

Evaluation Of Splinting Scan Bodies on The Accuracy of Complete-Arch Digital Implant Scans with Different Scanners

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Abstract

Objective

This study evaluated the effect of scan-body splinting on the trueness and precision of complete-arch digital implant scans obtained using two intraoral scanners (IOSs).

Materials and Methods

A maxillary edentulous epoxy model with six implants was used. Scan bodies were evaluated in three configurations: non-splinted, splinted with orthodontic wire and DuraLay resin, and splinted with a custom-made metal bar. A reference dataset was obtained using a Ceramill Map 400 laboratory scanner. Experimental scans were acquired using Medit i900 and Panda P3 IOSs, with eight scans per configuration for each scanner, yielding 48 experimental datasets. STL files were aligned and registered using iterative closest point analysis. Trueness was assessed using root mean square (RMS) deviation, and precision using the standard deviation of repeated measurements. Data were analyzed using two-way analysis of variance ($\alpha = 0.05$).

Results

The non-splinted configuration demonstrated the lowest RMS deviation and standard deviation values with both IOSs, indicating superior trueness and precision. Scan-body configuration significantly affected trueness and precision ($P < 0.001$), with no significant difference between the two splinting techniques. Scanner type did not significantly affect trueness ($P = 0.637$) but significantly affected precision ($P = 0.022$), with the Medit i900 showing greater repeatability than the Panda P3. No significant interaction was found between scanner type and scan-body configuration.

Conclusion

Within the limitations of this in vitro study, splinting scan bodies with orthodontic wire and DuraLay resin or a custom-made metal bar did not improve complete-arch implant scanning accuracy. The non-splinted configuration provided the highest trueness and precision, while the Medit i900 demonstrated superior precision.

Introduction

The condition of being edentulous primarily results in alterations to the jawbone structure, attributed to insufficient functional stimulation. The extent of bone resorption is not uniform; it varies based on the individual, systemic or local health issues, and the types of dental treatments employed to address the condition. After tooth loss, natural healing processes commence at the extraction site, triggering bone

remodeling and a gradual decrease in volume. ⁽¹⁻⁷⁾ Alongside changes to the alveolar bone in both the upper and lower jaws, remodeling mechanisms that promote involution also affect the basal bone; this process is known as post-extraction atrophy. ⁽⁸⁾ Numerous studies, including one by Schropp et al. ⁽⁹⁾ have examined post-extraction atrophy, revealing that the most significant loss of crestal bone occurs within the first three months following tooth extraction.

There are various prosthetic options available for addressing edentulism, each presenting its own set of benefits and drawbacks. Implants present a viable option for cases of edentulism, whether it is single, partial, or complete. ^(10, 11) Implant-supported over dentures provide a stable and secure solution, utilizing multiple implants to anchor the dentures, significantly improving retention compared to traditional removable dentures and they are another option, which rest on few strategically placed implants, allowing for easy removal while offering greater stability and comfort.

For those seeking a more permanent solution, fixed implant prostheses such as implant crowns or bridges can be used, where implants are placed directly into the jawbone and fitted with crowns that mimic natural teeth.

All-on-4 and all-on-6 protocols, rehabilitations utilizing axial implants, and zygomatic implants. Each option can be customized based on the patient's needs, preferences, and bone availability, ensuring optimal outcomes for function and aesthetics. ⁽¹²⁾

Accurate three-dimensional reproduction of implant positions is essential for obtaining passively fitting implant-supported prostheses. Implant positions may be transferred either by conventional impression procedures using impression materials and impression copings or by digital optical scanning techniques. ⁽¹³⁾ Irrespective of the impression technique used, precise reproduction of implant positions is fundamental for the fabrication of well-fitting implant-supported prostheses and plays a major role in their long-term clinical performance.

Digital scanning of scan bodies provides several clinical and laboratory advantages such as, reducing laboratory procedures and improving patient comfort and satisfaction compared with conventional impression procedures. ⁽¹⁴⁾

However, accurately scanning fully edentulous patients poses challenges. Some researchers have reported greater precision with digital implant scanning, ⁽¹⁵⁾ while others found conventional impressions to yield better results for complete arches.

Intraoral scanners are portable optical devices that directly record the geometry of intraoral structures, generating three-dimensional digital impressions with high accuracy and immediate visualization for restorative and orthodontic applications. Extra oral scanners digitize models outside the mouth, ideal for orthodontic applications. Desktop scanners are stationary machines can be used in dental labs to convert physical models into digital formats for CAD/CAM workflows.

The limited availability of recognizable anatomical landmarks, together with the relatively uniform surface morphology of completely edentulous arches, represents a major challenge for intraoral scanning systems (IOS). For complete-arch implant rehabilitation, conventional open-tray impression techniques incorporating splinted scan bodies are still widely considered the reference method owing to their well-documented accuracy. ⁽¹⁶⁾

The primary purpose of splinting the scan bodies is to prevent micro-movement during the impression process. Accordingly, this study aimed to determine the effect of intraoral scan-body splinting on the trueness of complete-arch digital implant scans obtained with different intraoral scanners. The findings may assist clinicians in selecting the most reliable and efficient digital workflow for complete-arch implant rehabilitation.

The null hypothesis assumed that neither scan-body splinting nor the choice of intraoral scanner would result in significant differences in scan accuracy.

Materials and Methods

The study was an in vitro laboratory experimental study that compared the accuracy of scan bodies across different types of scanners. **(Fig. 1)**. This study was approved by the Institutional Review Board of the Faculty of Dentistry, Pharos University, Egypt (IRB:00010556–IORG:0008839), and was conducted in accordance with the Declaration of Helsinki.

Sample size was estimated based on assuming confidence level = 95% and study power = 80%. The mean trueness values were $120 \pm 40 \mu\text{m}$ for the conventional un-splinted scan bodies and $70 \pm 10 \mu\text{m}$ for splinted scan bodies. Based on comparison between independent means, a minimum sample size of 7 samples was required per group yielding an effect size of 1.715. To account for potential errors in the scanning process, this was increased to 8 samples per group.

Scans of scan bodies that attached to the six implants (N = 72)

Total sample size = Number per group x Number of splinting groups x Number of scanners = $8 \times 3 \times 3 = 72$ samples. Sample size was based on Rosner's method ⁽¹⁷⁾ calculated by G*Power 3.1.9.7 ⁽¹⁸⁾

Figure 1

Study Design

Specimen fabrication and allocation

An epoxy resin (Polycraft ClearTop 35 Epoxy Water Clear Resin System, MB Fibreglass, Newtownabbey, Northern Ireland) maxillary model was designed (Ramses medical factory, Alexandria, Egypt) to hold six implants accurately positioned at the sites of the left first molar, left first premolar, left central incisor, right central incisor, right first premolar, and right first molar using a surgical guide. Six scan bodies were

also attached to the implants. The study was divided into three groups using the same epoxy cast according to the splinting method of the scan bodies.

Epoxy Cast Fabrication

A single epoxy resin maxillary reference cast was fabricated ⁽¹⁹⁾ of an average sized edentulous maxillary ridge. The vibrator machine was used at maximum speed to avoid the creation of air bubbles in the finished cast. The model was coated with a consistent layer of flexible polyurethane (Sawbones, Vashon, Washington, United States), which was 2 mm thick, to simulate the ridge mucosa. ⁽¹⁹⁾ Any extra material was scraped off using a sharp tool.

Master Denture Construction

A complete maxillary denture base was constructed on the epoxy maxillary cast following the conventional denture fabrication steps including; block-out, wax-up, flasking, curing, finishing, and polishing. This denture subsequently served as the anatomical reference for designing the surgical guide.

Surgical Guide Fabrication

The denture was scanned and imported into software to plan implant positions. A fully guided surgical template was designed with resin sleeves corresponding to the six implant locations. The guide was then fabricated using a Formlabs 3D printer (Formlabs printing machine). A CBCT2 scan was used to design the 3D printed surgical guide after dual scanning of the epoxy resin model and the fully edentulous maxillary denture. On the buccal surface of the maxillary denture, gutta percha were positioned. The first scan was performed using the model and denture, to visualize the three-dimensional (3D) data of the maxillary model. However, in the second scan, the denture was scanned without the model.

The DICOM (Digital Imaging and Communications in Medicine) files were transformed into a file format that could be used with the 3D designing software, which was used to determine the virtual plan's diameter, length, inclination and implant position. Virtual placement of six implants accurately positioned at the sites of the left first molar, left first premolar, left central incisor, right central incisor, right first premolar, and right first molar (Fig. 2, 3).

of implant position. of implant position.

Finally, the mucosa-supported surgical guide was virtually designed and exported as an STL file, then a fully resin surgical guide with Six built-in sleeves was fabricated using a 3D printer. ⁽²⁰⁾ (Fig. 4)

Implant placement and Scan-Body Attachment

The 3D-printed surgical guide was positioned on the epoxy cast. A rotary tissue punch was used to remove the tags of the mucosal material. Drilling of the osteotomy sites of the implants were performed at the sites of the left first molar, left first premolar, left central incisor, right central incisor, right first premolar, and right first molar using the guided sleeves to ensure identical angulation and depth for all implants. The drilling sequence protocol according to the manufacture instructions; point drill, initial drill, and final drill were used to finish drilling in implant osteotomy Six dummy Sky Implants (4 mm in diameter and 10 mm in length) were inserted through the guide using manual torque wrench at 30 Ncm. until their fully seated.

Six matching scan bodies were attached to all six implants. Scan bodies were tightened to the implants according to manufacturer's torque recommendations to ensure consistent seating (**Fig. 5**).

Figure 5

Maxillary epoxy model with six scan bodies.

Group Allocation and Splinting Procedures:

The same epoxy cast with implants and scan bodies was used for all the experimental groups. The study was divided into three groups according to the splinting method of the scan bodies; **Group I: Without any splinting (control group)**; no splinting material was applied and the scan bodies remained isolated, **group II: Splinting using orthodontic wire and DuraLay resin** (The orthodontic wire was manually shaped to follow the contour connecting the six scan bodies without causing displacement. DuraLay resin (Reliance Dental Manufacturing CompanyWorth, Illinois, United States) was incrementally applied to the wire and allowed for polymerization, forming a rigid splint. Any excess material was trimmed to avoid interference with scanning) and, **group III: Splinting using a metal bar**: Scan bodies were splinted using a metal bar. The metal bar was fabricated by applying a thin layer of separating medium around the scan bodies using brush-on technique, build the duralay resin around and between the scan bodies, forming a rigid connection of duralay. After polymerization of duralay, split the duralay and re-connect it, ⁽²¹⁾ then investing, burn out, casting and finishing. The metal bar was fitted and rigidly attached to the scan-body heads forming a stable metallic cross-connection.

Scanning Protocol:

Scanning was performed using three different scanners: Laboratory Scanner (Ceramill Map 400) and Intral-Oral scanners; Medit i900: manufacturer calibration kit and Panda P3: factory-provided calibration plate. Data acquisition was done following the manufactures' protocol.

Scanning Procedure:

For each studied group, 24 scans were performed; **Group I (n = 24)** Without any splinting (control group), **group II (n = 24)** Splinted using orthodontic wire and DuraLay resin and, **group III (n = 24)** Splinting using a metal bar.

Eight independent scans were acquired with three different scanners: A laboratory reference scanner (Cermaill Map 400) and two Intraoral scanners (Medit 900 and Panda P3). Prior to scanning, each assembly was inspected and cleaned with 70% isopropyl alcohol and allowed to dry completely. The scanners were calibrated immediately before data acquisition following the manufacturer's protocol.

Intraoral scanners followed a reproducible scanning path (occlusal from posterior to anterior, buccal sweep, lingual sweep) performed by a single experienced operator to reduce operator variability; the model was fixed in position on a stable stage, ambient lighting was controlled, and no additional scanning spray was used. The STL file of each scan was superimposed over its corresponding reference dataset using the 3D inspection software (Geomagic Control X; 3D System, Canada).

Initial alignment was performed using landmark registration followed by fine alignment using the iterative closest point (ICP) algorithm, and measurements. The 3D color-coded deviation map illustrating the deviation analysis between the non-splinted scan-body model also the splinting scan-body groups.⁽²²⁾ (Fig. 6).

Statistical Analysis

Normality of trueness and precision was checked using Shapiro Wilk test and Q-Q plots. Data was summarized using mean, standard deviation (SD), and 95% Confidence Interval (CI). Two Way ANOVA was used for assessing the effect of scanners and splinting methods and their interaction on trueness and precision. Prior to analysis, assumptions of homogeneity of variances were assessed using the Levene's test and were met. When significant interactions were detected, simple main-effects analyses with Bonferroni-adjusted pairwise comparisons were performed. Effect sizes were reported using partial eta-squared (η^2). All statistical tests were two-tailed, and significance was set at $p < 0.05$. Data was analyzed using IBM SPSS version 23 for Windows (Armonk, NY, USA).

Results

Comparison of trueness RMS between Medit i900 and Panda scanners:

In digital dentistry, root mean square (RMS) evaluates how closely a digital scan (or 3D-printed model) matches a reference model, with lower values of RMS indicating higher accuracy as, lower RMS value (closer to 0) means higher precision and fewer seating complications.

As shown in (Table 1) the highest trueness errors (largest RMS values) were recorded with the Duralay and wire method in the Medit i900 scanner (0.052 ± 0.004 mm) followed by the metal bar method (0.049

± 0.004 mm). For the Panda scanner, the metal bar (0.050 ± 0.003 mm) and Duralay and wire (0.049 ± 0.005 mm) methods also showed the highest RMS values. The lowest trueness errors for both scanners occurred with no splinting, with Medit i900 showing 0.039 ± 0.006 mm and Panda showing 0.043 ± 0.005 mm.

The results of two-way ANOVA which was performed to evaluate the effects of intraoral scanner type and splinting method on trueness (RMS) are shown in (Table 2a). The overall model was statistically significant, ($F(5) = 8.47, p < 0.001$), explaining 50.2% of the variance in trueness ($R^2 = 0.502$; adjusted $R^2 = 0.443$), with a large effect size (partial $\eta^2 = 0.502$).

There was **no significant main effect of scanner type** on trueness, ($F(1) = 0.23, p = 0.637$, partial $\eta^2 = 0.005$), indicating that trueness did not differ significantly between the intraoral scanners evaluated. In contrast, the splinting method had a significant main effect on trueness, ($F(2) = 18.40, p < 0.001$), with a large effect size (partial $\eta^2 = 0.467$), demonstrating that trueness was significantly influenced by the splinting approach used.

The interaction between scanner type and splinting method was not statistically significant, ($F(2) = 2.65, p = 0.082$, partial $\eta^2 = 0.112$), suggesting that the effect of splinting method on trueness was consistent across scanner types.

Overall, these findings indicate that trueness (RMS) is primarily affected by the splinting method rather than the intraoral scanner, with no evidence of a differential interaction between the two factors.

Pairwise comparisons (Table 2b) were conducted to assess differences in trueness (RMS) among splinting methods within each intraoral scanner group (Medit i900 and Panda).

For the **Medit i900**, no significant difference in trueness was observed between the **metal bar** and **duralay and wire** splinting methods (mean difference = -0.003 ; 95% CI: -0.009 to 0.002 ; $p = 0.493$). However, the metal bar method showed a significantly higher RMS value than the non-splinted group, indicating lower trueness. (mean difference = 0.009 ; 95% CI: 0.004 to 0.015 ; $p = 0.001$). Similarly, the DuraLay-and-wire method showed a significantly higher RMS value than the non-splinted group, indicating lower trueness (mean difference = 0.012 ; 95% CI: 0.007 – 0.018 ; $p < 0.001$).

For the **Panda** scanner, there was no significant difference in trueness between the **metal bar** and **duralay and wire** methods (mean difference = 0.001 ; 95% CI: -0.004 to 0.007 ; $p = 1.00$). The metal bar method showed a significantly higher RMS value than the non-splinted group, indicating lower trueness (mean difference = 0.006 ; 95% CI: 0.001 to 0.012 ; $p = 0.021$). In contrast, the difference between **duralay and wire** and **no splinting** did not reach statistical significance (mean difference = 0.005 ; 95% CI: 0.000 to 0.011 ; $p = 0.080$).

Overall, the non-splinted configuration produced the lowest RMS values and therefore the highest trueness for both scanners. Although significant differences were observed between the splinted and

non-splinted conditions, no significant differences were detected between the metal-bar and DuraLay-and-wire splinting techniques within either scanner group.

Table 1
Comparison of trueness (RMS) between Medit i900 and Panda P3 scanners using different splinting methods.

Splinting method	Medit i900 (n = 8)		Panda (n = 8)		p value
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
Metal Bar	0.049 $\pm$ 0.004	0.046, 0.052	0.050 $\pm$ 0.003	0.047, 0.053	0.621
Duralay and wire	0.052 $\pm$ 0.004	0.049, 0.055	0.049 $\pm$ 0.005	0.044, 0.053	0.153
No splint	0.039 $\pm$ 0.006	0.034, 0.044	0.043 $\pm$ 0.005	0.039, 0.047	0.083
CI: Confidence Interval, SD: Standard deviation					

Table 2

a: Two Way ANOVA assessing the effect of intra oral scanners and splinting methods on trueness (RMS).

Corrected Model	Type III Sum of Squares	df	Mean Square	F test	p value	Partial Eta Squared
	0.001	5	0.00	8.47	< 0.001*	0.502
Intercept	0.11	1	0.11	5288.47	< 0.001*	0.992
Scanner type	0.00	1	0.00	0.23	0.637	0.005
Splinting method	0.001	2	0.00	18.40	< 0.001*	0.467
Scanner type x splinting method	0.00	2	0.00	2.65	0.082	0.112
R Squared = 0.502 (Adjusted R Squared = 0.443), df: degree of freedom,						
*Statistically significant difference at p value < 0.05						

Table 2

b: Pairwise comparisons of trueness between different splinting methods within each group.

Splinting methods	Compared to	Medit i900			Panda P3		
		Mean diff	95% CI	p value	Mean diff	95% CI	p value
Metal bar	Duralay and wire	-0.003	-0.009, 0.002	0.493	0.001	-0.004, 0.007	1.00
	No splinting	0.009	0.004, 0.015	0.001*	0.006	0.001, 0.012	0.021*
Duralay and wire	No splinting	0.012	0.007, 0.018	< 0.001*	0.005	0.00, 0.011	0.080

*Statistically significant difference at p value < 0.05, CI: Confidence interval

Comparison of precision (SD) between Medit i900 and Panda scanners:

(Table 3) presents the comparison of precision, expressed as standard deviation (SD), between the Medit i900 and Panda scanners across different splinting methods. Lower SD values indicate higher precision.

For the **metal bar** splinting method, no statistically significant difference in precision was observed between the Medit i900 ($0.045 \pm 0.003\text{mm}$) and Panda ($0.049 \pm 0.004\text{mm}$) scanners ($p = 0.098$). Similarly, under the **duralay and wire** condition, precision did not differ significantly between Medit i900 ($0.049 \pm 0.005\text{mm}$) and Panda ($0.048 \pm 0.005\text{mm}$) scanners ($p = 0.671$). In contrast, for the **no splinting** condition, a statistically significant difference in precision was detected between the two scanners ($p = 0.007$). The Medit i900 demonstrated significantly higher precision (lower SD: 0.036 ± 0.006 ; 95% CI: 0.031–0.041) compared with the Panda scanner (0.043 ± 0.004 ; 95% CI: 0.039–0.046).

The highest precision errors (largest SD values) for the Medit i900 scanner were observed with the Duralay and wire method ($0.049 \pm 0.005\text{ mm}$), followed by the metal bar method ($0.045 \pm 0.003\text{ mm}$). For the Panda scanner, the highest SD values were recorded with the metal bar ($0.049 \pm 0.004\text{ mm}$) and Duralay and wire ($0.048 \pm 0.005\text{ mm}$) methods. The lowest precision errors for both scanners were obtained with the no-splinting method, with Medit i900 showing $0.036 \pm 0.006\text{ mm}$ and Panda showing $0.043 \pm 0.004\text{ mm}$.

Table 3
Comparison of precision (SD) between Medit i900 and Panda p3 scanners using different splinting methods.

Splinting methods	Medit i900 (n = 8)		Panda P3 (n = 8)		p value
	Mean ± SD	95% CI	Mean ± SD	95% CI	
Metal Bar	0.045 ± 0.003	0.042, 0.047	0.049 ± 0.004	0.046, 0.052	0.098
Duralay and wire	0.049 ± 0.005	0.045, 0.052	0.048 ± 0.005	0.043, 0.052	0.671
No splint	0.036 ± 0.006	0.031, 0.041	0.043 ± 0.004	0.039, 0.046	0.007*
*Statistically significant difference at p value < 0.05					

A two-way ANOVA was conducted to assess the effect of scanner type and splinting method on precision (Table 4a). The overall model was significant ($F(5) = 8.93$, $p < 0.001$, partial $\eta^2=0.515$). Scanner type showed a significant main effect ($F(1) = 5.64$, $p = 0.022$, partial $\eta^2=0.118$), indicating measurable differences in precision between the two scanners. Splinting method also showed a significant main effect ($F(2) = 16.74$, $p < 0.001$, partial $\eta^2=0.444$), confirming that precision varied according to splinting technique. The interaction between scanner type and splinting method was not significant ($F(2) = 2.76$, $p = 0.075$).

Pairwise comparisons of Precision (Table 4b) were performed to evaluate differences in **precision (SD)** among the splinting methods within each intraoral scanner group.

For the **Medit i900**, no significant difference in precision was observed between the **metal bar** and **duralay and wiresplinting** methods (mean difference = -0.004 ; 95% CI: -0.010 to 0.002 ; $p = 0.280$). However, the metal bar method showed a significantly higher SD value than the non-splinted group, indicating lower precision. mean difference = 0.009 ; 95% CI: 0.003 to 0.014 ; $p = 0.002$). Likewise, the DuraLay-and-wire method showed a significantly higher SD value than the non-splinted group, indicating lower precision (mean difference = 0.012 ; 95% CI: $0.007-0.018$; $p < 0.001$).

For the **Panda** scanner, no significant difference in precision was found between the **metal bar** and **duralay and wire** methods (mean difference = 0.001 ; 95% CI: -0.005 to 0.007 ; $p = 1.00$). The metal bar method showed a significantly higher SD value than the non-splinted group, indicating lower precision (mean difference = 0.006 ; 95% CI: 0.000 to 0.012 ; $p = 0.039$). In contrast, the difference in precision between **duralay and wire** and **no splinting** did not reach statistical significance (mean difference = 0.005 ; 95% CI: -0.001 to 0.011 ; $p = 0.103$).

Table 4

a: Two Way ANOVA assessing the effect of intra oral scanners and splinting methods on precision.

Corrected Model	Type III Sum of Squares	df	Mean Square	F test	p value	Partial Eta Squared
	0.001	5	0.00	8.93	< 0.001*	0.515
Intercept	0.10	1	0.10	4633.32	< 0.001*	0.991
Scanner type	0.00	1	0.00	5.64	0.022*	0.118
Splinting method	0.001	2	0.00	16.74	< 0.001*	0.444
Scanner type x splinting method	0.00	2	0.00	2.76	0.075	0.116
R Squared = 0.515 (Adjusted R Squared = 0.458), df: degree of freedom, *Statistically significant difference at p value < 0.05						

Table 4

b: Pairwise comparisons of precision between different splinting methods within each group.

Splinting methods	Compared to	Medit i900			Panda		
		Mean diff	95% CI	p value	Mean diff	95% CI	p value
Metal bar	Duralay and wire	-0.004	-0.010, 0.002	0.280	0.001	-0.005, 0.007	1.00
	No splinting	0.009	0.003, 0.014	0.002*	0.006	0.00, 0.012	0.039*
Duralay and wire	No splinting	0.012	0.007, 0.018	< 0.001*	0.005	-0.001, 0.011	0.103
*Statistically significant difference at p value < 0.05, CI: Confidence interval							

In (Table 5), the highest trueness deviations were observed in the Medit i900 scanner with the metal bar method (0.059 ± 0.002 mm) and Duralay and wire method (0.057 ± 0.001 mm) when compared to the control non-splinted group. In contrast, the Panda scanner showed lower RMS values for the same splinting methods (metal bar: 0.048 ± 0.004 mm; Duralay and wire: 0.045 ± 0.004 mm). The differences between the two scanners were statistically significant for both splinting methods ($p < 0.001$).

Table 5

Comparison of trueness (RMS) between Medit i900 and Panda P3 scanners using different splinting methods as compared to control non splinted group.

Splinting method	Medit i900 (n = 8)		Panda (n = 8)		p value
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
Metal Bar	0.059 $\pm$ 0.002	0.057, 0.060	0.048 $\pm$ 0.004	0.045, 0.051	< 0.001*
Duralay and wire	0.057 $\pm$ 0.001	0.056, 0.059	0.045 $\pm$ 0.004	0.042, 0.048	< 0.001*
CI: Confidence Interval, SD: Standard deviation, *Statistically significant difference at p value < 0.05					

A two-way ANOVA was conducted to assess the effects of scanner type and splinting method relative to the control non-splinted group (Table 6). The overall model was significant ($F(3) = 43.37$, $p < 0.001$, partial $\eta^2 = 0.823$), indicating that the predictors collectively explained a large proportion of the variance in RMS values. Scanner type had a significant main effect on trueness ($F(1) = 125.44$, $p < 0.001$, partial $\eta^2 = 0.818$), confirming that Medit i900 produced higher RMS values than Panda under the splinted conditions. Splinting method did not reach statistical significance ($F(1) = 3.84$, $p = 0.060$), and the interaction between scanner type and splinting method was also non-significant ($F(1) = 0.83$, $p = 0.372$), indicating that the effect of splinting method on trueness was similar for both scanners.

Table 6

Two Way ANOVA assessing the effect of intra oral scanners and splinting methods as compared to control non splinted group on trueness (RMS).

Corrected Model	Type III Sum of Squares	df	Mean Square	F test	p value	Partial Eta Squared
	0.001	3	0.00	43.37	< 0.001*	0.823
Intercept	0.09	1	0.09	10710.64	< 0.001*	0.997
Scanner type	0.001	1	0.001	125.44	< 0.001*	0.818
Splinting method	0.00	1	0.00	3.84	0.060	0.120
Scanner type x splinting method	0.00	1	0.00	.83	0.372	0.029
R Squared = 0.823 (Adjusted R Squared = 0.804), *Statistically significant difference at p value < 0.05						

In (Table 7), the highest precision errors (largest SD values) were observed in the Medit i900 scanner with the metal bar (0.058 ± 0.001 mm) and Duralay and wire (0.057 ± 0.001 mm) methods relative to the control non-splinted group. In contrast, the Panda scanner showed lower SD values for the same methods (metal bar: 0.046 ± 0.005 mm; Duralay and wire: 0.043 ± 0.005 mm). The differences between

scanners were statistically significant for both splinting methods ($p < 0.001$), indicating that the scanner type affected precision under splinted conditions.

Table 7

Comparison of precision (SD) between Medit i900 and Panda P3 scanners using different splinting methods as compared to control non splinted group.

Splinting method	Medit i900 (n = 8)		Panda P3 (n = 8)		p value
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
Metal Bar	0.058 $\pm$ 0.001	0.057, 0.060	0.046 $\pm$ 0.005	0.042, 0.050	< 0.001*
Duralay and wire	0.057 $\pm$ 0.001	0.056, 0.059	0.043 $\pm$ 0.005	0.038, 0.047	< 0.001*
CI: Confidence Interval, SD: Standard deviation, *Statistically significant difference at p value < 0.05					

A two-way ANOVA was conducted to assess the effects of scanner type and splinting method relative to the control non-splinted group (Table 8). The overall model was significant ($F(3) = 37.22$, $p < 0.001$, partial $\eta^2 = 0.800$), showing that the predictors collectively explained a substantial proportion of variance in SD values. Scanner type had a significant main effect on precision ($F(1) = 107.78$, $p < 0.001$, partial $\eta^2 = 0.794$), indicating higher SD values (lower precision) for Medit i900 compared with Panda. Splinting method did not reach statistical significance ($F(1) = 3.09$, $p = 0.090$), and the interaction between scanner type and splinting method was also not significant ($F(1) = 0.80$, $p = 0.378$), indicating that the effect of splinting method on precision was similar for both scanners.

Table 8

Two Way ANOVA assessing the effect of intra oral scanners and splinting methods as compared to control non splinted group on precision.

Corrected Model	Type III Sum of Squares	df	Mean Square	F test	p value	Partial Eta Squared
	0.001	3	0.00	37.22	< 0.001*	0.800
Intercept	0.08	1	0.08	6288.81	< 0.001*	0.996
Scanner type	0.001	1	0.001	107.78	< 0.001*	0.794
Splinting method	0.00	1	0.00	3.09	0.090	0.099
Scanner type x splinting method	0.00	1	0.00	0.80	0.378	0.028
R Squared = 0.800 (Adjusted R Squared = 0.778), df: degree of freedom, *Statistically significant difference at p value < 0.05						

Discussion

Edentulism remains a prevalent condition worldwide and is associated with functional, psychosocial, and nutritional consequences that negatively impact quality of life. ⁽²⁾ The WHO has highlighted oral diseases including tooth loss as a major global public health problem with substantial impacts across the life course. ⁽²³⁾ Edentulism is not merely the absence of teeth; it is a functional impairment that affects mastication, speech, facial esthetics, and social wellbeing. ⁽²⁴⁾ Tooth loss is frequently associated with progressive changes in the residual alveolar ridges and soft tissues, which complicates long-term prosthetic rehabilitation. ⁽³⁾

Residual ridge resorption is a chronic, multifactorial process that continues after extraction and may be particularly pronounced in the mandible. ⁽²⁵⁾ Because ridge resorption is continuous and highly variable among individuals, complete denture performance may deteriorate over time, increasing patient dissatisfaction. ⁽²⁴⁾

Conventional complete dentures are still commonly used to rehabilitate edentulous patients, but they often fail to provide adequate retention, stability and comfort especially in the mandible because of continuous residual ridge resorption and reduced denture-bearing area. These limitations have driven interest in alternative strategies so, dental implants have transformed the treatment of edentulous patients by improving retention, stability, and patient satisfaction, particularly when used to support overdentures. Current evidence supports implant-supported overdentures as a predictable rehabilitation option for edentulous patients. For many individuals with mandibular edentulism, they are regarded as the preferred standard of care because osseointegrated implants provide stable anchorage, resulting in improved prosthesis retention and function. ^(10, 26)

Digital dentistry has enabled more streamlined workflows, including computer-guided implant surgery, which aims to increase surgical predictability and prosthetically driven implant placement. ⁽²⁰⁾ The precise digital transfer of implant positions is fundamental for the accurate fabrication of implant prostheses, and this step relies heavily on intraoral scanning, scan bodies, and standardized scanning protocols. Digital implant impression workflows use intraoral scan bodies to accurately reproduce the three-dimensional position and orientation of implants within a virtual model. ⁽²⁷⁾

Compared with conventional impression procedures, digital scanning of scan bodies provides several clinical and laboratory advantages. These include reducing laboratory procedures, eliminating the need for gypsum cast fabrication, minimizing potential sources of error, facilitating digital storage and retrieval of virtual casts, and improving communication among clinicians, patients, and dental technicians. In addition, the digital workflow enhances treatment efficiency while improving patient comfort and satisfaction. ⁽¹⁴⁾

Scan body design features such as geometry, material, surface characteristics, height, and connection stability can influence scanning performance and downstream matching to the implant library. ⁽²⁸⁾

In implant prosthodontics, small deviations in implant position transfer can translate into prosthesis misfit, which may increase mechanical complications or strain at the implant–prosthesis interface.⁽¹²⁾ Grande et al.⁽²⁹⁾ studied the factors affected intraoral scan bodies accuracy and concluded that scan body-related factors and the digital workflow steps (including matching to libraries and alignment processes) are important determinants of overall digital impression accuracy. In multi-implant and complete-arch situations, errors may accumulate due to stitching limitations and reduced stable landmarks, potentially impacting the fidelity of implant position transfer.

For this reason, several authors have proposed splinting scan bodies to increase geometric stability and reduce relative movement between scan bodies during scanning.⁽¹⁹⁾

Splinting methods vary widely and include resin-based splints, wires, bars, floss-resin combinations, and prefabricated or customized rigid frameworks.⁽³⁰⁾ Scan bodies and different splinting approaches have been introduced to enhance the accuracy of digital implant impressions, particularly in multiple-implant and complete-arch situations.⁽²⁸⁾

Intraoral scanners (IOS) differ in their optical technologies, image acquisition strategies, and image-stitching algorithms, which can lead to different performance outcomes in various clinical scenarios.⁽²⁹⁾

In vitro studies evaluating multiple-implant scanning have shown that IOS performance varies among systems, and accuracy may decrease as the number of implants and scanning span increases therefore, scanner selection and protocol choices remain key considerations in multi-implant digital rehabilitation.⁽²⁸⁾

This in vitro study investigated the effect of different scan-body splinting techniques on the accuracy of full-arch digital implant impressions acquired with two intraoral scanner systems. Accuracy was assessed using both trueness, expressed as the root mean square (RMS) deviation, and precision, expressed as standard deviation (SD).

The discussion of the present findings is organized according to the main outcomes of the study, including the influence of scan-body splinting on trueness and precision, the influence of scanner type, the interaction between scanner type and splinting method, and the comparison of splinted configurations in comparison with the non-splinted control group.

The present study demonstrated that the non-splinted technique produced the highest scan accuracy, exhibiting superior trueness and precision compared with both the DuraLay-and-wire and cast metal-bar splinted groups.

Regarding trueness, the current findings are consistent with Azevedo et al.⁽³¹⁾ reported that scan-body splinting did not result in a significant improvement in the trueness of full-arch digital implant impressions. Similarly, Ali et al.⁽¹⁹⁾ reported that splinting implant scan bodies did not significantly improve the trueness of complete-arch digital implant impressions. Furthermore, Gehrke, Grande, and

Pachiou^(28, 29, 32) emphasized that scan-body configuration, scanner technology, and scanning protocol may play a greater role in determining scan accuracy than scan-body stabilization alone.

In contrast, the present findings disagree with Retana et al.⁽³³⁾ who demonstrated that scan-body splinting improved trueness in complete-arch implant scanning. Similar findings were reported by Farahat and El Saaedi,⁽³⁴⁾ who observed superior trueness values after splinting scan bodies. Furthermore, the systematic review conducted by Shetty et al.⁽³⁵⁾ concluded that most available studies favored scan-body splinting in complete-arch digital implant impressions.

Regarding precision, the present results followed the same trend observed for trueness, with the non-splinted technique demonstrating the highest precision among all tested groups. This finding is in agreement with Azevedo et al.⁽³¹⁾ who reported that modifications intended to facilitate complete-arch scanning, including scan-body splinting and artificial landmarks, did not necessarily improve scan accuracy and could affect scanner performance differently. Similarly, Gehrke, Grande, and Pachiou^(28, 29, 32) highlighted that scan-body configuration and scanning strategy significantly. These observations support the present findings, suggesting that increasing scan complexity through splinting may negatively affect scan repeatability rather than improve it.

The present results are also supported by studies reporting that complete-arch implant scans are particularly susceptible to cumulative stitching errors. In such situations, the addition of splint structures may increase geometric complexity and introduce additional variables that affect image acquisition and software stitching, thereby reducing repeatability.

In contrast, the present precision findings also disagree with Retana et al.⁽³³⁾ who reported improved accuracy following scan-body splinting. Similarly, Farahat and El Saaedi.⁽³⁴⁾ found that splinted scan bodies produced superior results compared with separate scan bodies. The systematic review conducted by Shetty et al.⁽³⁵⁾ also concluded that most available studies favored scan-body splinting for complete-arch digital implant impressions.

The disagreement between the present findings and previous investigations may be explained by differences in implant number, implant distribution, arch configuration, scan-body design, splinting material, scanner systems, and evaluation methods. The present study evaluated six implants distributed across a complete maxillary arch, whereas several previous investigations used fewer implants or different implant configurations.^(19, 31) Moreover, some previous studies used prefabricated scan aids or industrially manufactured reference structures rather than manually fabricated splints.^(30, 36) Such devices may provide additional geometric references without introducing the fabrication-related distortions associated with acrylic resin or cast-metal frameworks. In contrast, the manually fabricated DuraLay-and-wire and cast metal-bar splints used in the present study required multiple fabrication steps that may have introduced dimensional changes and increased scan variability.⁽²¹⁾

Interestingly, no significant differences were observed between the metal-bar and DuraLay-and-wire groups despite the theoretically greater rigidity of the metal framework. This finding suggests that rigidity alone may not be sufficient to improve either scan trueness or repeatability.⁽¹⁹⁾ Instead, the presence of additional splint structures appears to have a greater influence on scan accuracy than the material used for splint fabrication.

Therefore, the results of the present study suggest that scan-body splinting should not be assumed to improve the trueness or precision of complete-arch digital implant scanning. Rather, its effectiveness appears to depend on the specific clinical and digital workflow employed and should not be considered universally beneficial.

The present study demonstrated that scanner type had a differential effect on scan accuracy. While no significant differences were observed in trueness between the evaluated intraoral scanners, scanner type significantly influenced precision, with the Medit i900 demonstrating superior repeatability compared with the Panda P3 scanner.

Regarding trueness, the present findings are in agreement with studies suggesting that modern intraoral scanners may achieve comparable levels of trueness under standardized laboratory conditions. Gehrke et al.⁽²⁸⁾, Grande et al.⁽²⁹⁾, and Pachiou et al.⁽³²⁾ reported that digital implant impression accuracy is influenced by multiple factors, including scan-body design, scanner technology, scanning strategy, and implant distribution, rather than being determined by a single variable alone. In contrast, the present findings disagree with those of Revilla-León et al.⁽³⁷⁾, Mangano et al.⁽³⁸⁾, and Azevedo et al.⁽³¹⁾ who identified scanner type as a significant factor affecting complete-arch implant scan accuracy. Likewise, systematic reviews by Abuduwaili et al.⁽¹⁶⁾ and Shetty et al.⁽³⁵⁾ concluded that scanner-related factors may significantly influence digital impression accuracy and that differences in scanner performance can become evident in complete-arch implant scans.

Unlike trueness, precision was significantly influenced by scanner type ($p = 0.022$). The Medit i900 consistently demonstrated lower standard deviation values than the Panda P3 across the evaluated groups, indicating superior repeatability. These findings are consistent with Mangano et al., who reported that scanner-related factors can significantly influence the reproducibility of complete-arch implant scans.⁽³⁸⁾ Similarly, Azevedo et al. demonstrated that scanner performance is highly dependent on the scanner system used, with different scanners exhibiting varying levels of repeatability despite producing similar trueness values.⁽³¹⁾ These observations are further supported by studies reporting that complete-arch scans are particularly sensitive to cumulative image stitching and software processing behaviour. Because precision reflects the consistency of repeated image acquisition rather than simple closeness to the reference model, scanner-specific differences in optical acquisition, frame capture, image overlap, and stitching algorithms may become more evident when repeatability is evaluated.

The disagreement between the present findings and previous reports may be explained by differences in study design and experimental conditions. Many previous studies included multiple scanner generations,

different scan-body systems, varying implant configurations, or clinical variables such as saliva, soft-tissue movement, restricted access, and patient movement. In addition, some investigations compared scanners from different technological generations, whereas the present study evaluated two contemporary systems under highly standardized in vitro conditions using the same epoxy model, implant distribution, scan-body design, and scanning protocol for all groups. Such standardization may have minimized scanner-related differences in trueness while allowing scanner-specific variations in repeatability to become apparent.

Another possible explanation is that advances in optical acquisition systems, software processing, and image-stitching algorithms have substantially reduced differences in trueness between contemporary intraoral scanners.⁽³⁸⁾ However, repeatability remains highly dependent on scanner-specific image acquisition and data-processing algorithms. While both scanners were capable of generating scans that closely approximated the reference model, the Medit i900 may have provided more consistent image registration and stitching during repeated scans, resulting in lower scan-to-scan variability and superior precision.

Overall, the present findings indicate that scanner performance should not be evaluated solely according to trueness. Although both scanners produced scans that were similarly close to the reference model, the Medit i900 demonstrated greater consistency across repeated scans. Therefore, scanner-specific differences may become more evident when repeatability rather than absolute accuracy is assessed, suggesting that scanner selection may influence the consistency of complete-arch digital implant impressions even when overall trueness remains comparable.

The present study demonstrated that no significant interaction was detected between scanner type and splinting method for either trueness ($p = 0.082$) or precision ($p = 0.075$).

This finding indicates that the effect of splinting followed a similar pattern across both scanners, with the non-splinted configuration consistently demonstrating the lowest RMS and SD values.

The absence of a significant interaction suggests that scan-body configuration exerted a similar influence regardless of scanner type.⁽⁵⁷⁾ Therefore, the effect of splinting appeared to be largely independent of the scanner system used under the conditions of the present study.

Similar findings were reported by Ali et al.⁽¹⁹⁾ and were further supported by the systematic review of Shetty et al.⁽³⁵⁾, which suggested that the influence of scan-body splinting is not necessarily scanner-dependent and may be affected by multiple workflow-related variables. In contrast, Azevedo et al. reported scanner-dependent responses to splinted scan bodies.⁽³¹⁾

An additional finding of the present study emerged when the splinted groups were analysed relative to the non-splinted control group. Although scanner type did not significantly affect trueness in the primary analysis ($p = 0.637$), scanner type became highly significant when deviations were calculated relative to

the control condition. This observation suggests that the effect of splinting on scan accuracy was not identical for the two evaluated scanners.

For trueness, the Medit i900 demonstrated greater deviations from the non-splinted control group than the Panda P3 scanner. The metal-bar and DuraLay-and-wire groups showed RMS deviations of 0.059 ± 0.002 mm and 0.057 ± 0.001 mm, respectively, relative to the control group for Medit i900, whereas the corresponding values for Panda P3 were 0.048 ± 0.004 mm and 0.045 ± 0.004 mm.

Similar findings were observed for precision, where deviations relative to the control group were significantly greater for Medit i900 than for Panda P3. These results indicate that the introduction of splinted structures affected the two scanners differently.

This finding agrees with Azevedo et al., who demonstrated that the influence of scan-body splinting and artificial landmarks varied among different intraoral scanners.⁽³¹⁾ Their results suggested that scanner performance may depend not only on scan-body configuration itself but also on how individual scanner systems process additional geometric structures.

Similarly, recent investigations have reported that scanner-specific image acquisition and software stitching algorithms may influence the response of different intraoral scanners to modifications in scan-body configuration. The present finding also agrees with studies emphasizing that complete-arch implant scanning accuracy is influenced by the interaction between scanner technology and scan geometry.

Several authors have reported that scanners may behave differently when confronted with complex scanning situations involving long spans, multiple implants, or additional reference structures. These findings support the present observation that splinting may affect different scanner systems unequally.

Directly comparable studies evaluating control-group deviations in the same manner as the present investigation are relatively limited. However, some previous studies reported that scanner-dependent differences become more apparent as scan complexity increases. Such observations indirectly support the present finding that scanner-specific behavior may not be evident under simple scanning conditions but may emerge after the introduction of splinted structures.

A possible explanation for the greater deviations observed with Medit i900 is that the scanner may be more sensitive to the increased geometric complexity introduced by splinting.

The addition of connecting structures between scan bodies alters the distribution of recognizable landmarks and may affect image overlap, feature recognition, and software stitching. Under non-splinted conditions, both scanners demonstrated comparable trueness; however, after splinting was introduced, differences in image-processing behavior became more apparent.

Another possible explanation is related to differences in proprietary stitching algorithms. Although both scanners utilize optical image acquisition and digital reconstruction principles, each manufacturer

employs unique methods for image alignment and surface registration.

Consequently, the same splinted configuration may influence scanners differently depending on how the acquired data are processed and stitched together.

The present findings suggest that scanner type and scan-body configuration should not be evaluated independently. Instead, the effectiveness of a particular splinting technique appears to depend on the interaction between scanner technology and scan geometry.

Therefore, clinicians should avoid assuming that a splinting protocol that performs favorably with one scanner system will necessarily produce similar results with another scanner.

Overall, the control-group comparison provides additional evidence that the influence of scan-body splinting is scanner-dependent. While scanner type did not significantly affect overall trueness in the primary analysis, significant differences became apparent when the effect of splinting was isolated.

This finding highlights the importance of evaluating scanner performance within the context of the complete digital workflow rather than considering scanner type or splinting method independently.

Conclusion

Within the limitations of the present study, the following conclusions can be drawn: Splinting scan bodies using either orthodontic wire with DuraLay resin or a custom metal bar did not improve the accuracy of complete-arch digital implant scans. The non-splinted scan body group demonstrated superior trueness and precision values compared with the splinted groups for both intraoral scanners. Medit i900 and Panda P3 demonstrated comparable trueness; however, Medit i900 showed significantly higher precision.

The overall findings indicate that splinting scan bodies may introduce additional distortion or scanning interference, resulting in higher deviation values rather than enhancing stability during scanning.

Declarations

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Author Contribution

M.N.E. performed the experimental work, collected and analyzed the data, interpreted the results, and drafted the manuscript. A.M.E.S., I.M.S.M., and D.A.A. supervised the study, contributed to the study design and methodology, provided scientific guidance, and critically revised the manuscript. M.N.E.

coordinated the manuscript submission and correspondence. All authors read and approved the final manuscript.

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Figures

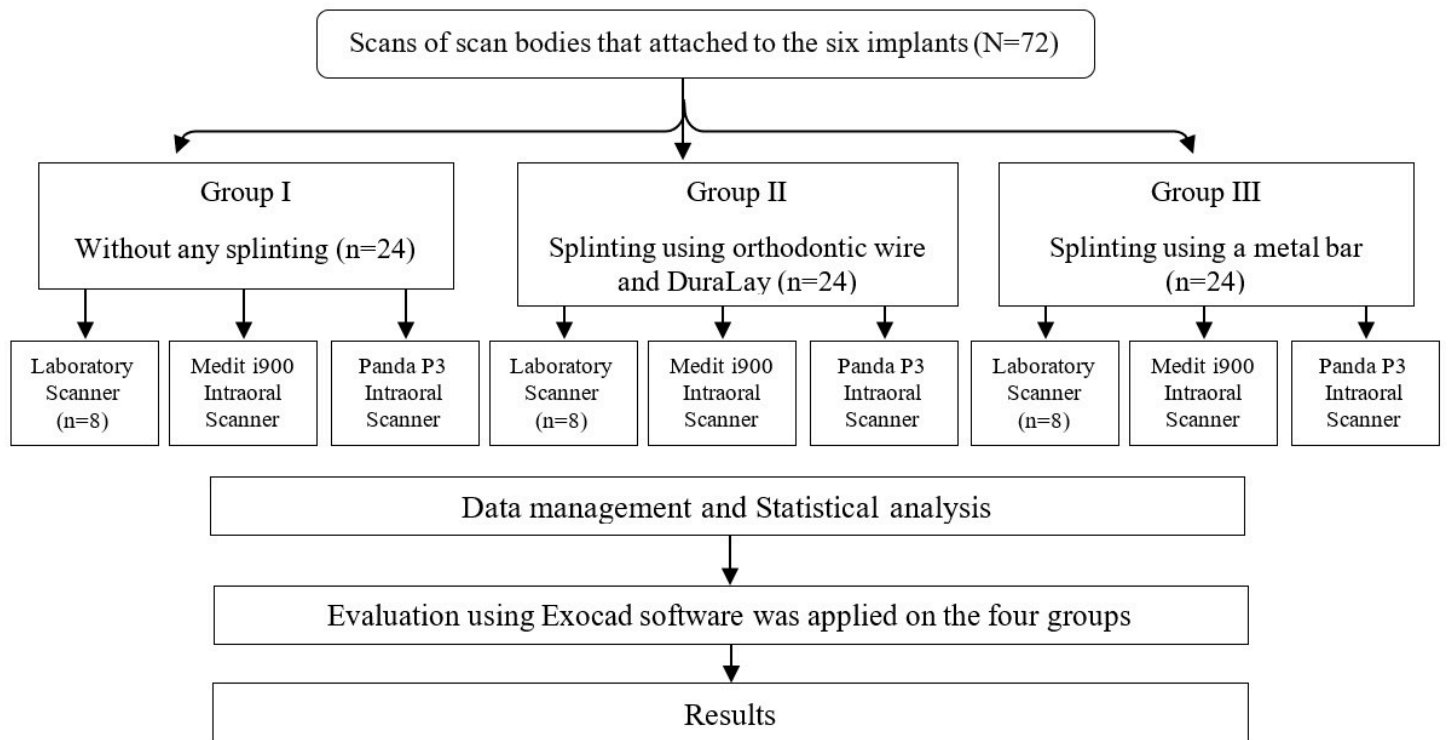


Figure 1

Study Design

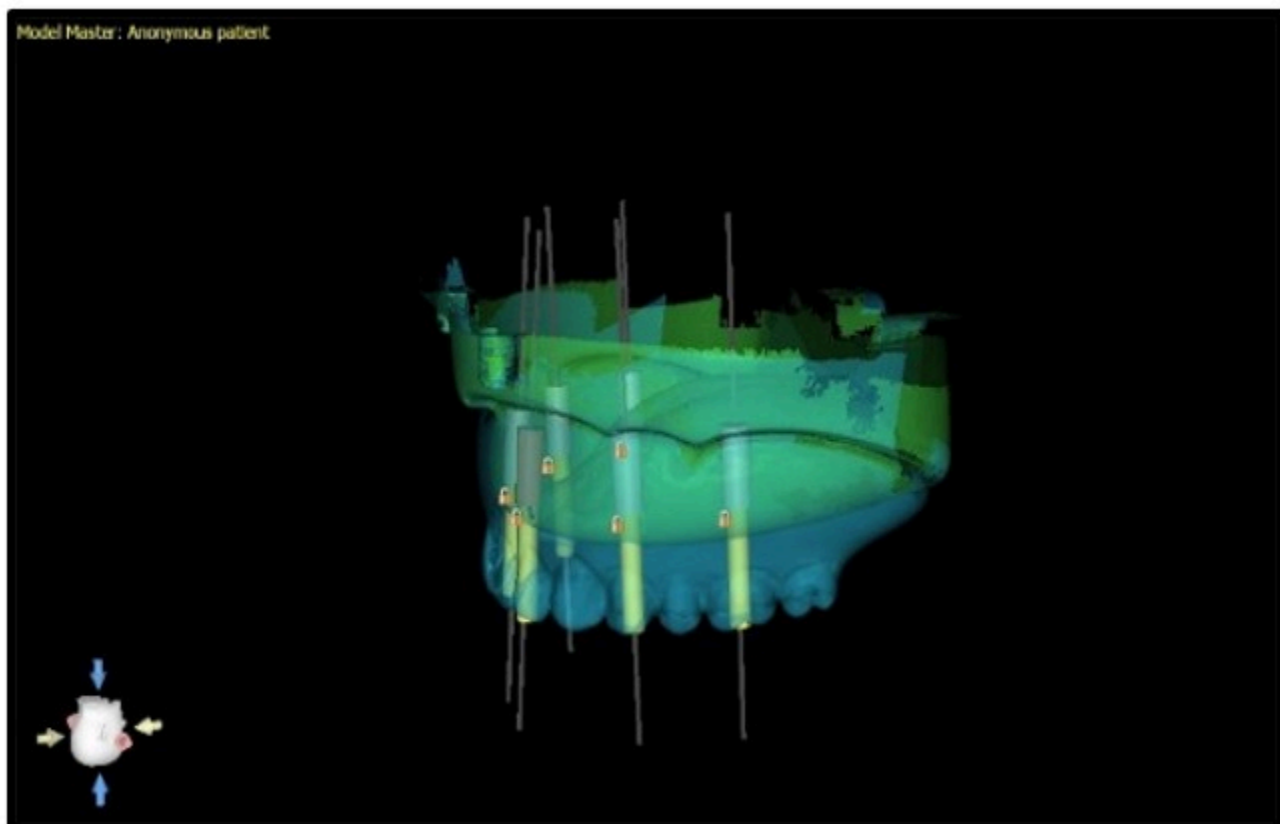


Figure 2

Frontal view of digital planning of implant position.



Figure 3

Occlusal view of digital planning of implant position.

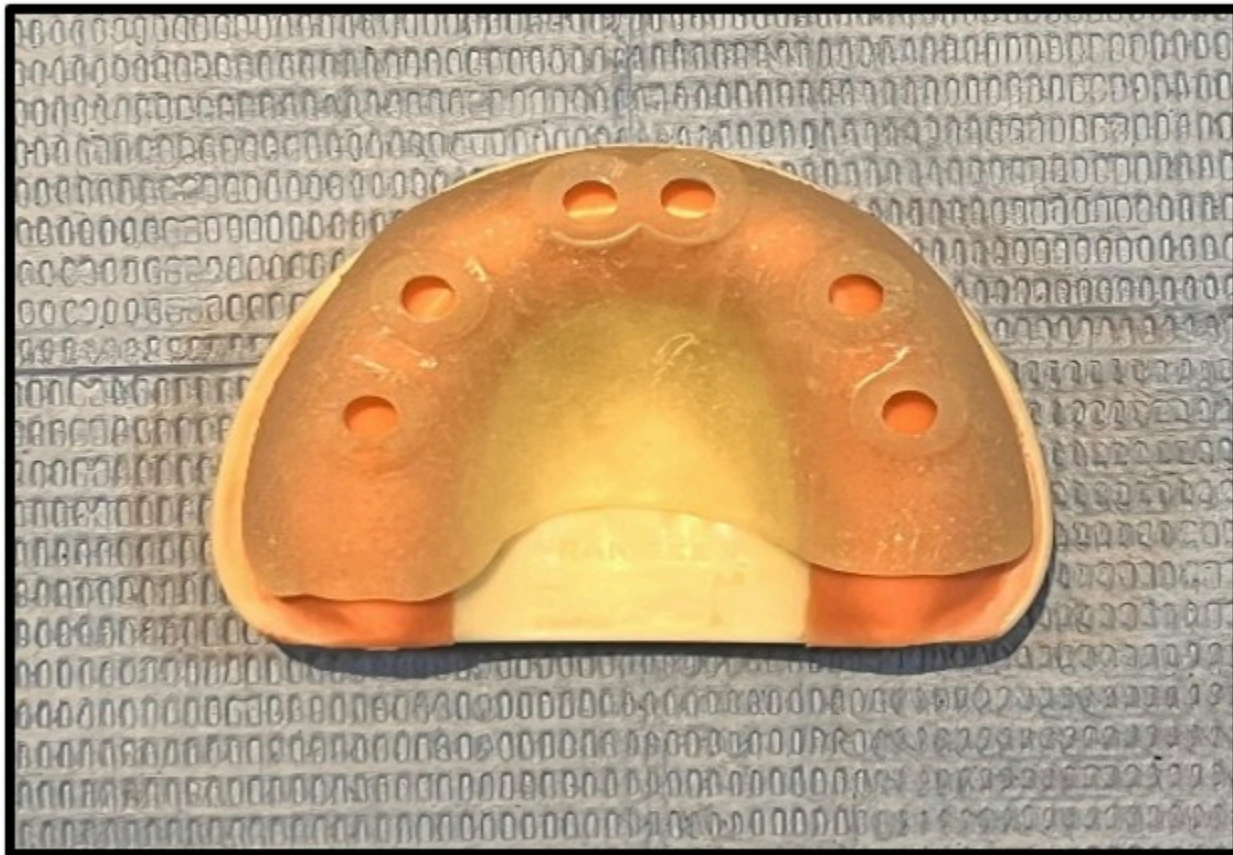


Figure 4

3D fully surgical guide and maxillary epoxy model.

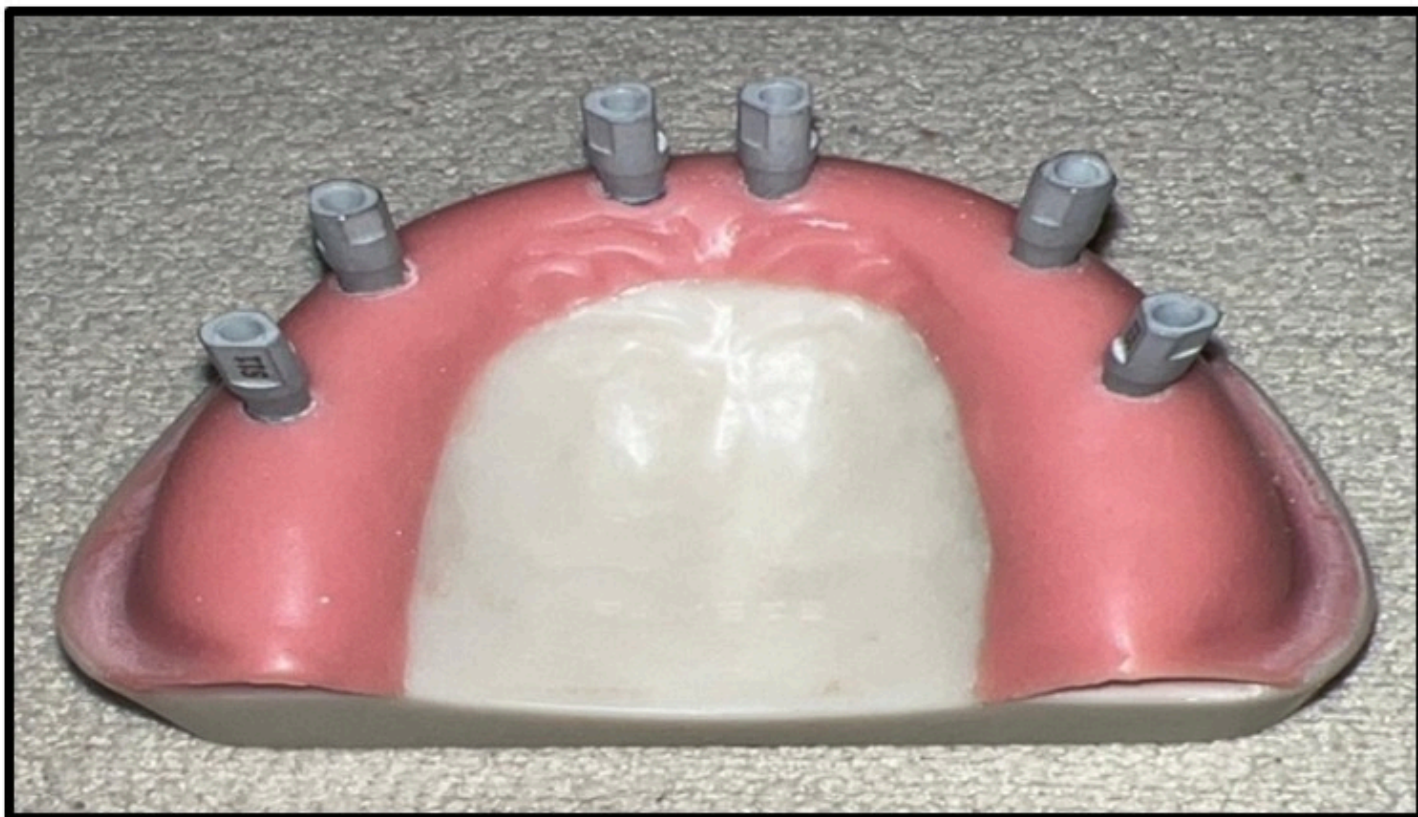


Figure 5

Maxillary epoxy model with six scan bodies.

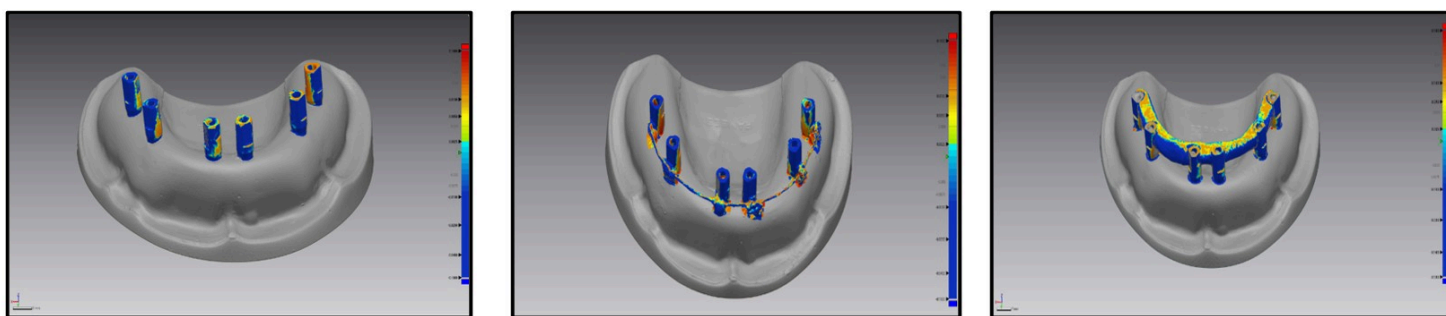


Figure 6

3D color-coded deviation map illustrating the deviation analysis between the non-splinted scan-body model and the splinting scan-body groups.