameworks. [5-7]

CAD/CAM fabricated frameworks demonstrate a more consistent and superior passive fit than conventional cast frameworks. The CAD/CAM process allows the omission of several steps used in the conventional casting technique, including waxing, investment, casting, and polishing. These procedures are considered to introduce inaccuracies and the inaccuracies may become more evident with more extensive frameworks. The optical impression can be done directly or indirectly. For the indirect systems, the digitalization is obtained from the impression or cast, and for the direct techniques the images are taken directly from the mouth using intraoral scanners. [6-8] For clinical application one central question arises; how accurate are digital impression methods compared to the conventional procedure of impression taking, cast fabrication and indirect digitalization in the dental laboratory? To describe the accuracy of digital three-dimensional models, the parameters of "trueness" and "precision" are applied. Precision describes how close repeated measurements are to each other. The higher the precision, the more predictable is the measurement. Trueness describes how far the measurement deviates from the actual dimensions of the measured object. A high trueness delivers a result that is close or equal to the actual dimensions of the measured object. [9]

The present study was conducted both invivo and invitro. The aim was to evaluate the trueness and precision of three-dimensional datasets acquired from digital impressions by chair-side intraoral scanning, or extraoral scanning of the impressions and gypsum casts of completely edentulous patient with multiple implants (All-on-4 concept).

MATERIALS AND METHODS

I) In-vivo study

The diagnosis was made clinically and radiographically (Preoperative cone beam computed tomography scan (CBCT) was obtained. The patient received his written informed consent for implant

placement and impression procedures. Research Ethics Committee (REC) approval was obtained. Information about treatment and follow up appointments were given to the patient prior to surgical procedure.

Surgical procedures:

The surgical guide was secured in position with the aid of the pins, then the tissue was punched four punches. The posterior implants, which were 4.2 mm in diameter and 16 mm in length, typically emerged at the second premolar position. The posterior implants were placed close to the anterior wall of the mental loop and were tilted distally about 30 degrees relative to the occlusal plane. Anterior implants were 3.7 mm in diameter and 13 mm in length (implant direct, legacy 1). The anterior implants were typically placed in lateral incisor positions. This implant arrangement resulted in a large inter-implant distance and short cantilever length.

Comparison of digital impression techniques:

The present in-vivo study compared the precision of three-dimensional datasets acquired from digital impressions (direct data acquisition by chair-side intraoral scanner) with extraoral scanning of the impression and gypsum casts obtained from them (indirect data acquisition) for completely edentulous arch with four implants.

Test groups-implant impression techniques:

Precision of direct and indirect digital impression techniques were compared through five test groups (for the same patient) **(Table 1).**

Direct digital implant impression procedure:

Following the manufacturer's protocol, 5 repeated digital impressions were taken with a digital intraoral scanner (Planmeca OY, Helsinki, Finland). This is a device that relies on short wavelength laser light projection (450 nm). The scanner does not require the application of powder on the intraoral surface. In addition, the scanning software allows digital casts to be exported in the open STL format. Scan adapters (Implant Direct, Sybron international) were connected to the implants in the patient's mouth by hand tightening. After the acquisition of 5 repeated digital impressions, the digital volumes were exported as STL files for comparison. The model rendered from the first scan served as the control surface for the consecutively acquired models in each group. To obtain the precision or repeatability data, the linear and angular measurements obtained from direct digital impressions were compared, and the differences showed their precision. The repeatability of the scanning was confirmed by unscrewing the scan adapters after every scan and re-screwing them back and re-scanning. [4]

Table (1): *Test groups for the in-vivo study:*

Test group	Description
GROUP I:(IOS n=5)	Direct digital scans of the patient's mouth, using **intraoral digital scanner.**
GROUP II:(IMPR IL n=5)	Indirect digital scans of the conventional **implant level impressions** using extraoral scanner.
GROUP III:(CAST IL n=5)	Indirect digital scans of the **stone casts** - obtained from the conventional **implant level** impressions- using extraoral scanner.
GROUP IV:(IMPR AL n=5)	Indirect digital scans of the conventional **abutment level impressions**, using extraoral scanner.
GROUP V:(CAST AL n=5)	Indirect digital scans of the **stone casts**- obtained from the conventional **abutment level** impressions- using extraoral scanner.

Conventional implant level / abutment level impression procedures:

Addition silicone impression material (Imprint II Garant quick step, heavy and light, 3M ESPE) was used for all conventional implant impressions. Five implant impressions were taken to fabricate 5 implant casts for each technique (5 implant level impressions and 5 abutment level impressions). Two different techniques were used for impression taking: I- Closed tray, pick up, abutment-level impression technique: Multiunit abutments (overdenture abutment) were fastened to the implants. The overdenture abutment plastic copings were connected to the abutments. All impression copings were secured. An auto-mixing cartridge was used for mixing the impression material. The impression materials were allowed to polymerize for 4 minutes after the start of the procedure according to the manufacturer's recommendation**.** II-Closed tray, pick up, implant-level impression technique: All copings were connected to the implants by press fit. PVS was placed inside the tray (heavy body) and injected around the copings (light body) using a dispenser. After the impression material had polymerized (4 minutes from the start of mixing), the tray was removed.

Indirect data capturing (extraoral scanning of the addition silicone impressions) (Novel technique):

The impressions were disinfected with Lysoformin 3000 for 10 min (Lysoform, Berlin, Germany) .Open technologies scanner was used (Open Technologies, Italy).The accuracy of the system is 5 um, and the repeatability is 2 um based on company tests, comparing to results with CMM (coordinate measurements machine).Three hours after impression taking, all trays were digitized by the extraoral scanner, [(1)] and STL data were exported (IMPR 1–10):For the implant level impressions, implant analogs were connected to the overdenture plastic copings inside the addition silicone impressions, then digitized (IMPR IL 1-5). For the abutment level impressions, abutment analogs were connected to the overdenture abutment plastic copings inside the impressions (IMPR AL 1-5). Each impression was sprayed with a thin layer of scanning powder, then scanned.

Fabrication of casts from conventional impressions:

Twenty-four hours after removal, the impressions were poured with a low expansion (0.08%) type IV dental stone (Elite Rock, Zermack S.P.A -via Bovazecchino,100 45021 Badia polesine (Rovigo) -Italy), and master casts were obtained. [(1)] Stone was mixed with a powder/water ratio of 100 g/20 mL. The stone was mixed manually with distilled water for 15 s to aid the incorporation of the water. An initial pour of stone up to the middle of the analogs was carried out. After 30 mins, the second pour of stone was carried out. This double pouring technique minimizes the volumetric expansion of the stone and has been shown to lead in more accurate casts. The stone casts were allowed to set for 1 hr, as per manufacturer's recommendations, before separation from the impressions. All casts were stored at room temperature of 21°C for at least 96 hrs until the expansion of gypsum was complete.

Indirect data capturing (Extraoral scan of gypsum casts with lab scanner):

For the implant level stone cast (CAST-IL 1-5), scanbodies were placed on the first test cast.[(10)] For all digital scans, the same scanbodies were moved from their mandibular corresponding position in cast 1 to cast 5 to eliminate the effect of scanbodies. For the abutment level stone cast (CAST-AL 1-5) the abutment analogs were sprayed with the scan spray to be prepared for scanning. Each model was applied on the object support of the extraoral scanner and digital scanning was performed. The same scanning procedures were carried out for all 10 casts of the two test groups (CAST-IL 1-5, and CAST-AL 1-5). The STL digital files were saved to a compact disc.

Linear and angular measurements:

All STL datasets (IOS 1–5, IMPR 1–10 and CAST 1–10) were imported into industrial reverse engineering software (Geomagic design X 2015,

Geomagic, Morrisvelle, USA) and evaluated for possible irregularities such as deformations. The linear and angular deflections of the centerlines of the scan abutments (in IOS or CAST groups) or analogs in (IMPR group) were measured with linear and angular measurement tool in the software. Measurements included the differences in individual implant positions in the 3 planes of space. The distance data were saved as an STL file and imported into a statistical program. The measurements were noted in a table and compared with the same measurements made with other scans of the same group. [10]

II) In-vitro study:

The invitro study compared the trueness (comparison between a control dataset and a test dataset) and precision (comparison between repeated measurements in the same test group) of three-dimensional datasets acquired from:1- Direct data acquisition (by using intraoral scanner) of four implants, on a resin cast (N.B; Resin cast of the patient in the in-vivo part of the study was utilized).2- Indirect data acquisition (by using extraoral scanner) of: a- Impressions (at both implant level and abutment level), for the four implants, on the resin cast .b- Gypsum casts generated from them. Thus, two master models were used for this study: **Master model 1**: contains implant analogs, representing the four implants in the patient's mouth. This model was used for obtaining direct scans by using the intraoral scanner, and implant level impressions. **Master model 2**: contains abutment analogs, representing the four abutments in the patient's mouth. This model was used for obtaining abutment level impressions.

Impression procedures

Direct digital implant impression procedures (using intraoral scanner):

ter model 1 with hand tightening. The master model was digitized, following the manufacturer's protocol. Five repeated digital impressions were taken with a digital intraoral scanner at implant level. The same steps were followed as in the in-vivo part of the study. After the acquisition of 5 repeated digital impressions, the digital volumes were exported as STL files for comparison. The model rendered from the first scan served as the control surface for the consecutively acquired models in each group.

Indirect digital scanning (using extraoral scanner):

Two different techniques were used for impression taking (in special trays): a) Closed tray, pick up, implant-level impression technique (for master model 1) b) Closed tray, pick up, abutment-level impression technique (for master model 2). The same impression protocol followed

for the invivo study was used. Indirect data capturing (using extraoral scanner) of addition silicon impressions was done following the same steps used in the in-vivo study.

Standardized pouring techniques were used for the fabrication of all casts. Following the same steps used in the in-vivo study. Indirect data capturing (using extraoral scanner) of the stone casts was carried out exactly as in the in-vivo study.

Trueness is defined as the comparison between a control dataset and a test dataset. Linear and angular measurements of the master casts (golden reference, control dataset) were taken using highly accurate reference scanner [Smart optics scanner (Activity 885, Germany)] which is a fast, fully automatic scanner with large measurement field.

The comparison of the measurements taken from digital impressions with measurements taken from the control dataset (golden reference) provided the basis for the trueness of the direct digital impression method. To obtain the trueness of the indirect scanning technique, measurements taken from the impression and cast scans were compared to the measurements taken from the control dataset (golden reference; reference scan of the master model).

To obtain the precision data, the direct digital impressions were compared to each other and the differences showed their precision. To obtain the precision data, the scans were compared to each other to determine the precision of the indirect scanning procedures.

Statistical analysis:

Differences between groups and control represent the dimensional changes. Dimensional change data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. All data showed non-normal (non-parametric) distribution. Data were presented as mean, standard deviation (SD), median and range values. Friedman's test was used to compare between the groups. Dunn's test was used for pair-wise comparisons when Friedman's test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® (IBM Corporation, NY, USA) SPSS® (® SPSS, Inc., an IBM Company) Statistics Version 20 for Windows.

RESULTS

I. In-vivo study: Precision (repeatability, agreement, reliability) measurements:

The highest agreement (reliability) between distance measurements was found with Group 1 (IOS), while the lowest agreement was found with Group 5 (CAST-AL). However; all Cronbach's alpha coefficients showed very good agreement (range between 0.812 - 1.000). There were no statistically significant differences between the five groups. **(Table 2)** As regards angle measurements; Group 2 (IMPR-IL) showed the highest agreement while Group 5 (CAST-AL) showed the lowest agreement. Cronbach's alpha coefficients showed very good agreement (range between 0.912 – 0.988). There were no statistically significant differences between the five groups **(Table 2).**

Table (2): *Results of Cronbach's alpha reliability coefficient and Intra-Class Correlation Coefficient (ICC) for in-vivo measurements*

Group	Distance (mm)		Angle (°)	
	Cronbach's alpha	ICC	Cronbach's alpha	ICC
Group 1 (IOS)	1.000	0.999	0.984	0.953
Group 2 (IMPR-IL)	0.998	0.995	0.988	0.966
Group 3 (CAST-IL)	0.995	0.985	0.923	0.799
Group 4 (IMPR-AL)	0.999	0.997	0.979	0.939
Group 5 (CAST-AL)	0.812	0.775	0.912	0.776

II. In-vitro study: Precision (repeatability, agreement, reliability) measurements:

The highest agreement (reliability) between distance measurements was found with Group 1(IOS) while the lowest agreement was found with Group 5 (CAST-AL). However; all Cronbach's alpha coefficients showed very good agreement (range between 0.871 - 1.000). There were no statistically significant differences between the five groups. **(Table 3)** As regards angle measurements; Group 5 (CAST-AL) showed the highest agreement while Group 3 (CAST-IL) showed the lowest agreement. Cronbach's alpha coefficients showed very good agreement (range between 0.749 – 0.992). There were no statistically significant differences between the five groups. **(Table 3)**

Table (3): *Results of Cronbach's alpha reliability coefficient and Intra-Class Correlation Coefficient (ICC) for in-vitro measurements*

Group	Distance (mm)		Angle (°)	
	Cronbach's alpha	ICC	Cronbach's alpha	ICC
Group 1(IOS)	1.000	0.999	0.961	0.892
Group 2 (IMPR-IL)	0.995	0.974	0.985	0.929
Group 3 (CAST-IL)	0.999	0.995	0.749	0.428
Group 4 (IMPR-AL)	0.999	0.991	0.989	0.928
Group 5 (CAST-AL)	0.871	0.575	0.992	0.962

Trueness measurements for the invitro study:

Descriptive statistics of dimensional changes in the different groups regarding Distance I are presented in **(Table 4).** There were no statistically significant differences between the five groups.

Descriptive statistics of dimensional changes in the different groups regarding Distance II are presented in **(Table 5)**. There were no statistically significant differences between the five groups.

Descriptive statistics of dimensional changes in the different groups regarding Distance III are presented in **(Table 6)**. There were no statistically significant differences between the five groups.

Table (4) *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding distance I*

Group		Mean	SD	Median	Range (Minimum-Maximum)		*P*-value
Group 1	Model 1	0.120	0.125	0.046	0.034	0.282	0.331
Group 2		-0.063	0.335	-0.090	-0.505	0.333	
Group 3		0.223	0.092	0.237	0.099	0.321	
Group 4	Model 2	0.384	0.256	0.418	0.006	0.699	
Group 5		-0.087	0.351	0.029	-0.636	0.275	

**: Significant at P ≤ 0.05*

Table (5) *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding distance II*

Group		**Mean**	**SD**	**Median**	**Range(Minimum-Maximum)**		**P-value**
Group 1	**Model 1**	**0.046**	**0.056**	**0.045**	**-0.016**	**0.109**	**0.215**
Group 2		**0.041**	**0.328**	**0.125**	**-0.492**	**0.386**	
Group 3		**-0.374**	**0.345**	**-0.489**	**-0.634**	**0.115**	
Group 4	**Model 2**	**-0.729**	**0.405**	**-0.903**	**-1.044**	**0.068**	
Group 5		**-0.040**	**0.192**	**-0.062**	**-0.300**	**0.214**	

**: Significant at P ≤ 0.05*

Table (6) *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding distance III*

Group		Mean	SD	Median	Range (Minimum – Maximum)		*P*-value
Group 1	Model 1	-0.196	0.061	-0.196	-0.264	-0.128	0.406
Group 2		-0.145	0.266	-0.238	-0.463	0.150	
Group 3		0.016	0.162	-0.004	-0.159	0.233	
Group 4	Model 2	0.461	0.451	0.467	-0.257	1.008	
Group 5		0.063	0.509	-0.160	-0.300	0.957	

**: Significant at P ≤ 0.0*

Descriptive statistics of dimensional changes in the different groups regarding Angle I are presented in **(Table 7)**. There were no statistically significant differences between the five groups.

Descriptive statistics of dimensional changes in the different groups regarding Angle II are presented in **(Table 8)**. There were no statistically significant differences between the five groups.

Overall comparison between errors in distance measurement (In-vitro study):

Calculating the arithmetic mean from positive and negative deviations leads to results close to zero and is not displaying the real divergences sufficiently. The mean absolute values of the Euclidean distances were calculated by summing up the absolute positive and negative deviations and dividing the results by the number of measured points. There was no statistically significant difference between overall dimensional changes in distance measurements in all groups.**(Table 9)**

Table (7) *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding angle I*

Group		Mean	SD	Median	Range(Minimum-Maximum)		*P*-value
Group 1	Model 1	0.445	0.999	0.548	-0.721	1.507	0.147
Group 2		-1.442	2.777	-1.848	-4.498	3.019	
Group 3		0.392	2.089	0.437	-2.129	2.823	
Group 4	Model 2	-2.298	2.977	-2.486	-7.545	0.744	
Group 5		0.051	4.089	-1.203	-2.892	7.225	

**: Significant at P ≤ 0.05*

Table (8): *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding angle II*

Group		Mean	SD	Median	Range (Minimum –Maximum)		*P*-value
Group 1	Model 1	2.333	1.004	2.495	1.138	3.366	0.558
Group 2		-0.619	3.757	-0.686	-5.254	4.626	
Group 3		1.424	2.637	0.925	-1.135	4.982	
Group 4	Model 2	1.799	3.295	0.946	-2.900	6.007	
Group 5		1.803	2.737	2.662	-2.769	4.548	

**: Significant at P ≤ 0.05*

Table (9): *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding overall distance measurement (mean of distance I, II and III)*

Group		Mean	SD	Median	Range (Minimum – Maximum)		*P*-value
Group 1	Model 1	0.02	0.02	0.01	0.00	0.04	0.151
Group 2		0.09	0.08	0.07	0.01	0.19	
Group 3		0.08	0.05	0.08	0.02	0.13	
Group 4	Model 2	0.06	0.07	0.06	0.00	0.21	
Group 5		0.15	0.15	0.10	0.00	0.31	

**: Significant at P ≤ 0.05*

Overall comparison between errors in angle measurement (In-vitro study) :

There was no statistically significant difference between overall dimensional changes in angle measurements in all groups. **(Table 10)**

Table (10) *Descriptive statistics and results of Friedman's test for comparison between dimensional changes of the different groups regarding overall angle measurement (mean of angle I and II)*

Group		Mean	SD	Median	Range (Minimum – Maximum)		*P*-value
Group 1	Model 1	1.39	0.81	0.89	0.84	2.44	0.736
Group 2		1.47	1.54	1.00	0.11	3.55	
Group 3		0.91	0.36	0.79	0.62	1.43	
Group 4	Model2	0.65	0.47	0.71	0.02	1.24	
Group 5		1.76	1.79	1.86	0.10	4.56	

**: Significant at P ≤ 0.05*

DISCUSSION

The results of our study were in accordance with many previous studies. [1,5,11-16] A previous study concluded that digital impressions create accurate physical models for all-on-four implants rehabilitation, [5] and that x-ray examination revealed a bar – implant connection accuracy. Another study concluded that clinical precision of digital quadrant impression models (I Tero Cadent, Lava COS, Lava true definition, 3 Shape Trios, Trios color, Cerec blue cam and Cerec omnicam) is sufficient to cover broad variety of restorative indications, giving precision within clinically acceptable range. [17] Another study performed a systematic review and concluded that measurements from digital models produced from intraoral scanners appear to be reliable and accurate in comparison with those from conventional impressions. [13] Another investigation concluded that intraoral scanners are as reliable as traditional plaster models. [14]

Conversely, our results contradicted many results in the literature. [18,17,19,20,21,22,23,10,24] It was stated that Lava COS intraoral scanner revealed significantly better marginal fit of crowns, than crowns fabricated from silicone impressions. [21] In 2013, another study concluded that direct digitalization with Lava COS was more accurate than conventional procedures of impression making and indirect digitalization for 4 – unit FPD. This could be explained on the basis that all these studies scanned single tooth or small section of the dental arch. Meanwhile, the full arch scanning protocol used in our study might have resulted in greater error in the direct digital scan group. In 2013, it was stated that scanning edentulous jaw clinically with I-Tero Cadent intra-oral scanner, resulted in lower precision than scanning conventional casts with laboratory scanner (3 shape D 250). [23] In 2014, it was concluded that intra-oral scans obtained from edentulous mandibles invivo with i-Tero Cadent had too large distance and angle errors to fabricate a well-fitting framework on implants in edentulous mandibles. [10] This can be easily explained on the basis of the single picture scanning technique of the I-Tero scanner, which results in great error in full arch scans of edentulous patients due to wrong stitching of the multiple pictures. This is in turn due to the lack of anatomic landmark for scanning caused by mucosa little variation in texture and height.

In general, the abutment level impression technique has been the favored technique for internal connection implant systems. However, selection of abutments can be difficult under conditions of extensive rehabilitation where vertical space or

angulation of implants is inappropriate. Laboratory evaluation of the master cast produced from an implant-level impression facilitates the selection and correction of abutments and prostheses. [25] Digital scanning of the abutment level cast is considered as a recent technique, proposed by few implant prosthetics companies (like Zirkonzahn, Dess, Arum), which recently began to supply scanbodies to be fitted on the abutments, and are compatible with many implant systems (like Noble biocare, Straumann, Dentium, Implant direct). So, in our present study, we compared implant position accuracy in casts obtained from both implant level and abutment level impressions. The results of our study revealed that there was no significant difference between both implant level and abutment level impression scanning groups. This is because we used metal coping for implant level impression, which makes it more advantageous over the less accurate plastic coping used for the abutment level impression. Yet, we evaluated impressioning of four implants placed in the master cast with All-on-4 implant scenario (two straight, and two angulated implants 30^0), which makes the abutment level impression more advantageous, as the impression copings are fitted on the multiunit abutments which negate the implant angulation, and makes impression removal easier, generating less stresses, with less distortion. So, the net result was non-significant difference between both techniques.

The relative difference in the positional accuracy of the impression coping/ laboratory analog within the impression can be measured directly without the use of a dental cast, thereby eliminating the possible inherent additional distortion caused by the laboratory fabrication of a cast. The pouring procedure can alter the positional relationship of the copings because of the expansion involved in the setting of the dental stone. [3] Impression scanning is a well-documented technique for crown and bridge work, but for implant work only few researches evaluated implant impression scanning. [26] Implant impression scanning is considered a novel technique, and is still under investigation by implant prosthetics companies like Zirkonzahn. Scannable analogs are still not released in the market nor included in the digital library of the CAD software. So, in our study, we compared implant position accuracy through scanning the implant impressions (for both implant level and abutment level) and casts generated from them, for multiple, angulated, internal connection implants. In the present study, we introduced a novel procedure to scan implant impressions and use the generated STL files for framework milling.

The results revealed that there was no statistically significant difference between impression and cast scanning groups. This is in accordance with the previous study in 2008 [11] which stated that the precision of digital impression and stone casts did not differ significantly. Also in 2016 it was concluded that no advantage in accuracy was gained by digitizing the conventional impression directly compared with using conventional pouring procedures. [20] In 2013, it was concluded that there is a statistically significant difference between impression and cast scanning. [18] This might be due to the different scanning techniques used for both groups. In the impression scan group, they used micro CT, while in the cast scan group they used desktop scanner Lava ST, which might be the cause of the diverse results. So, it seems that all of the digital impression techniques used in our study gave misfit that fall within the acceptable range (ranging from 20 +/-20 um for group 1 to 150+/-150 um in group 5).

CONCLUSIONS

Within the limitations of the current investigation, it was concluded that:

1. The five digital impression techniques tested were comparable under all conditions.
2. The misfits of the five digital scans were all within the clinically acceptable range.

CLINICAL RECOMMENDATIONS

Each clinician has the freedom to select the suitable digital impression technique for his patient, according to the demands of each clinical situation.

Further studies, particularly long-term prospective clinical trials, are needed to determine more accurately the amount of distortion tolerable biologically and mechanically to clinically analyze failures and complications in this context.

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