Cumhuriyet Dental Journal, 28(4): 567-574, 2025
DOI: https://doi.org/10.7126/cumudj.1758867

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 Publisher: Sivas Cumhuriyet Üniversitesi

Digital Alignment Accuracy of Zirconia Abutments Using Library Data on Incompletely Captured Implant Impressions: An In Vitro Study

Başak Topdağı[1,a,*], Fatih Oktay[2,b], Türker Akar[3,c]

[1]*Department of Prosthodontics, Faculty of Dentistry, Health Sciences University, Istanbul, Türkiye.*
[2]*Department of General Dentistry, Erzincan Oral and Dental Health Center, Erzincan, Türkiye.*
[3]*Department of Prosthodontics, Faculty of Dentistry, Erzincan Binali Yıldırım University, Erzincan, Türkiye.*
**Corresponding author*

Research Article

History

Received: 05/08/2025
Accepted: 02/12/2025

ABSTRACT

Objectives: This in vitro study aimed to evaluate the feasibility and accuracy of digitally aligning zirconia customized abutment library files onto incomplete abutment scan datasets. Superimposition was compared to the conventional "Close holes" reconstruction function in computer-aided design (CAD) software.

Materials and Methods: A single-implant dental model was used, and a custom zirconia abutment was scanned to generate a digital library file. Complete scans of the abutment and adjacent teeth served as the control group (C). Two experimental datasets were produced by selectively deleting marginal regions (NC2) and both marginal and proximal surfaces (NC3) from the complete scan. Defective scans were processed either by digital superimposition with the abutment library file (S group) or by applying the "Close holes" function in CAD software to reconstruct missing areas (CH group). All datasets were analyzed in Geomagic Control X (3D Systems, USA) to assess trueness using root mean square (RMS) error and point-based deviation analysis. Statistical evaluation was performed using one-way ANOVA and Tukey HSD post hoc tests

Results: Superimposition significantly improved trueness compared with unprocessed scans. RMS values decreased from 39.11 ± 0.98 µm in the IOS (intraoral scanner) group to 35.41–37.59 µm across the C, NC2, NC3, and S groups datasets ($p = 0.032$). The CH group showed significantly higher deviations than all superimposition groups ($p < 0.001$). Point-based analysis confirmed lower deviations after superimposition ($p = 0.008$). No significant differences were found among the superimposed groups.

Conclusions: Digital superimposition of zirconia abutment library data onto incomplete scans enhances trueness and geometric reliability. This method is superior to conventional reconstruction tools for restoring incomplete implant impressions.

Keywords: Computer-aided design, dental prosthesis, implant-supported prosthesis, impression technique, prosthesis design, zirconium

Eksik Dijital İmplant Ölçülerinde Zirkonya Abutmentlerin Kütüphane Verisi ile Dijital Eşleştirme Doğruluğu: İn Vitro Çalışma

Araştırma Makalesi

Süreç

Geliş: 05/08/2025
Kabul: 02/12/2025

ÖZ

Amaç: Bu çalışmanın amacı, eksik taranmış zirkonya abutment modellerine ait verilerin, kütüphane dosyaları ile dijital olarak süperimpoze edilmesinin doğruluğunu değerlendirmek ve bu yöntemi bilgisayar destekli tasarım (CAD) yazılımındaki geleneksel "boşluk doldurma" fonksiyonu ile karşılaştırmaktır.

Gereç ve Yöntemler: Tek implant içeren bir dental model kullanıldı. Kişiye özel olarak tasarlanmış zirkonya abutment, 3D Shape laboratuvar tarayıcısıyla taranarak kütüphane dosyası oluşturuldu. Tam tarama verileri kontrol grubu (C) olarak referans kabul edildi. Marjinal alanların ve proksimal yüzeylerin silinmesiyle oluşturulan NC2 ve NC3 veri setleri, eksik taramaları simüle etti. Eksik verilerin dijital olarak kütüphane abutment modeliyle hizalandığı süperimpozisyon grubu (S) ve "boşluk doldurma" fonksiyonunun uygulandığı CH grubu oluşturuldu. Tüm veriler, kütüphane abutment modeli ile dijital olarak hizalandı. Her bir veri seti, Geomagic Control X yazılımında karekök ortalama kare (RMS) hata değerleri ve nokta bazlı sapma analizi ile değerlendirildi. İstatistiksel analizde tek yönlü ANOVA ve Tukey HSD post hoc testi kullanıldı.

Bulgular: Zirkonya abutment kütüphane verisinin süperimpozisyonu, işlenmemiş taramalara göre anlamlı düzeyde daha yüksek doğruluk sağlamıştır (RMS: 39,11 ± 0,98 µm → 35,41–37,59 µm; p = ,032). C, NC2, NC3 ve S grupları arasında istatistiksel olarak anlamlı bir fark saptanmamıştır (p > ,05). Buna karşın, CH grubundaki sapmalar tüm süperimpozisyon gruplarına kıyasla anlamlı düzeyde daha yüksektir (p < ,001). Nokta bazlı analiz sonuçları, marjinal sırtlar dışında tüm bölgelerde sapmaların azaldığını göstermiştir (p = ,008).

Sonuçlar: Zirkonya abutment kütüphane verisinin eksik taramalara dijital olarak hizalanması, geometrik doğruluğu artırmakta ve geleneksel boşluk doldurma algoritmalarına kıyasla daha yüksek performans sağlamaktadır.

Anahtar Kelimeler: Bilgisayar yardımlı tasarım, diş ölçü tekniği, diş protezi, implant destekli protezler, protez tasarımı, zirkonyum

Copyright

This work is licensed under Creative Commons Attribution 4.0 International License

[a] *basak.topdagi@sbu.edu.tr* *0000-0002-4242-7681*
[b] *oktayfatih@hotmail.com* *0000-0002-6484-4224*
[c] *turkerakar24@gmail.com* *0000-0003-2035-8686*

How to Cite: Topdağı B, Oktay F, Akar T. (2025) Digital Alignment Accuracy of Zirconia Abutments Using Library Data on Incompletely Captured Implant Impressions: An In Vitro Study, Cumhuriyet Dental Journal, 28(4): 567-574.

Introduction

Intraoral scanning technologies have gained widespread use in contemporary dental workflows, providing a digital alternative to conventional impression techniques in the fabrication of implant-supported restorations. In routine digital impression procedures, scan bodies compatible with implant systems are used to accurately capture implant positions, enabling seamless integration with CAD library components.[1] In clinical practice, abutment-level impressions are required when a customized abutment has been modified intraorally and no longer corresponds to its original library geometry. This study simulated such conditions in vitro to evaluate how missing proximal data affect the superimposition of customized abutment scans. Therefore, the customized abutment was scanned directly in the laboratory environment, without any intraoral procedures.[2,3] Although this study did not involve clinical procedures, in real-world settings, capturing accurate digital impressions of zirconia abutments remains challenging, especially when finish lines are located subgingivally, where gingival retraction may be required to expose the margins.[4] Customized abutments are frequently adjusted intraorally during soft-tissue conditioning or long-term provisionalization, causing their final morphology to deviate from the original CAD library geometry. In such situations, abutment-level scanning becomes clinically necessary, as standard transfer copings cannot reproduce the emergence profile and margin configuration that have been clinically developed.[4,5] Despite their effectiveness, these approaches are often technically demanding and time-intensive. Moreover, the use of gingival retraction cords has been associated with soft tissue trauma such as bleeding, pain, and gingival recession.[4,5] Moreover, the morphologic complexity of the abutment's proximal areas, along with limited intraoral access, further complicates the scanning process. In addition, the optical properties of zirconia, such as its high translucency and low reflectivity, can impair the scanner's ability to accurately capture surface details, sometimes resulting in incomplete or distorted data.[6] In recent years, to overcome accuracy limitations in the digital scanning of zirconia abutments, researchers have proposed superimposing laboratory-scanned abutment data onto intraoral scans.[7-9] In this approach, custom zirconia abutments are scanned using desktop scanners, and the resulting datasets are aligned.[10,11] Trueness was evaluated using 3D analysis tools, and findings showed that this method significantly improved the accuracy of digital impressions, regardless of the software used.[12,13] Particularly for zirconia, which has low reflectivity and is challenging to scan in detail, this hybrid scanning protocol offers notable clinical advantages.[14] Intraoral scanning of zirconia abutments often yields incomplete data due to subgingival margins, limited accessibility, and the material's optical properties.[15-17] An alternative approach involves merging laboratory-scanned zirconia abutments with intraoral scan datasets, allowing for a more controlled reconstruction of missing or poorly captured areas. Although this has been shown to enhance accuracy in various scenarios, its performance under different extents of incomplete scan coverage has not been thoroughly evaluated in the context of zirconia abutments.[7,18] Although restorations on Ti-base abutments can be fabricated using existing library data, intraoral scanning of zirconia abutments becomes essential when the definitive restoration is fabricated directly on the customized abutment. After intraoral modifications during soft-tissue conditioning or provisionalization, the abutment geometry may differ from the original library file, requiring a new digital scan to ensure accurate adaptation and emergence profile.

Therefore, the present study aimed to examine how varying the amount of available scan data affects the trueness of superimposed digital models for zirconia abutments and adjacent teeth. Additionally, the accuracy of these superimposed models was compared with reconstructions generated by the hole-filling function embedded in CAD software.

Two null hypotheses were formulated:

1. Increasing the scanned surface area of the abutment does not influence the trueness of the superimposed models.
2. There is no significant difference in trueness between models obtained through superimposition and those created using the software's hole-filling algorithm.

Materials and Methods

Experimental Design

This in vitro study was performed entirely on non-biological, inert materials without the involvement of human participants or animal subjects. As such, ethical approval was not required based on current institutional and regulatory standards for laboratory-based experimental designs.

Scanning Procedures

A NobelParallel implant system (NobelParallel, Nobel Biocare, Zurich, Switzerland), featuring an internal conical connection, was inserted into the maxillary right first molar region of a resin-based dental arch model to simulate a posterior single-tooth edentulous site. A polyether ether ketone (PEEK) scan body compatible with the NobelParallel implant system (NobelParallel, Nobel Biocare, Zurich, Switzerland) was manually connected to the implant fixture positioned in the resin model.

The specimen was digitized using a desktop laboratory scanner (E4, 3Shape, Copenhagen, Denmark). Two laboratory scanners were employed to ensure optimal data quality for both reference and library datasets: the E4 scanner (3Shape, Copenhagen, Denmark) was used to capture the overall model geometry and implant position, whereas the T500 scanner (Medit Corp., Seoul, South Korea) was used for the customized zirconia abutment due to its higher optical resolution and ability to capture fine marginal details required for library file generation.

A customized zirconia abutment was virtually designed in CAD software (Dental System, 3Shape, Copenhagen, Denmark). The milled abutment was subsequently scanned with a separate high-resolution laboratory scanner (T500, Medit Corp., Seoul, South Korea) to generate a digital library file for use in subsequent superimposition processes. To reduce reflections during scanning, a thin layer of scanning spray (Scan Spray Plus, Renfert GmbH, Hilzingen, Germany) was applied to the customized zirconia abutment. After

placement onto the implant in the model, the specimen was scanned using the E4 scanner (3Shape, Copenhagen, Denmark) to obtain a reference STL file.

Intraoral Scanning

For the IOS (intraoral scanner) group, partial-arch scans were performed by an experienced operator (B.T.) using an intraoral scanner (i500, Medit Corp., Seoul, South Korea), focusing on the implant and neighboring teeth. Scanning followed a standardized horizontal path with calibrated equipment, and no scan spray was used intraorally, as per the manufacturer's recommendations.

Group Definitions

In total, six groups were created and analyzed. The IOS group represented partial-arch intraoral scans obtained under clinically realistic conditions. The control group (C) consisted of complete laboratory scans capturing all marginal and proximal details of the abutment and adjacent teeth.

Two defective datasets were generated by systematically modifying the control scan:

- NC2: created by deleting marginal regions (2-mm band).
- NC3: created by removing both marginal and proximal surfaces (3-mm band).

To investigate different data recovery strategies, two additional groups were derived from NC3:

- S: incomplete scans digitally aligned with the customized abutment library file via superimposition using CAD software (DentalCAD, exocad GmbH, Darmstadt, Germany).
- CH: incomplete scans algorithmically reconstructed using the "Close holes" function within the same CAD software (DentalCAD, exocad GmbH, Darmstadt, Germany).

Data Processing and Superimposition

The nine IOS datasets were imported into CAD software (DentalCAD, exocad GmbH, Darmstadt, Germany). The previously prepared customized abutment library file was employed to superimpose the respective abutments of the IOS files using the multidie function within the CAD software.

The multidie function enables superimposition of individual abutment dies onto the master model using a point-based registration method. This involved identifying corresponding points on both the customized abutments and the master model, facilitating accurate superimposition of each abutment. The outcomes were saved as the C group reference files.

Potential inadequacies in scanning the margin area, particularly at subgingival regions, were simulated by intentionally removing 2-mm or 3-mm band-shaped sections from the abutment margins in the IOS group. The customized abutment library file was then superimposed onto these intentionally deleted datasets to form the NC2 and NC3 groups, respectively.

For the S group, square regions (3 × 3 mm) were digitally removed from the mesial and distal surfaces to simulate proximal scanning deficiencies. These modified datasets were aligned with the abutment library file through superimposition. In contrast, the CH group datasets were repaired using the "Close holes" function within the CAD software (DentalCAD, exocad GmbH, Darmstadt, Germany), allowing automatic reconstruction of missing regions.

3D Analysis and Measurement

To assess trueness, STL files from all six groups (IOS, C, NC2, NC3, S, CH) were aligned with the reference data using inspection software (Geomagic Control X, 2020 release; 3D Systems, Rock Hill, SC, USA) in accordance with ISO 12836 guidelines. Initial and best-fit alignments were performed, and deviations were calculated as root mean square (RMS) values with a tolerance threshold of ±50 µm. The proportion of surface points within this threshold (inTOL) was also recorded.[19]

Visual analysis was conducted using color deviation maps with a 20-segment scale ranging from ±50 µm (nominal) to ±500 µm (critical). To evaluate local deviations, 66 landmarks were manually placed along the abutment finish line on the reference model. These were divided into buccal (18), palatal (18), mesial (14), and distal (14) regions, and mean deviations for each surface were calculated individually.

Statistical Analysis

All statistical analyses were performed using statistical software (SPSS v29; IBM Corp., Armonk, NY, USA) with a significance level set at $\alpha = 0.05$. Data normality and homogeneity were assessed using the Shapiro–Wilk and Levene tests, respectively. Group comparisons for RMS, inTOL, and local deviations were conducted using one-way ANOVA followed by Tukey HSD post hoc tests.

Results

Discrepancies between the reference scan and the six test groups were evaluated. A significant decrease in RMS values and an increase in inTOL were observed when comparing the IOS group to the C group ($p = 0.032$), indicating that superimposing the customized abutment library enhanced the accuracy of intraoral scans. Similarly, the NC2, NC3, and S groups—which simulated scanning deficiencies by selectively removing specific regions—also exhibited improved trueness compared to the IOS group, with no statistically significant differences relative to the C group. In contrast, the CH group demonstrated significantly higher deviations than both the S and IOS groups (Tables 1 and Figure 1).

Figure 2 illustrates the deviation maps, presented with a color scale, to visualize the differences between each experimental group and the reference scan. In the IOS group, deviations exceeding the acceptable tolerance—indicated by blue and yellow color regions—were primarily localized on the proximal surfaces (Figure 2A). In contrast, the superimposition-based groups (C, NC2, NC3, and S) exhibited a uniform green distribution over the entire surfaces of both the abutment and adjacent teeth, regardless of the level of artificial data omission (Figure 2B–E). The CH group, on the other hand, consistently demonstrated pronounced blue deviations at both the margins and proximal contacts across all cases, with additional yellow discrepancies observed in four datasets (Figure 2F).

The discrepancy at the abutment margin was assessed by calculating the mean x-, y-, and z-axis deviation at each of the 66 designated points for all six groups. The IOS group showed

significantly greater average marginal deviation than the superimposition groups (C, NC2, NC3, and S) ($p = 0.008$; Table 2). After superimposition, deviations at each of the four tooth surfaces (buccal, palatal, mesial, and distal) were notably reduced compared to IOS (Table 2). No statistically significant differences were found among the superimposed groups (C, NC2, NC3, and S) in terms of total margin discrepancy or surface-based deviations.

In contrast, the CH group showed higher overall and surface-specific deviations than all superimposition groups, and significantly higher values on the mesial, palatal, and distal surfaces compared to IOS. No group differences were found at the marginal ridges, but cusp and pit deviations were significantly lower in the superimposition groups (C, NC2, NC3, and S) than in IOS and CH (Table 3). When the 16 predefined anatomical points on the first molar were analyzed, abutment deviations were lower in the superimposed groups compared to IOS and CH, confirming enhanced trueness after library alignment. Among the superimposed groups, no significant differences were found (Table 4).

Table 1. Comparative 3D assessment of RMS and inTOL values between test groups and reference model (Mean ± SD)

Group	RMS (mm)	inTOL (%)
IOS Scan	39.12 ± 0.92^{a}	91.21 ± 0.86^{a}
C (IOS + superimposition)	35.37 ± 0.64^{b}	89.61 ± 0.61^{b}
NC2 (IOS + 2 mm band margin defect + superimposition)	36.73 ± 0.62^{b}	88.35 ± 0.47^{b}
NC3 (IOS + 3 mm band margin defect + superimposition)	35.81 ± 0.62^{b}	91.30 ± 0.54^{b}
S (IOS + square proximal defect + superimposition)	34.51 ± 0.68^{b}	90.72 ± 0.63^{b}
CH (IOS + square proximal defect + close holes)	46.58 ± 2.01^{c}	85.85 ± 1.02^{c}

**Superscript letters within each column denote statistically significant differences ($p < 0.05$) as determined by repeated measures ANOVA. ($p < 0.05$).*

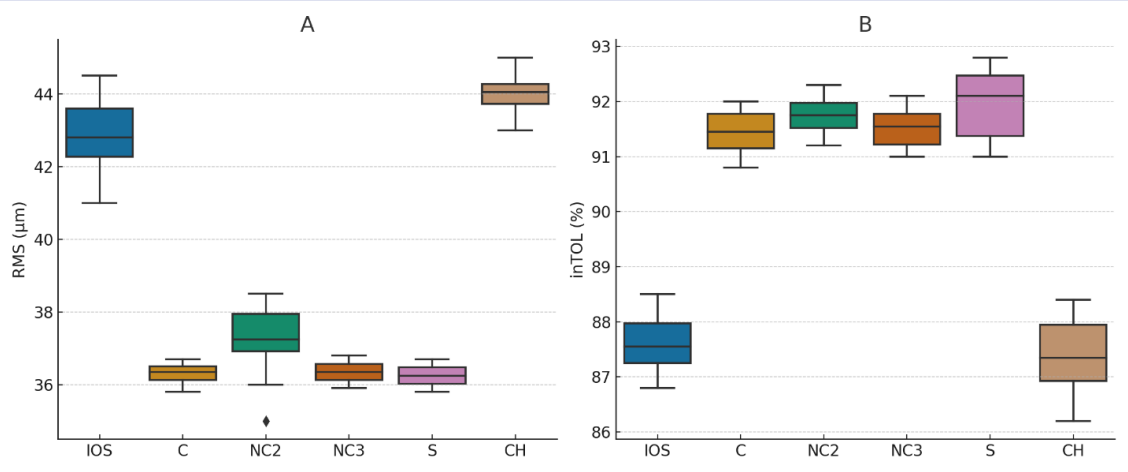

Figure 1. Boxplots comparing (A) root mean square error (RMS, µm) and (B) percentage of deviation values within tolerance (inTOL, %) across all test groups.

Table 2. Mean marginal discrepancy (µm) across groups and tooth surfaces (Mean ± SD)

Group	Total	Buccal	Mesial	Palatal	Distal
IOS	58.41 ± 17.42^{a}	63.41 ± 24.22^{a}	54.67 ± 28.85^{a}	69.93 ± 32.27^{a}	52.27 ± 22.36^{a}
C	24.39 ± 1.21^{b}	16.19 ± 1.66^{b}	36.03 ± 3.91^{ab}	26.60 ± 1.12^{b}	9.12 ± 1.53^{b}
NC2	27.01 ± 1.36^{b}	15.05 ± 1.31^{b}	34.52 ± 5.06^{ab}	21.31 ± 1.25^{b}	9.04 ± 2.37^{b}
NC3	28.04 ± 1.79^{b}	16.63 ± 1.39^{b}	21.33 ± 14.65^{b}	22.71 ± 1.11^{b}	9.75 ± 2.06^{b}
S	25.19 ± 1.07^{b}	14.49 ± 1.38^{b}	36.86 ± 3.79^{ab}	21.83 ± 1.06^{b}	9.68 ± 2.3^{b}
CH	63.22 ± 29.60^{a}	63.61 ± 24.67^{a}	83.09 ± 38.21^{c}	187.28 ± 28.79^{c}	114.62 ± 51.03^{c}

**Superscript letters within each column denote statistically significant differences ($p < 0.05$) as determined by repeated measures ANOVA. ($p < 0.05$).*

Table 3. Average deviation metrics for each tooth type (mean ± SD)

Group	Total	Buccal	Mesial	Palatal	Distal
IOS	62.03 ± 17.51^{a}	65.15 ± 23.96^{a}	54.04 ± 30.11^{a}	68.57 ± 32.35^{a}	50.88 ± 23.28^{a}
C	21.39 ± 1.35^{b}	15.46 ± 1.73^{b}	34.67 ± 3.83^{ab}	25.87 ± 1.08^{b}	9.03 ± 1.62^{b}
NC2	27.11 ± 1.51^{b}	15.12 ± 1.26^{b}	34.52 ± 4.87^{ab}	21.45 ± 1.39^{b}	9.83 ± 2.36^{b}
NC3	27.08 ± 2.11^{b}	16.19 ± 1.52^{b}	22.38 ± 14.66^{b}	22.33 ± 1.03^{b}	10.03 ± 2.43^{b}
S	26.33 ± 1.08^{b}	15.53 ± 1.47^{b}	36.91 ± 3.91^{ab}	22.20 ± 1.17^{b}	10.32 ± 1.97^{b}
CH	65.32 ± 30.53^{a}	63.48 ± 25.71^{a}	82.85 ± 38.18^{c}	190.04 ± 31.85^{c}	109.47 ± 50.12^{c}

**Superscript letters within each column denote statistically significant differences ($p < 0.05$) as determined by repeated measures ANOVA.*

Table 4. Descriptive Statistics of Deviation by Individual Tooth (Mean ± SD)

Group	2nd Premolar	1st Molar (abutment)	2nd Molar
IOS	11.16 ± 1.69[a]	28.23 ± 4.84[a]	9.23 ± 1.76[a]
C	11.29 ± 3.86[b]	12.55 ± 1.73[b]	9.14 ± 1.71[a]
NC2	11.79 ± 1.87[c]	13.03 ± 1.62[b]	9.03 ± 1.67[a]
NC3	12.13 ± 2.02[bc]	12.88 ± 1.34[b]	9.09 ± 1.51[a]
S	11.74 ± 2.23[c]	13.57 ± 1.44[b]	9.36 ± 1.53[a]
CH	10.12 ± 1.68[a]	27.67 ± 5.37[a]	9.41 ± 1.56[a]

**Superscript letters within each column indicate statistically significant differences ($p < 0.05$) as determined by repeated measures ANOVA.*

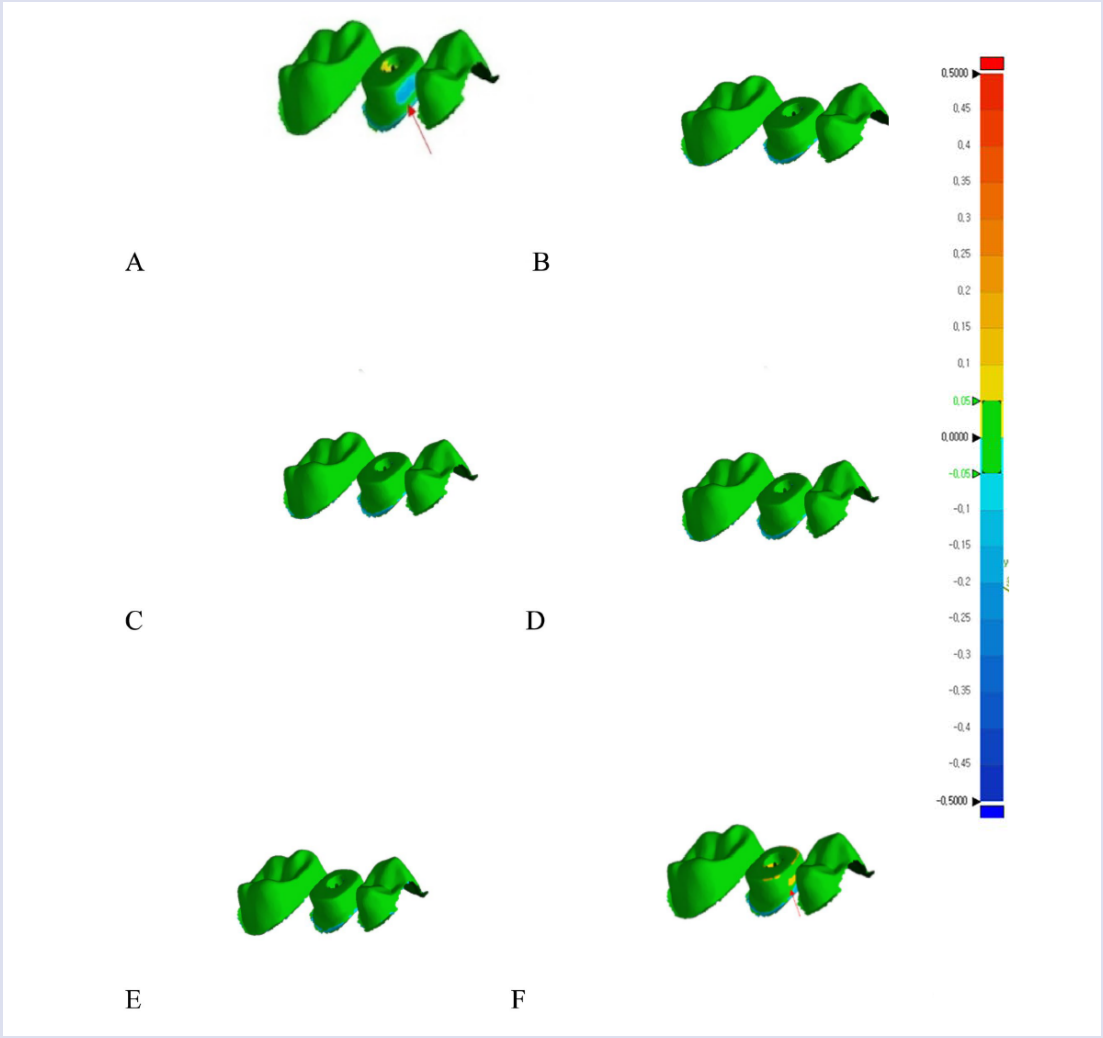

Figure 2. Color-coded deviation maps illustrating the differences between each experimental group and the reference scan. (A) IOS group showing localized deviations beyond tolerance, predominantly on the proximal surfaces. (B–E) Superimposition-based groups (C, NC2, NC3, and S) demonstrating uniform green distribution, indicating high trueness regardless of data omission extent. (F) CH group exhibiting pronounced deviations, with blue areas at the margins and proximal contacts, and yellow discrepancies in four samples.

Discussion

The accuracy of intraoral scan data improved significantly after applying the superimposition method. Among the superimposed groups, no statistically significant difference in trueness was observed, regardless of how much of the abutment surface was scanned. This finding supports the first null hypothesis, which stated that increasing the scanned surface area would not influence the trueness of the superimposed models. On the other hand, a significant difference in trueness was found between the superimposition-based models and those created using the software's hole-filling function. Therefore, the second null hypothesis, which assumed no significant difference between these two reconstruction methods, was rejected. A laboratory scanner was employed to obtain reference and library data, as recent evidence has demonstrated that contemporary lab-based scanners provide sufficient accuracy to serve as reliable references for assessing the trueness of intraoral scans.[20]

Compared to the IOS group, the C, NC2, NC3, and S groups exhibited significantly reduced mean RMS values and increased inTOL (%) scores, indicating that the trueness of the data improved following abutment-level superimposition when evaluated against the reference dataset. Th marginal discrepancy around the abutment was notably reduced after superimposition, with significant improvements observed on all tooth surfaces. Additionally, the variation in marginal deviation narrowed, reflecting enhanced repeatability and consistency of digital impressions at the abutment level. These findings have direct clinical relevance, as accurate internal and marginal fit is essential for long-term restoration success.[21,22] Poor adaptation can compromise mechanical integrity, increase the risk of marginal leakage, and lead to biological issues such as plaque retention and gingival inflammation.[23] The improved trueness observed in the C, NC2, NC3, and S groups suggests that superimposition enhances the reliability and predictability of prosthetic outcomes by minimizing internal misfit and associated stress accumulation. Moreover, reduced marginal discrepancies help prevent microleakage and periodontal complications.[23]

In contrast, the CH group demonstrated higher RMS and lower inTOL (%) values than the C, NC2, NC3, S, and even IOS groups, indicating reduced trueness. Marginal discrepancies were also greater in the CH group, particularly at the mesial, palatal, and distal surfaces, likely due to errors introduced during the hole-filling process. These findings suggest that the hole-filling method may compromise both internal and marginal adaptation, highlighting the superiority of superimposition techniques for achieving clinically reliable fits.

This study evaluated the feasibility of using superimposition across different intraoral scan ranges and investigated whether the scanned area affects trueness. To simulate common clinical limitations, subgingival margins and proximal surfaces, which are often incompletely captured, were intentionally excluded from the scan data. Despite these missing areas, superimposition with a premade library file remained effective and produced trueness values comparable to those obtained from complete abutment scans. These findings align with Kim et al., who also reported no significant loss in trueness when 1 mm of the margin or part of the proximal surface was removed prior to library-based alignment. [24] In a separate study, Choi et al. reported that when the scan body is partially submerged in the gingiva, limiting the scannable area, the accuracy of digital alignment may be negatively affected, especially when the exposed height is reduced by more than 1.0 mm.[25,26]

In the present study, digital impression errors were notably reduced following the superimposition process. This improvement is likely related to the reflective properties of the metallic abutment surface, which can interfere with image capture during intraoral scanning, as previously noted in the literature.[27,28] Capturing accurate digital data with intraoral scanners can be hindered by light scattering from metallic or translucent prosthetic surfaces. Previous studies have recommended the application of scanning powder to minimize reflection-related distortions and enhance scan quality.[29,30] Although modern intraoral scanners are designed to operate without scanning powder, they may still struggle to capture clear images when confronted with reflective prosthetic materials or intraoral moisture. Several studies have indicated that applying a thin layer of scanning powder can improve the trueness of such devices, even though their manufacturer's instructions do not require its use.[29,31] Scanning powder was applied only to the customized zirconia abutment before generating its digital library file to reduce reflections, while intraoral scans were performed powder-free per the manufacturer's instructions. This contrast in scanning conditions may explain the improved accuracy after superimposition, suggesting that powder-free scans can still achieve high trueness when superimposition is used. This contrast in scanning conditions—powdered for the library but powder-free for clinical scans—may explain the improved accuracy observed after superimposition, as the library surface data provided a more stable reference for aligning powder-free scans, thereby enhancing trueness.

This study showed that the limited omission of the abutment's marginal or proximal surfaces, within a certain threshold, does not reduce the accuracy of superimposition using library data. However, when the scanned region is excessively restricted, aligning with a digital library may become impractical. Such extreme scan deficiencies are uncommon in routine clinical workflows, and most missing areas are likely to remain within acceptable bounds as tested here. Overall, the findings suggest that partial scan deficiencies frequently encountered in practice can be compensated for by integrating premade abutment libraries, leading to improved trueness compared to relying solely on uncorrected scan data. This method may also reduce the clinical burden during impression-taking for implant-supported restorations.[32,33]

Most intraoral scanning systems and CAD software provide automated tools to detect and fill missing regions in scan data, aiming to generate a continuous 3D surface. In this study, the CAD software exocad was used, which includes a built-in mesh repair feature based on a patented method for closing gaps in digital meshes.[34] Although clinicians often rely on hole-filling to correct scan defects, this study found that superimposing abutment library data provided greater accuracy in restoring incomplete areas.

This study had limitations regarding its generalizability, as it involved only one intraoral scanner, a single implant system, and a maxillary model missing one molar. The findings may not extend to other devices or clinical conditions. Moreover, only one CAD program's hole-filling function was assessed, and the scanning defects were restricted to predefined scenarios. Future research should incorporate various scanners, implant systems, and software platforms, and simulate a broader spectrum of clinical situations to validate and expand upon these results.

Conclusions

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Integrating a pre-scanned abutment library into the digital workflow significantly improved the accuracy of intraoral scan data, even in cases where subgingival margins or interproximal areas were partially missing.
2. Compared to conventional mesh repair tools such as the "Close holes" feature, the library-based superimposition method yielded more reliable alignment and superior dimensional fidelity.
3. From a clinical standpoint, this approach may offer a practical solution for overcoming common scan limitations without compromising precision, potentially enhancing workflow efficiency and restorative outcomes.

Acknowledgements

The authors would like to thank Tacirler Education Foundation Sultanbeyli Oral and Dental Health Training and Research Hospital for their support and collaboration during the laboratory phase of this study.

Conflicts of Interest Statement

The authors declare no conflicts of interest.

References

1. Kihara H, Hatakeyama W, Komine F, Takafuji K, Takahashi T, Yokota J, et al. Accuracy and practicality of intraoral scanner in dentistry: a literature review. J Prosthodont Res 2020;64:109-113.
2. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health 2017;17:149.
3. Han X, Li Y, Liu X. Modification and evaluation of a custom impression technique for soft tissue around dental implant. Chinese J Oral Implantol 2021;26:159-163.
4. Derksen W, Tahmaseb A, Wismeijer D. A randomized clinical trial comparing the clinical fit of CAD/CAM monolithic zirconia fixed dental prostheses on Ti-base abutments based on digital or conventional impression techniques: 1-year follow-up. Int J Prosthodont 2021;34:441-449.
5. Mejía JBC, Wakabayashi K, Nakamura T, Yatani H. Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions. J Prosthet Dent 2017;118:392-399.
6. Medina-Sotomayor P, Pascual-Moscardó A, Camps I. Influence of scanning strategy on the accuracy of zirconia crowns fabricated by a digital workflow. J Prosthodont 2019;28:e536–e541.
7. Revilla-León M, Özcan M. The influence of material translucency and scanning distance on the accuracy of intraoral scanners. J Prosthodont 2020;29:785-793.
8. Kaushik K, Bhatt S, Gupta RY, Patadiya HH, Luthra A, Rao KA. Intraoral scanner in dentistry: a comprehensive review. J Adv Med Dent Scie Res 2025;13:57-61.
9. Zhu H, Zhou Y, Jiang J, Wang Y, He F. Accuracy and margin quality of advanced 3D printed monolithic zirconia crowns. J Prosthet Dent 2025;133:1284-1292.
10. Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci 2016;24:85-94.
11. Zeller S, Guichet D, Kontogiorgos E, Nagy WW. Accuracy of three digital workflows for implant abutment and crown fabrication using a digital measuring technique. J Prosthet Dent 2019;121:276-284.
12. Bertolini MdM, Kempen J, Lourenço EJV, de Moraes Telles D. The use of CAD/CAM technology to fabricate a custom ceramic implant abutment: a clinical report. J Prosthet Dent 2014;111:362-366.
13. Kim JH, Jang Y, Jeon JH, Park JM. Effect of translucency of CAD-CAM ceramic restorative materials and scanning-aid conditions on the accuracy of intraoral scans. J Dent Sci 2023;18:1212-1218.
14. Cho JH, Jang Y, Jeon JH, Kim CM, Park JM. Effects of scanning-aid materials and CAD-CAM restorative materials on the accuracy and time efficiency of intraoral scans. J Prosthet Dent 2024;132:548-555.
15. Mitchell HL, Koch I, Chadwick RG. Linear interpolation error in measured surfaces in a dental erosion study. Med Biol Eng Comput 2004;42:100-105.
16. Târtea DA, Ionescu M, Manolea HO, Mercuț V, Obădan E, Amărăscu MO, et al. Comparative study of dental custom CAD-CAM implant abutments and dental implant stock abutments. J Clin Med 2023;12:2128.
17. Revilla-León M, Quesada-Olmo N, Gómez-Polo M, Sicilia E, Farjas-Abadia M, Kois JC. Influence of rescanning of mesh holes on the accuracy of an intraoral scanner: an in vivo study. J Dent 2021;115:103851.
18. Joda T, Braegger U, Gallucci G. Systematic literature review of digital three-dimensional superimposition techniques to create virtual dental patients. Int J Oral Maxillofac Implants 2015;30:126-134.
19. Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci 2016;24:85-94.
20. Borbola D, Berkei G, Simon B, Romanszky L, Sersli G, DeFee M, et al. In vitro comparison of five desktop scanners and an industrial scanner in the evaluation of an intraoral scanner accuracy. J Dent 2023;129:104391.
21. Al Assadi F. Influence of gingival retraction on the accuracy of an intraoral scanner for subgingival finish lines. University of British Columbia; 2023.
22. Zhang ZC, Li PL, Chu FT, Shen G. Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. J Orofac Orthop 2019;80:194-204.
23. Boitelle P, Tapie L, Mawussi B, Fromentin O. Evaluation of the marginal fit of CAD-CAM zirconia copings: comparison of 2D and 3D measurement methods. J Prosthet Dent 2018;119:75-81.
24. Rhee YK, Huh YH, Cho LR, Park CJ. Comparison of intraoral scanning and conventional impression techniques using 3-dimensional superimposition. J Adv Prosthodont 2015;7:460-467.
25. Choi YD, Lee KE, Mai HN, Lee DH. Effects of scan body exposure and operator on the accuracy of image matching of implant impressions with scan bodies. J Prosthet Dent 2020;124:379.e1-379.e6.
26. Nam NE, Shin SH, Lim JH, Lee B, Shim JS, Kim JE. Accuracy of implant position reproduction according to exposed length of the scan body during optical scanning: an in vitro study. Appl Sci 2021;11:1689.
27. Oh HS, Lim YJ, Kim B, Kim MJ, Kwon HB, Baek YW. Influence of scanning-aid materials on the accuracy and time efficiency of intraoral scanners for full-arch digital scanning: an in vitro study. Materials 2021;14:2340.
28. Fratila AM, Saceleanu A, Arcas VC, Fratila N, Earar K. Enhancing intraoral scanning accuracy: From the influencing factors to a procedural guideline. J Clin Med 2025;14:3562.
29. Oh HS, Lim YJ, Kim B, Kim MJ, Kwon HB, Baek YW. Effect of scanning-aid agents on the scanning accuracy in specially designed metallic models: a laboratory study. PLoS One 2022;17:e0267742.
30. Kurz M, Attin T, Mehl A. Influence of material surface on the scanning error of a powder-free 3D measuring system. Clin Oral Investig 2015;19:2035-2043.

31. Li H, Lyu P, Wang Y, Sun Y. Influence of object translucency on the scanning accuracy of a powder-free intraoral scanner: a laboratory study. J Prosthet Dent 2017;117:93-101.
32. Park TM, Jung CM, Yoon MJ, Huh JB, Lee SH, Sailer I, et al. Accuracy of customized abutment data superimposition according to the extent of scanning area. Int J Prosthodont 2021;34:390-394.
33. Lee B, Nam NE, Shin SH, Lim JH, Shim JS, Kim JE. Evaluation of the trueness of digital implant impressions according to the implant scan body orientation and scanning method. Appl Sci 2021;11:3027.
34. Pérez E, Salamanca S, Merchán P, Adán A. A comparison of hole-filling methods in 3D. Int J Appl Math Comput Sci 2016;26(4):885-903.