ISSN 0973-2063 (online) 0973-8894 (print)

Bioinformation 22(10): 6870-6874 (2026)

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BIOINFORMATION
Discovery at the interface of physical and biological sciences

BIOMEDICAL INFORMATICS

www.bioinformation.net

Volume 22(10)

Research Article

Received October 1, 2026; Revised October 31, 2026; Accepted October 31, 2026, Published October 31, 2026

DOI: 10.6026/973206300226870

SJIF 2026 (Scientific Journal Impact Factor for 2026) = 8.478
2022 Impact Factor (2023 Clarivate Inc. release) is 1.9

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Citation: Pavani *et al.* Bioinformation 22(10): 6870-6874 (2026)

A comparative *in vitro* study of complete-arch implant impressions: Conventional open-tray, closed-tray and digital implant scan body techniques

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ISSN 0973-2063 (online) 0973-8894 (print)
Bioinformation 22(10): 6870-6874 (2026)
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Abstract:
Passive fit is essential for the success of complete-arch implant-supported prostheses. Therefore, it is of interest to compare the open-tray and closed-tray implant impression techniques. A PMMA edentulous maxillary model with six implants served as the reference. The open-tray technique showed significantly lower RMS and deviation values ($p < 0.05$). Thus, the open-tray technique was more accurate than the closed-tray technique.

Keywords: Dental implants (DI), open-tray implant impression, closed-tray implant impression, intraoral scanner (IOS), digital implant impressions, intraoral scan body

Background:
The primary objective of dental implant therapy is to restore oral function, esthetics and patient comfort through implant-supported prostheses that accurately reproduce the planned implant positions **[1]**. Achieving a passive fit of implant supported prostheses is essential for reducing biological and mechanical complications, including screw loosening, component fracture and peri-implant bone loss **[2]**. The accuracy of impression procedures and the transfer of three-dimensional implant positions from the clinical environment to the laboratory are important determinants of prosthetic fit **[3]**. Conventional implant impression techniques, primarily the open-tray and closed-tray approaches, have traditionally been regarded as reliable methods for recording implant positions **[4]**. However, these techniques are technique-sensitive and may involve multiple clinical and laboratory procedures, potentially increasing chairside time and patient discomfort **[5].** Advances in digital dentistry have introduced intraoral scanners (IOS) as an alternative approach for implant impressions, with potential advantages including reduced clinical time, improved patient acceptance, simplified workflows and elimination of several conventional laboratory procedures **[6]**. Nevertheless, the accuracy of digital implant impressions may be influenced by factors such as scanning strategy, implant distribution, scan-body design and the extent of the edentulous span, with greater deviations reported in complete-arch situations **[7]**. Consequently, comparison of digital and conventional implant impression techniques remains clinically relevant for determining their accuracy and suitability for complete-arch implant rehabilitation **[8]**. Therefore, it is of interest to evaluate and compare the accuracy of open-tray, closed-tray and digital implant scan body impression techniques for complete-arch implant-supported prostheses.

Materials and Methods:
A photopolymer resin (Elegoo, China) was used to fabricate the edentulous maxillary master model and tissue moulage because of its high dimensional accuracy and ability to reproduce fine surface details. The models were fabricated using a Phrozen Sonic Mighty 4K LCD three-dimensional printer (Phrozen, Taiwan), which operates at a wavelength of approximately 405 nm with a resolution of 3840 × 2400 pixels and a build volume of 200 × 125 × 220 mm, enabling precise production of anatomically accurate edentulous maxillary models. Digital implant analogs (DIO Corporation, Korea) were placed in the printed models to accurately simulate implant positions for both conventional and digital impression procedures. Titanium scan bodies (581H; DIO Corporation, Korea), manufactured from Ti-6Al-4V Grade 5 alloy, were secured using a 1.2 mm hex driver and tightened to a standardized torque of 5–8 Ncm according to the manufacturer's recommendations to ensure consistent seating during scanning. All digital scans were performed with the same intraoral scanner (Runyes, China) for both the reference model and all stone casts to eliminate inter-device variability. Following printing, the resin models were cleaned with 95–99% isopropyl alcohol to remove uncured resin and post-cured under 405 nm ultraviolet light to achieve complete polymerization and enhance dimensional stability. The study was conducted under standardized *in vitro* laboratory conditions to eliminate clinical variables such as saliva, patient movement and soft tissue resilience. An edentulous maxillary reference model was designed using computer-aided design (CAD) software to reproduce the anatomical contours of the residual ridge and palatal vault accurately. The finalized STL file was processed using Chitubox slicing software and fabricated with a stereolithography (SLA) three-dimensional printer using the recommended printing parameters for the selected resin, including a layer thickness of 0.025–0.05 mm, exposure time of 2–8 seconds per layer and bottom-layer exposure of 30–60 seconds. After fabrication, the models were rinsed in isopropyl alcohol for 2–5 minutes and post-cured under ultraviolet light for 2–10 minutes to optimize mechanical properties and dimensional stability. Six implant analogs were then positioned in the printed resin model at the right and left lateral incisors, first premolars and first molars. Implant placement was standardized with a dental surveyor to maintain parallelism and minimize angulation-related errors,

allowing the resin model to serve as the master reference model for the study.

Reference model generation:
The 3D-printed resin model served as the master reference model. Implant scan bodies compatible with the implant system were attached to all six implant analogs according to the manufacturer's recommendations, typically tightened to 5–10 Ncm using a calibrated torque driver to ensure accurate seating without distortion or damage to the scan body interface. Care was taken to avoid over-tightening, which may lead to deformation and inaccuracies during scanning. The master model with scan bodies *in situ* was digitized using an intraoral scanner based on confocal optical scanning technology. Scanning was performed following the manufacturer's recommendations, maintaining an optimal working distance of approximately 10–20 mm with continuous motion to ensure proper image stitching and data acquisition. The scanner was calibrated prior to use and ambient light conditions were controlled to minimize optical interference, ensuring high-resolution, accurate digital capture of the scan bodies and surrounding structures. A standardized scanning protocol was followed, beginning from one posterior segment and progressing sequentially across the arch to the contralateral side to minimize stitching errors. The acquired data were processed using the scanner's proprietary software to generate a high-resolution standard tessellation language (STL) file, designated as the reference scan and used as the control dataset for all subsequent accuracy comparisons.

Study groups: The impressions were divided into two study groups:

Group I: Open-tray impression technique (n = 5)
Group II: Closed-tray impression technique (n = 5)

Conventional impression procedures:
For Group I, open-tray impression copings were placed onto the implant analogs. A custom tray with access holes corresponding to the implant positions was used. Polyvinyl siloxane (PVS) impression material was employed with a putty-wash technique. After polymerization, the copings were unscrewed and the impression retrieved. For Group II, closed-tray impression copings were placed onto the implant analogs. A stock tray was used and impressions were made with the same PVS putty-wash technique. Following impression removal, the copings were repositioned into the impression along with laboratory analogs. Er's recommended water-to-powder ratio and setting protocol. Manufacturers typically suggest a water-to-powder ratio of approximately 0.20 to 0.24 (20 to 24 mL of water per 100g of powder) to achieve optimal flow and strength. The gypsum was mixed under vacuum for 20 to 30 seconds to minimize air incorporation and improve homogeneity. Working time was maintained at 5 to 7 minutes, with an initial setting time of 8 to 12 minutes and a final setting time of 45 to 60 minutes.

Digitization of master casts:
After the Type IV gypsum had fully set, the scan bodies were reattached to the implant analogs on each stone cast using the same tightening protocol applied to the master reference model. Each stone cast was then digitized using the same intraoral scanner and the identical scanning protocol used for the reference model. By maintaining the same scanner, operator, scanning path and environmental conditions, variability related to device and operator was minimized, ensuring consistency across all digital datasets. The scanned data were converted into STL files for subsequent three-dimensional comparisons.

Accuracy assessment:
The STL files were imported into three-dimensional inspection software and overlaid onto the reference STL file obtained from the resin master model. Superimposition was conducted using the Geomagic best-fit alignment algorithm, based on the geometry of the scan body. Deviations between the reference scan and the test scans were calculated to assess accuracy. Color coded deviation maps were created to visualize spatial discrepancies across the complete arch and numerical deviation values were recorded for comparative analysis between the open-tray and closed-tray techniques.

Statistical analysis:
The collected data were organized and statistically analyzed to compare the accuracy and trueness of the open-tray and closed-tray impression techniques. Descriptive statistics, including mean and standard deviation, were calculated for both groups based on root mean square (RMS) and overall deviation (DEV) values obtained from three-dimensional analysis. To assess the significance of the difference between the two groups, inferential statistics were performed using an independent-samples t-test. All analyses were conducted with the Statistical Package for the Social Sciences (SPSS) software (IBM Corp., Armonk, NY, USA), version 25.0. A p-value of less than 0.05 was considered statistically significant.

Results:
Comparison of the root mean square (RMS) values between the study groups is presented in **Table 1** and **Figure 1**. The open-tray technique demonstrated a significantly higher mean RMS value than the closed-tray technique (1.2739 ± 0.17119 vs. 0.7681 ± 0.07899; t = 5.999, p < 0.001), indicating a statistically significant difference between the two techniques. Comparison of the overall deviation (DEV) values between the study groups is presented in **Table 2** and **Figure 2**. The open-tray technique demonstrated a significantly higher mean DEV value than the closed-tray technique (1.1746 ± 0.15897 vs. 0.7170 ± 0.06634; t = 5.940, p < 0.001), indicating a statistically significant difference between the two techniques.

Table 1: Comparison of RMS among the study groups

Parameter	Groups	Mean	Std. Deviation	Std. Error Mean	t value	p value
RMS	Open tray	1.2739	0.17119	0.07656	5.999	**0.000***
	Closed tray	0.7681	0.07899	0.03533		

ISSN 0973-2063 (online) 0973-8894 (print)
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Independent t-test, p < 0.05 significant; NS: not significant*

Table 2: Comparison of DEV among the study groups

Parameter	Groups	Mean	Std. Deviation	Std. Error Mean	t value	p value
DEV	Open tray	1.1746	0.15897	0.07109	5.94	**0.000***
	Closed tray	0.717	0.06634	0.02967		

Independent t-test, p < 0.05 significant; NS: not significant*

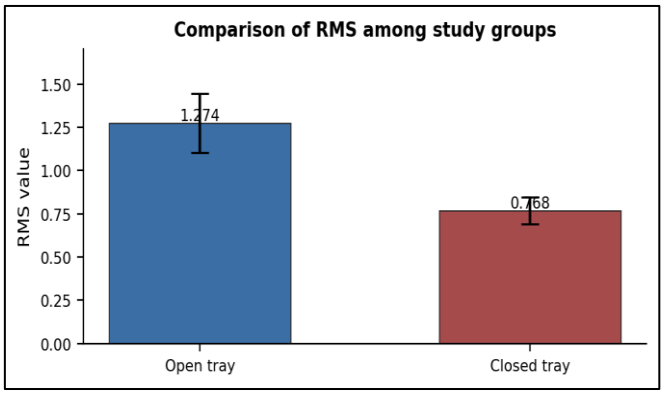


Figure 1: Comparison of RMS among the study groups

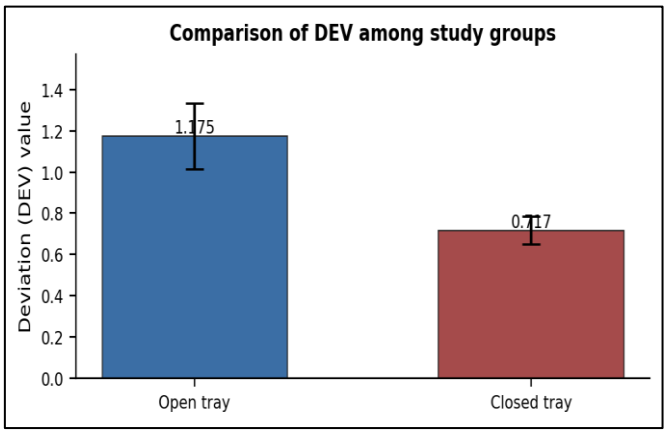


Figure 2: Comparison of DEV among the study groups

Discussion:

The accuracy and trueness of implant impressions are crucial for achieving a passive fit in complete-arch implant-supported prostheses. Any discrepancy in transferring implant positions from the clinical setting to the master cast can lead to biomechanical problems such as screw loosening, framework misfit and peri-implant bone loss. Choosing the appropriate impression technique is therefore essential for the long-term clinical success of implant prosthodontic rehabilitation **[6, 7]**. In this study, a three-dimensional comparative evaluation of open-tray and closed-tray impression techniques was conducted using RMS and overall deviation values obtained through digital superimposition. The open-tray technique showed significantly lower deviation values than the closed-tray technique, demonstrating its superior accuracy under the experimental conditions tested **[8, 9].** These findings align with conventional prosthodontic principles, which widely recommend the open-tray technique for multiple implants and complete arch situations. The main advantage of this technique is the direct transfer of impression copings without the need for repositioning, which minimizes the risk of positional errors. Previous studies have shown that the open-tray technique reduces coping displacement during impression removal and enhances accuracy, especially with multiple implants **[10, 11]**. In contrast, the closed-tray technique necessitates repositioning of the impression copings, potentially introducing errors during the transfer process, particularly in complete-arch cases. The higher deviation values observed in the closed-tray group may be attributed to these repositioning inaccuracies, even in controlled laboratory settings **[12, 13]**. The application of a three-dimensional digital analysis method provided an accurate and objective evaluation of discrepancies. By superimposing STL files using best-fit algorithms, spatial deviations across the entire arch could be comprehensively assessed, overcoming the limitations of traditional linear measurement techniques. The incorporation of intraoral scanning and scan bodies further improved reproducibility and allowed precise visualization of deviation patterns **[14]**. Additionally, a stereolithography-based 3D-printed resin model ensured dimensional stability and standardization of the experimental setup. Additive manufacturing techniques are increasingly employed in implant research owing to their capability to produce consistent and highly accurate models, enhancing the reliability of *in vitro* studies **[15]**. Despite the advantages of digital workflows, concerns about cumulative errors in complete-arch scanning remain. In this study, digital scanning served as a reference standard rather than a test variable, enabling reliable comparisons with conventional impression techniques. The standardized scanning protocol, consistent torque application and use of a single intraoral scanner minimized variability and strengthened the validity of the findings **[16]**. It is important to note that clinical conditions can vary significantly from laboratory settings. Factors such as saliva, soft-tissue dynamics, patient movement and limited access can affect impression accuracy. Therefore, while the present study supports the superiority of the open-tray technique under controlled conditions, further clinical studies are needed to validate these findings in real-world scenarios **[17, 18]**.

Conclusion:

The open-tray technique showed significantly higher accuracy and trueness than the closed-tray technique for complete-arch implant impressions. Standardized digital analysis using intraoral scanning and STL superimposition provided reliable assessment of impression accuracy. Further *in vivo* studies are warranted to validate these findings under clinical conditions.

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