ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
March 2025 • Vol. 37

Assessment of the effect of scan body splinting on the trueness of digital impression in complete-arch implant-supported prosthesis: A comparative in vitro study

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Aim: To assess whether splinting of scan bodies or not affects the trueness of a complete-arch digital implant impression by comparing it with the gold standard splinted open-top conventional technique.
Materials and Methods: A mandibular resin model with four parallel digital implant analogues in the 36, 33, 43, and 46 tooth positions was used. On the model, three impression techniques were performed: conventional splinted implant level open tray impression (Group I), digital impression using an intraoral scanner with separate scan bodies (Group II), and digital impression using an intraoral scanner with splinted scan bodies (Group III). The trueness of the impressions was evaluated using surface matching software. Statistical analysis was done using repeated measures ANOVA, followed by Bonferroni post hoc test.
Results: The results revealed that there is a significant difference between the trueness of the three techniques ($p > 0.001$), with the least deviation recorded in Group I (54.45±5.60 µm) and the highest deviation recorded in Group II (97.90±6.62 µm).
Conclusion Splinting of the scan bodies causes significant improvement in the trueness of the complete-arch digital impression using an intraoral scanner.

Keywords: accuracy, geomagic software, scan body splinting.

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Introduction

The key to a successful complete-arch implant-supported prosthesis is the proper acquisition of the spatial orientation of the dental implants inside the patient's mouth and their transfer to the master cast on which the final prosthesis is fabricated. This procedure influences the marginal fit of the final prosthesis on the dental implants, which is crucial for long-term mechanical and biological implant-prosthesis success. [1] In the past decades, different conventional impression techniques have been used. The splinted open tray impression technique was considered the gold standard for complete-arch implant-supported prosthesis. [2,3]

Nowadays, with the advancement of digital technology in the dental field, digitalization of the process of constructing a complete-arch implant-supported prosthesis has become a high priority. [4] One of the most critical steps in the construction of a complete arch prosthesis using CAD/CAM technology is obtaining the impression using dental scanners. Originally, disc top scanners were used to scan conventional impressions done by the open tray technique with the implant analogues attached to the impression copings or to scan the master cast with the scan bodies (SBs) attached to it. [5,6]

With the continuous development of digital technology, the current intraoral scanners (IOSs) have allowed for the proper recording of the implant's spatial orientation as well as the peri-implant structures, [7] while avoiding the potential errors of the conventional technique, such as the dimensional changes of the materials used and the potential for cross-infection. [8,9] It also allows for virtual evaluation of the prosthetic space and the emergence profile, as well as easier communication between the clinician and the dental lab. [10]

Several studies have proved that IOSs can be used successfully in the fabrication of implant-supported single crowns and fixed partial dentures, [11–14] yet their accuracy for the fabrication of implant-supported complete-arch prostheses is still controversial. The accuracy of IOSs can be described in terms of trueness and precision, where trueness is determined by the ability of the used IOS to produce a digital image that is closely related to the captured object without deviation or distortion, while precision is determined by the degree of reproducibility between repeated scans under the same conditions. [6,15]

As reported by Zhang YJ et al., [16] many factors affect the accuracy of a complete-arch digital scan using IOSs, including limited landmarks and reference points, implant position, angulation, and depth; width of the mouth opening of the patient; operator's experience; type of SBs used; accuracy of the used IOS; and scanning strategy. The limited number of landmarks and reference points, such as teeth or keratinized mucosa, lead to errors in the stitching process, causing larger deviations. [6,16–18]

Several options have been suggested to overcome the effect of limited landmarks on the stitching process, like positioning adhesive radiopaque markers, composite resin in the span between the implants, [19] or splinting the SBs to act as landmarks, thus increasing the number of reference points to be scanned. [20]

Therefore, this study was conducted to assess the trueness of the digital impression using IOS with separate and splinted SBs in comparison to the gold standard conventional technique for complete-arch implant-supported prosthesis. The null hypothesis assumed that there was no statistically significant difference between the trueness of the three impression techniques.

Materials and Methods

Study design and sample size calculation

In this study, a mandibular resin model having four parallel digital implant analogues was used. On the model, three impression techniques were performed, conventional splinted implant level open tray impression (Group I), digital impression using an intraoral scanner with separate scan bodies (Group II), and digital impression using an intraoral scanner with splinted scan bodies (Group III). Sample size calculation was performed using G*Power version 3.1.9.7 based on the results of a previous study. [21] A power analysis was designed to have adequate power to apply a two-sided statistical test to reject the null hypothesis that there is no difference between the tested groups regarding the impression trueness. By adopting an alpha level of 0.05, a beta level of 0.8, an effect size of 0.6, and an actual power of 0.8, the predicted total sample size was found to be 30 samples, 10 per group.

Reference model fabrication

A desktop scanner (D850, 3Shape, Copenhagen, Denmark) with an accuracy of 7-8 µm calibrated according to the manufacturer's recommendations was used for scanning an edentulous mandibular educational cast, and then the scan was saved as a standard tessellation language (STL) file. The STL file was imported into a model creator CAD software (Exocad, DentalCAD 3.0 Galway; Exocad GmbH, Darmstadt, Germany). Four parallel virtual implant analogues were placed in 36, 33, 43, and 46 tooth positions with an inter-implant distance of 22 mm between the two anterior implants and 15 mm between the anterior and posterior implants on either side. The design was exported in the form of an STL file.

The model was printed using a 3D LCD printer (Phrozen printer, Phrozen Tech Co. Ltd., Taiwan) and polymethyl methacrylate resin (NextDent Model, NextDent, Soesterberg, Netherlands) with a build layer thickness of 100 µm. The printer and the resin were calibrated according to the manufacturer's recommendations. After printing, the model was rinsed twice with ethanol for 3 minutes and air-dried for 15 minutes. The mandibular resin model was placed in the post-curing unit (Phrozen Cure Luna, Phrozen Tech Co. Ltd., Taiwan) for 15 minutes to ensure the curing of the unreacted monomer. Digital implant analogues (Flotechno, Milan, Italy) were retrofitted into the implant beds and cemented using a small amount of cyanoacrylate cement; this model served as the master cast. SBs were attached to the implant analogues, and the cast was scanned using a desktop scanner (D850, 3Shape, Copenhagen, Denmark). The created STL file served as the reference file for the three groups.

Conventional impression technique

For group I, implant-level pick-up impression copings (Flotechno, Milan, Italy) were hand-tightened to the implant analogues on the master cast. Two layers of baseplate wax were applied to the copings and one layer to the posterior edentulous areas, followed by the fabrication of ten custom impression trays (Acrostone Medical and Dental Supplies, Egypt) with holes corresponding to the guiding pins of the copings. After fabricating the trays, the baseplate wax was removed to expose the copings, which were subsequently splinted together using dental floss and injectable light-cured hard liner resin material (Crezion pattern LC jig gel, Korea) (Figure 1)
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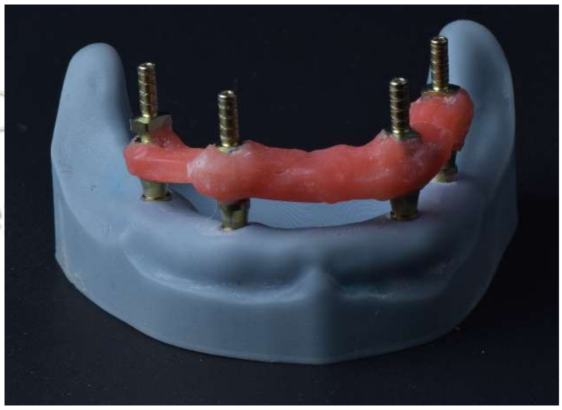

Figure 1: Group I, open tray impression copings splinted with hard liner material.

To decrease the amount of shrinkage in the resin splint, after the hard liner set, the splint was sectioned using a disc, and then the sections were reassembled by adding a thin film of injectable hard liner resin (Crezion pattern LC jig gel, Korea).

Adhesive (Identium adhesive, kettenbach, USA) was applied to the fitting surface of the tray for 7 to 10 minutes, then medium-body consistency polyether impression material (Impregum F, 3M, USA) was added, and the tray was seated over the master model and held in place until the material set. When the impression material set, the tray with the copings picked inside it was removed from the cast, and the implant analogues (Flotechno, Milan, Italy) were secured to the copings. The cast was poured using a vacuum-mixed type IV dental stone (Elite Master, Zhermack, Rome, Italy) with a water-powder ratio of 1:5. The cast was separated from the impression after 1 hour and stored at room temperature. SBs (Flotechno, Milan, Italy) were screwed to the implant analogues with a torque of 15 Ncm (Figure 2) and the cast was digitized using the desktop scanner (D850, 3Shape, Copenhagen, Denmark), and the STL file was saved.

Figure 2: Scan bodies screwed to the implant analogues embedded in the stone cast.

Digital scan with separate SBs

For Group II, the SBs (Flotechno, Milan, Italy) were hand-tightened to the digital implant analogues on the master model (Figure 3).

The model was digitally scanned using an IOS (OVO, 3Disc, Virginia, USA) with software version 4.1.0507.1 and an accuracy of 37.2 µm calibrated according to the manufacturer's instructions. The curvilinear scanning protocol was adopted. The scanning began at the occluso-buccal surface of the distal SB on the right side and progressed toward the distal SB on the left side. From this point, the IOS began to scan the occluso-lingual surface of the distal SB on the left side, progressing to the right side. After the scanning procedure was completed, the STL file was saved.

Figure 3: Group II, scan bodies hand tightened to the digital implant analogues on the master cast.

Digital scan with splinted SBs

For Group III, on the master model, the SBs (Flotechno, Milan, Italy) were splinted at the neck of the SBs, which is the non-scannable portion of the SB—fabricated from non-reflective titanium—using dental floss and an injectable hard-liner resin material (Crezion pattern LC jig gel, Korea). The scanning procedure followed the same sequence using the same IOS (OVO, 3Disc, Virginia, USA) as in Group II (Figure 4), and the STL file was saved.

Figure 4: Digital scan for group III.

The entire workflow for each technique was performed ten times. All the digital scans were performed on the same day, following a standardized scanning path and under the same lighting conditions, by the same prosthodontist, who has 3 years of experience in using IOSs. SBs were not detached from the implant analogues until all the repeated scans for each group were completed. When errors occurred during image acquisition, such as distortions or overlaps, the procedure was repeated.

Data measurement (Evaluation of the trueness of the impression techniques)

All STL files were imported into CAD software (Exocad, DentalCAD 3.0 Galway, Exocad GmbH, Darmstadt, Germany). The matching SB (Flotechno, Milan, Italy) in the library was selected, superimposed on each SB one by one, and then the areas containing the SBs were isolated from the whole scan and saved as an STL file. The original STL file was discarded, and the new STL file was used for the 3D deviation analysis. A surface matching software (Geomagic Control X; 3D Systems Inc.) was used to assess the degree of deviation (trueness) between the reference STL and the STL files of the three impression techniques. The reference file was imported to the software and set as reference data, and the STL file for each impression scan was imported to the software and set as measured data. First, manual initial overlap was done, and then, for better alignment between the two files, the best fit algorithm option was selected, followed by the 3D compare option. The 3D deviation was presented in the form of a colorimetric map (Figure 5) with a maximum deviation scale from +100 µm to –100 µm, where the green color represents no or minimal deviation, the different shades of blue represent inward deviations, and the different shades of yellow and red represent outward deviations.

This process was repeated for each impression scan by the same operator (T.M. El-S.). The resultant data for each comparison was presented in the form of root mean square (RMS) values.

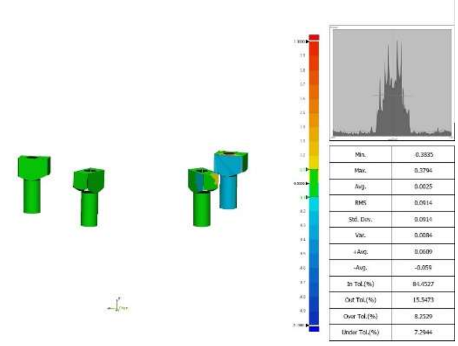

Figure 5: Colorimetric map showing the 3D deviation of the isolated scan bodies, showing inward deviation in different shades of blue, outward deviation in different shades of yellow, and minimal deviation in green.

Data analysis

Statistical analysis was performed with R statistical analysis software version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria) for Windows. Numerical data was represented as mean and standard deviation (SD) values. Normality and variance homogeneity assumptions were confirmed using Shapiro-Wilk's and Levene's tests, respectively. Data were analyzed using repeated measures ANOVA followed by Bonferroni post hoc test. Effect sizes were calculated and interpreted according to Cohen J. (1988). The significance level was set at $p<0.05$ within all tests.

Results

Table 1 shows the mean and standard deviation for the trueness of the three impression techniques. The results showed that there was a statistically significant difference ($p < 0.001$) between the trueness of the three tested techniques, with Group I (conventional open tray impression technique) having the highest accuracy (i.e., the lowest deviation), followed by Group III (splinted SB digital impression), while the lowest accuracy (i.e., the highest deviation) was found in Group II (separate SB digital impression) with values of 54.45±5.60 µm, 87.87±4.34 µm, and 97.90±6.62 µm, respectively.

Table 1: Descriptive statistics and results of repeated measures ANOVA test for the comparison of the deviation in the scan bodies positions in the 3 groups.

Measurement (µm)	Open tray impression (n=10 impressions)		Separate scan bodies (n=10 scans)		Splinted scan bodies (n=10 scans)		f-value	p-value	PES (95% CI)	Magnitude of effect size
	Mean	SD	Mean	SD	Mean	SD				
	54.45^{C}	5.60	97.90^{A}	6.62	87.87^{B}	4.34	175.38	<0.001*	0.924 (0.862:0.944)	Large
95% CI of mean	(50.98: 57.92)		(93.79:102.01)		(85.18: 90.56)					

SD= Standard deviation, CI= Confidence interval, PES= partial eta squared, *: Significant at P ≤ 0.05, Different superscripts in the same column indicate statistically significant change by time.

Discussion

The results of this study revealed that splinting of the SBs has an impact on the trueness of a complete-arch digital impression taken with an IOS; thus, the null hypothesis that there is no significant difference between the trueness of the three impression techniques was rejected.

The curvilinear pattern was the chosen scanning protocol for Group II (separate SB digital impression) and Group III (splinted SB digital impression) based on the study done by Denneulin et al., [22] which reported that this scanning pattern is more accurate when compared with the zigzag and half arch patterns.

To allow for a more accurate comparison, the SBs were isolated from the entire scan to overcome the error of minimizing the mesh distance caused by the surface matching software and increase the accuracy of the results. [23]

The mesh of the SB file in the library was used as it is considered geometrically perfect when compared to the mesh of the STL file of the scanned SB on the master cast, which is always a geometrical approximation of the scanned SB, [24,25] this allows for a more accurate comparison between the STL files of the three groups and the reference file.

In this study, comparing the trueness of the three impression techniques, a statistically significant difference was found. Group I (conventional open tray impression technique) showed the lowest deviation, and this coincides with the results of other studies that evaluated the accuracy of complete-arch implant impressions. Revilla Leon M et al. [26] used a maxillary edentulous model with six implant analogues to compare the accuracy of the splinted open tray impression technique with photogrammetry and digital intraoral scanning using two different IOSs (iTero Element and TRIOS 3); Kim KR et al. [27] compared the accuracy of the splinted open tray impression technique with the digital intraoral scanning using separate SBs; Lyu M et al. [28] used a mandibular model with eight implants to compare the accuracy of the conventional impression technique with the digital scans. The previously mentioned studies proved that the conventional impression is more accurate when compared with the digital impression using IOS.

When comparing the trueness of Groups II (separate SB digital impression) and III (splinted SB digital impression), Group III exhibited less deviation; this could be attributed to the presence of the splint, which bridges the gap between the

SBs and acts as a continuous landmark, providing an easily traceable path, allowing for more accurate stitching, and enhancing the accuracy of the resulted scan. This is consistent with the results of other studies; Kernen F et al. [29] compared the accuracy of the full-arch digital scans with and without SBs splinting using a 3D printed scan aid device with two different IOSs (CS3600 and TRIOS3). The study proved that the use of the scan aid device improves the accuracy of the produced scan in the case of the CS3600 scanner but not for the TRIOS3 scanner because of the difference in their scanning technology, as the former scanner uses active triangulation while the latter uses confocal microscopy. Ashraf Y et. al. [30] compared the accuracy of three IOSs (TRIOS4, Primescan, and Medit i600) for full-arch impressions with and without SBs splinting using a maxillary cast with the implants inserted following an All-on-four configuration. It was concluded that while there is a difference in accuracy between the three scanners, SB splinting enhances the accuracy of the resultant scan.

These results also coincide with other studies that used different materials and techniques to act as landmarks or reference points to bridge the gap between the SBs: Azevedo L et al. [20] used adhesive radiopaque markers as an artificial landmark, Huang R et al. [31] used customized SBs with lateral extension, and Arkan H et al. [3] used an auxiliary device.

Despite the statistically significant difference between groups II and III, the deviation recorded in group III of 97.90±6.62 µm is within the clinically acceptable range recorded in the literature of 59-200 µm. [5,31]

Study limitations

This study is limited by the in vitro settings, which exclude a lot of the factors that challenge the operator while using the IOSs inside the patient's mouth, like the presence of blood or saliva or the patient's mouth opening. These factors have an impact on the quality of the final scan. Aside from these in vitro settings, the study was limited by using a single model. So further research should be done to validate these results in vivo settings with variable dental arch forms.

Conclusion

Within the limitations of this in vitro study, the following was concluded; there is a positive correlation between SB splinting in complete-arch implant scans and improving the trueness of the resulting digital scan using IOS. Although the deviation of the digital impression with separated SBs from the reference scan is the highest, it is within the clinically accepted range.

Funding

None

Data availability

Data are available upon request from the corresponding authors.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

Non-applicable since the study is an in vitro study with no human or animal participants.

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