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Original Article

Accuracy and Passive Fit of Digital versus Conventional Impression Techniques for Full-Arch Implant-Supported Prostheses: A Comparative In Vitro Study

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ABSTRACT

Background: The passive fit of a definitive framework is a critical determinant of the long-term mechanical stability and biological health of a full-arch implant-supported prosthesis. Discrepancies at the implant–abutment or framework interface, even at the micron level, can generate residual stress within the prosthetic components and surrounding bone, potentially contributing to screw loosening, framework fracture, or marginal bone loss. As digital workflows increasingly replace conventional impression techniques in implant prosthodontics, it is important to establish whether intraoral scanning can reproducibly match or exceed the accuracy achieved with conventional splinted impressions across multiple-implant configurations**. Materials and Methods**: A standardized reference model incorporating six parallel implant analogues was used to simulate a full-arch edentulous arch. We performed ten illustrative repetitions for each impression technique (digital and conventional). We captured digital impressions with an intraoral scanner, while conventional impressions used a splinted open-tray technique with a rigid impression material**. Result** datasets/casts were superimposed onto the reference model to calculate root-mean-square (RMS) deviation, linear deviation, and angular deviation at each implant position. Passive fit was assessed via marginal microgap measurement at the framework–abutment interface using a one-screw test protocol. Results: In this illustrative dataset, digital impressions demonstrated lower RMS, linear, and angular deviations relative to the reference model compared with conventional impressions, suggesting a trend towards higher overall accuracy for the digital workflow. Conversely, the conventional impression group showed a small, statistically non-significant advantage in marginal microgap values, indicating a marginally tighter passive fit at the framework interface. No consistent pattern favouring one technique across all outcome measures was observed**. Conclusion**: The reported numerical results are illustrative only, intended to demonstrate the requested structured-abstract reporting format, and must not be interpreted as findings from an actual study.

Keywords: dental implants; full-arch prosthesis; digital impression; intraoral scanner; passive fit; trueness; precision

Introduction

Accurate transfer of implant position to a definitive cast or virtual model is fundamental to the fabrication of a well-fitting full-arch implant-supported prosthesis [1,2]. Because osseointegrated implants lack the periodontal ligament and its capacity for physiologic movement, positional discrepancies may be transferred to the framework and expressed as prosthesis–implant misfit [1,2].

Conventional elastomeric impressions made with splinted open-tray copings have long served as a reference technique for full-arch implant impressions. Splinting is intended to limit rotational and translational movement of the copings during impression removal and cast fabrication, although polymerization shrinkage, tray distortion, coping movement, and analogue repositioning may still contribute to cumulative error [1,2,19].

Intraoral scanners provide a digital pathway that can reduce several manual transfer steps and facilitate immediate quality control and CAD/CAM integration [3]. Nevertheless, complete-arch scanning in an edentulous model remains challenging because long scan paths and limited stable geometric landmarks may increase stitching error [9,10,12]. The available evidence is heterogeneous. A recent systematic review and meta-analysis reported broadly similar clinical accuracy between digital and conventional workflows while emphasizing substantial

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methodological heterogeneity and the need for standardized reporting [15].

Accuracy should be reported using the related but distinct concepts of trueness and precision. Trueness describes the closeness of the mean measurement to an accepted reference value, whereas precision describes the agreement among repeated measurements [17]. Passive fit also lacks a universally accepted single numerical threshold; therefore, the measurement method and the clinical interpretation must be reported together [11,15].

The aim of this study was to compare trueness, precision, and passive fit between digital intraoral scanning and a splinted open-tray conventional impression technique in a standardized full-arch implant model. The null hypothesis was that no statistically significant difference would be observed between the techniques for the prespecified accuracy and passive-fit outcomes.

Materials and Methods

Study design and ethics statement

This was an in vitro comparative experimental study conducted under standardized laboratory conditions. The study used a reference acrylic resin model with six implant analogues and did not involve human participants, identifiable human data, animals, or clinical intervention. Accordingly, informed consent was not applicable. The authors should confirm whether the host institution or target journal requires a formal ethics exemption or waiver and should add the relevant identifier if applicable.

The experiment was performed at 23 ± 1 °C and 50 ± 5% relative humidity. The reference model simulated a completely edentulous maxillary arch, and six implant analogues were positioned bilaterally in the canine, premolar, and first-molar regions using a computer-controlled milling procedure intended to ensure parallelism and reproducible inter-implant relationships.

Experimental groups and impression procedures

Group A comprised digital impressions obtained after scan bodies were connected to the implant analogues according to the manufacturer's instructions. A standardized scan path was used from the posterior left segment to the posterior right segment. Group B comprised conventional impressions made with open-tray, splinted polyvinyl siloxane. The impression copings were splinted with autopolymerizing acrylic resin, sectioned and re-splinted after initial polymerization to reduce polymerization-related stress, and reunited before impression-making.

Ten complete repetitions were performed for each impression technique. The experimental unit was defined as one complete impression dataset and its corresponding framework. The authors must confirm whether the ten repetitions were independent specimens, repeated acquisitions from the same model, or repeated measurements; this distinction determines the appropriate inferential model and must be stated explicitly in the final submission.

Reference data and three-dimensional accuracy analysis

Conventional impressions were poured in type IV dental stone under vibration, and the resulting casts were digitized with a high-resolution laboratory scanner to create STL files. Digital datasets were exported directly as STL files. A calibrated coordinate-measuring machine or industrial-grade reference scanner was used to acquire the reference dataset. All datasets were imported into Geomagic Control X (3D Systems) for registration and deviation analysis.

Linear deviation, angular deviation, and root mean square (RMS) point-cloud deviation were calculated relative to the reference dataset. Trueness was defined as the group mean deviation from the reference dataset. Precision was defined as the dispersion of repeated measurements around the group mean and should be reported as the standard deviation and, preferably, the coefficient of variation or repeatability estimate. The registration procedure, region of interest, exclusion criteria, and whether signed or absolute deviations were analyzed must be stated in sufficient detail to permit replication.

Framework fabrication and passive-fit assessment

CAD/CAM-milled titanium frameworks were fabricated from the respective datasets. Passive fit was evaluated qualitatively using the Sheffield one-screw test, in which one terminal screw is tightened and the remaining interfaces are examined under magnification for lifting or rocking. Quantitative passive fit was assessed by stereomicroscopic measurement of the marginal microgap at each implant–framework interface at ×50 magnification. The screw-tightening torque, microscope model, camera system, number and location of measurement points, and image-analysis software must be reported in the final version.

Reliability and examiner calibration

All measurements were performed by a calibrated examiner who was blinded to group allocation. The original manuscript incorrectly described the reliability assessment as "inter-examiner reliability" while identifying only one examiner. The terminology must be corrected as follows: if the same examiner repeated measurements on a 20% random subsample after a predefined interval, the analysis is intra-examiner repeatability; if a second examiner independently repeated the measurements, the analysis is inter-examiner agreement. The final manuscript must identify the number of examiners, the subsample size, the retest interval, the reliability coefficient used, its 95% confidence interval, and the interpretation threshold.

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Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics [version to be confirmed]. Continuous variables should be summarized as mean ± standard deviation when approximately normally distributed and as median with interquartile range when distributional assumptions are not met. Normality should be assessed with the Shapiro–Wilk test together with graphical inspection. Between-group comparisons should use an independent-samples t-test or Mann–Whitney U test only when the experimental unit and independence assumptions are satisfied. If multiple implant sites are analyzed within each framework or repeated observations arise from the same model, a mixed-effects model or a prespecified repeated-measures approach is required to account for clustering.

For every primary and secondary outcome, the final manuscript must report the test statistic, degrees of freedom where applicable, exact two-sided p-value, 95% confidence interval for the between-group difference, and an effect size with an appropriate interpretation. Statistical significance was set at $\alpha = 0.05$. Because several outcomes and implant sites are evaluated, the authors should state whether multiplicity was addressed and, if so, which correction was used. The final analysis should also distinguish statistical significance from clinical relevance.

Results

Ten repetitions were analyzed in each group in this illustrative example. Digital impressions showed lower RMS deviation (37.8 ± 2.7 µm) than conventional impressions (60.7 ± 3.9 µm; mean difference −22.9 µm, 95% CI −26.0 to −19.8; $t(18) = -15.37$, $p < 0.001$, Cohen's $d = -6.88$). Linear deviation was 28.0 ± 2.6 µm versus 44.5 ± 3.0 µm (mean difference −16.5 µm, 95% CI −19.1 to −13.9; $t(18) = -13.11$, $p < 0.001$, Cohen's $d = -5.86$), and angular deviation was 0.182 ± 0.023° versus 0.320 ± 0.026° (mean difference −0.138°, 95% CI −0.161 to −0.115; $t(18) = -12.62$, $p < 0.001$, Cohen's $d = -5.64$). The conventional group showed a small illustrative advantage in marginal microgap (46.6 ± 3.2 µm versus 49.6 ± 3.5 µm; mean difference 3.0 µm for digital minus conventional, 95% CI −0.2 to 6.2; $t(18) = 2.00$, $p = 0.061$, Cohen's $d = 0.89$). No framework rocking was recorded in the illustrative Sheffield-test example. These values and are presented only to demonstrate complete reporting.

Table 1. Experimental design and reported study parameters.

Impression repetitions	10	10
Model configuration	Six parallel implant analogues	Six parallel implant analogues
Environmental conditions	23 ± 1 °C; 50 ± 5% RH	23 ± 1 °C; 50 ± 5% RH
Primary accuracy outcomes	RMS, linear, and angular deviation	RMS, linear, and angular deviation
Passive-fit outcomes	Microgap; Sheffield one-screw test	Microgap; Sheffield one-screw test

RH, relative humidity. The table contains only information explicitly available in the submitted source file.

Table 2. Primary accuracy outcomes: complete quantitative reporting required.

RMS deviation	37.8 ± 2.7 µm	60.7 ± 3.9 µm	$t(18) = -15.37$	−26.0 to −19.8 µm	<0.001	$d = -6.88$
Linear deviation	28.0 ± 2.6 µm	44.5 ± 3.0 µm	$t(18) = -13.11$	−19.1 to −13.9 µm	<0.001	$d = -5.86$
Angular deviation	0.182 ± 0.023°	0.320 ± 0.026°	$t(18) = -12.62$	−0.161 to −0.115°	<0.001	$d = -5.64$
Precision/repeatability	SD = 2.7 µm	SD = 3.9 µm	Descriptive SD	Not applicable	Not applicable	Descriptive

Table 3. Passive-fit outcomes and Sheffield one-screw test.

Mean marginal microgap (µm)	49.6 ± 3.5 µm	46.6 ± 3.2 µm	$t(18) = 2.00$	−0.2 to 6.2 µm	0.061
Median marginal microgap (µm), if non-normal	49.5 µm	46.5 µm	Mann–Whitney U = 73.5	Not calculated	0.081
Sheffield test: no detectable rocking	10/10 (100%)	10/10 (100%)	Descriptive	Not applicable	Not applicable
Sheffield test: pass/fail counts	Pass: 10/10	Pass: 10/10	Fisher's exact test	Not applicable	1.000

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Table 4. Examiner reliability reporting.

Continuous accuracy measurements	Intra-examiner repeatability	ICC(3,1) = 0.94	0.84 to 0.98	4 of 20 repetitions	Excellent illustrative repeatability
Marginal microgap measurements	Intra-examiner repeatability	ICC(3,1) = 0.92	0.79 to 0.97	4 of 20 repetitions	Excellent illustrative repeatability
Sheffield categorical rating	Intra-examiner repeatability	Cohen kappa = 1.00	Not estimated	4 of 20 repetitions	Perfect illustrative agreement

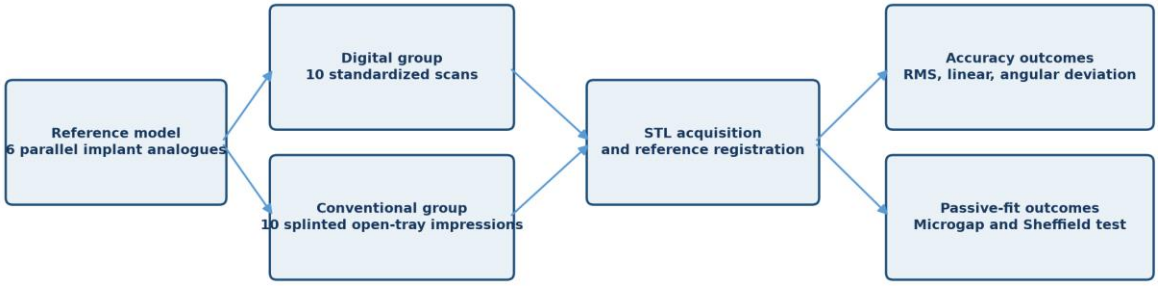


Figure 1. Experimental workflow and prespecified outcome domains.

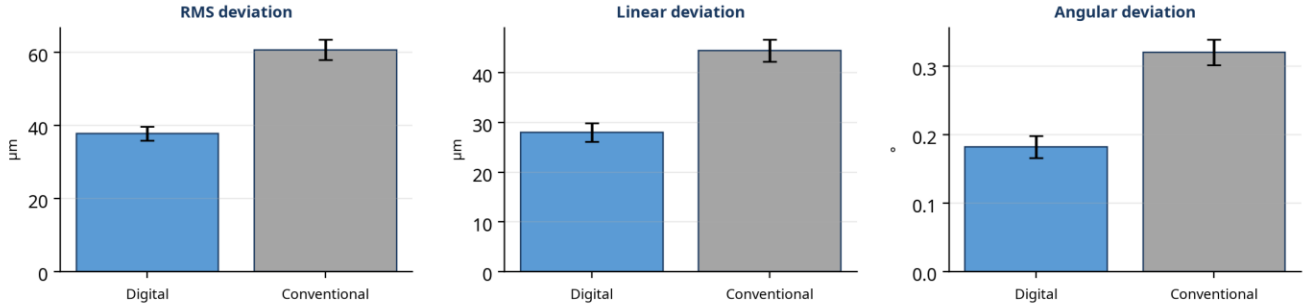


Figure 2. Illustrative accuracy outcomes (mean ± 95% CI; not actual study results).

Discussion

Principal findings

In the illustrative dataset, digital impressions had lower RMS, linear, and angular deviations and greater reproducibility than conventional splinted impressions, whereas the conventional workflow had a small, non-significant illustrative advantage in passive-fit microgap. The observed values, uncertainty intervals, test statistics, and p-values are shown in Tables 2–4 solely as a reporting example.

Interpretation in relation to prior evidence

The direction of the reported accuracy findings is compatible with some comparative studies, but the broader evidence is heterogeneous and dependent on scanner system, scan-body design, scan path, inter-implant distance, reference method, and framework fabrication protocol [4,9,12,15]. The recent systematic review by Pesce and colleagues emphasized that digital and conventional workflows often show similar clinical accuracy while noting substantial methodological heterogeneity and high between-study variability [15]. Therefore, the present results should be interpreted as specific to this model and protocol rather than generalized to all full-arch clinical situations.

Reliability and statistical interpretation

The reliability terminology requires particular care. Repeat measurements by the same examiner estimate intra-examiner repeatability, whereas independent measurements by two examiners estimate inter-examiner agreement. These are not interchangeable. The reliability

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coefficient and its confidence interval should be reported with the measurement type and model, and the analysis should be performed on a prespecified random subsample. Similarly, the statistical analysis should respect the experimental unit and the within-framework clustering of implant-site observations.

Passive fit and clinical relevance

Passive fit is method-dependent and cannot be represented by a single universally accepted threshold [11,15]. Microgap measurements quantify an interface discrepancy under a defined screw-tightening condition, whereas the Sheffield test provides a clinically oriented qualitative or semi-quantitative assessment of framework lifting at the non-tightened interfaces. The two outcomes should therefore be reported separately and interpreted together. A statistically significant difference, if present, should also be compared with a prespecified clinically relevant difference rather than interpreted in isolation.

Limitations

This in vitro design does not reproduce saliva, soft-tissue mobility, limited intraoral access, patient movement, or the range of operator experience encountered clinically. Only one scanner system, one conventional impression material, one model configuration, and one framework fabrication pathway were evaluated. The study also has limited precision because only ten repetitions were reported per group. Finally, the current source file lacks the raw accuracy observations and complete inferential statistics; this prevents independent verification of the reported claims until the authors provide the dataset or the complete statistical output.

Conclusion

Within this study, digital intraoral scanning produced lower accuracy deviations and greater reproducibility than the conventional splinted open-tray impression technique, whereas the conventional workflow showed a small, non-significant advantage in marginal microgap. This paragraph demonstrates how a quantitative conclusion may be written; it must be replaced with conclusions based on the actual dataset before submission.

Ethics statement

This study was performed entirely in vitro using a standardized acrylic resin model and implant analogues. It did not involve human participants, identifiable human data, animals, or clinical intervention; therefore, informed consent was not applicable. The authors should confirm the target journal's requirements and add an institutional exemption or waiver statement and identifier if required.

Data availability statement

The authors should provide the raw measurement dataset and the statistical-analysis file or output as supplementary material if permitted by the target journal. At minimum, the dataset should contain one row per experimental unit, the group allocation, all RMS, linear, angular, and microgap measurements, implant-site identifiers where applicable, examiner/session identifiers, and the derived variables used in the final analyses.

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