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Influence of Scan Body Geometry, Implant Angulation, and Interimplant Distance on the Accuracy of Maxillary Full-Arch Digital Implant Scans: An In Vitro Study

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: This study compared the accuracy of different scan body geometries under different implant angulation and interimplant distance conditions. Evidence regarding full-arch digital implant scanning under these conditions remains limited.

Material/Methods: In this in vitro study, 5 implants were placed in maxillary edentulous plaster models representing 3 implant systems (Bioinfinity, Meisinger, and Mode). The reference implant was positioned perpendicular to the ridge crest at the midline. Implant angulations (5° and 10°) and interimplant distances (5 mm and 10 mm) were standardized. Scan bodies were attached to the master model, and each model was scanned 10 times using an intraoral scanner (TRIOS 5). Three-dimensional deviations were calculated. Data were analyzed using 1-way ANOVA and Tukey HSD tests ($\alpha=0.05$).

Results: No significant differences were observed among the groups at 5° angulation ($P>0.05$), whereas significant differences were detected at 10° angulation for implants 1 and 5 ($P<0.01$). Bioinfinity showed higher deviation values at implant 1, while Meisinger demonstrated higher deviations at implant 5. At a 10-mm interimplant distance (implants 1 and 2), significant differences were found among the groups ($P<0.001$), with Bioinfinity exhibiting lower deviation values. At a 5-mm distance, no significant difference was observed at implant 4 ($P>0.05$), whereas a significant difference was found at implant 5 ($P<0.001$), with the highest deviation in the Meisinger group.

Conclusions: Increased implant angulation and interimplant distance are associated with reduced accuracy and higher deviation values in digital full-arch scans. The influence of scan body geometry varies depending on implant position.

Keywords: **Dental Implant-Abutment Design • Dentistry • Digital Technology • Prosthodontics**

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Introduction

Implant-supported restorations have become a predictable and widely accepted treatment modality for the rehabilitation of partially or completely edentulous patients, as evidenced by the high survival rates reported in long-term clinical studies [1,2]. The accuracy of the fit between implants and prosthetic superstructures plays a critical role in the long-term success of implant-supported prostheses [3]. Therefore, accurate recording of intraoral implant positions is essential for the fabrication of implant-supported prostheses with adequate fit [4,5]. In recent years, digital workflows have been increasingly adopted in implant dentistry because they offer several advantages over conventional impression techniques, including the reduction of errors associated with impression material deformation, simplification of laboratory procedures, and improved patient comfort [6].

The accuracy of implant impressions is critical for achieving passive fit in implant-retained and implant-supported prostheses [7,8]. Because osseointegrated implants are rigidly anchored to the alveolar bone, errors in implant impressions can lead to prosthetic misfit [9], potentially resulting in biological and mechanical complications, such as marginal bone loss, screw loosening or fracture, abutment fracture, implant fracture, framework fracture, and even implant loss [10,11]. Therefore, digital scanning must demonstrate high accuracy to achieve passive fit [12]. According to the International Organization for Standardization (ISO) 5725-1, accuracy is defined as the combination of trueness and precision [13-15].

During intraoral scanning, the position of the scan body is recorded together with adjacent teeth and surrounding soft tissues [16]. A virtual model is then generated, in which the scan body surface is used to determine implant position via a digital library compatible with the scan body and implant system [17].

Factors reported to affect the accuracy of digital implant scans include operator-related factors [18,19], ambient lighting conditions [20], scanning protocols [21,22], implant scan body design [23,24], type of intraoral scanner (IOS) used [25,26], characteristics of the scanned surface [27], and rescanning procedures [28]. Furthermore, the implant position and interimplant distance [29,30], extent of digital scanning [31], and presence of edentulous areas [32] should also considered. Many scan body designs incorporate anti-rotational features, such as flat facets or beveled surfaces, to accurately register the spatial position of the implant in digital models. However, the optimal configuration of these features has not yet been clearly established [29,33].

With regard to factors affecting the accuracy of implant position transfer, various patient-related, operator-dependent, and scan body design-related variables have been identified and investigated [34]. Among the scan body design–related factors reported to influence implant scanning accuracy are the following: the geometric configuration of the scan body [33,35], scan body material [36,37], geometric modifications of the scanned surface [24,38], height of the scan body [32,39], tightening torque value [40,41], sterilization and reuse of the scan body [40,42], implant connection type [43], interimplant angulation [36,44], implant position within the dental arch [29], and manufacturing tolerances [42].

The influence of implant angulation on the accuracy of digital implant impressions remains controversial. A recent in vitro study reported that increasing implant angulation and interimplant distance significantly reduced digital implant impression accuracy [8]. Several studies have reported higher scanning accuracy in angulated implants than in parallel implants [45,46]. In contrast, other studies have reported lower accuracy in angulated implants [33,47]. However, some studies have found no significant difference between angulated and parallel implants [5,44].

Previous studies have demonstrated that implant angulation and interimplant distance may affect the accuracy of complete-arch implant impressions and digital scans [8]. However, limited information is available regarding how different scan body geometries perform under varying implant angulation and interimplant distance conditions in full-arch implant scans. The aim of this in vitro study was to evaluate the effect of implant angulation (5° and 10°), interimplant distance (5 mm and 10 mm), and 3 different scan body geometries on the accuracy of complete-arch digital implant scans obtained using an intraoral scanner. The null hypotheses were as follows: (1) implant angulation of 5° and 10° would not result in significant differences in scanning accuracy; (2) interimplant distance of 5 mm and 10 mm would not significantly affect scanning accuracy; and (3) no significant differences in scanning accuracy would be observed among the 3 different implant scan body geometries.

Material and Methods

A standardized completely edentulous maxillary plaster cast was fabricated by pouring high-strength dental stone into a commercially available educational silicone mold. The model was not associated with any patient and contained no patient data. The cast was digitized using an intraoral scanner (TRIOS 5 Wired; 3Shape A/S, Denmark). The acquired digital data were transferred to implant planning software, where a surgical guide was designed according to the planned implant angulations and interimplant distances and subsequently fabricated. The surgical guide was positioned on the cast, and

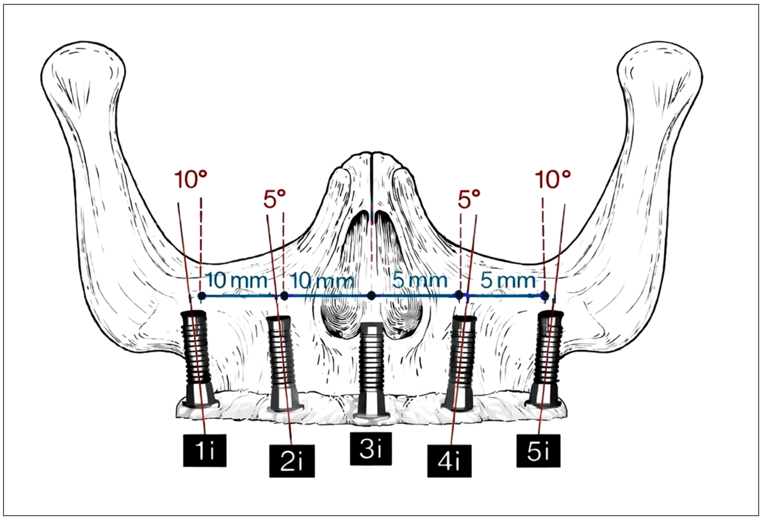

Figure 1. Schematic illustration of the experimental setup showing implant positions, angulations (5° and 10°), and interimplant distances (5 mm and 10 mm).

implant placement was performed accordingly. The same master cast was used throughout the study to ensure consistency during implant placement and repeated scanning procedures.

Five interforaminal internal connection implants were placed on 3 plaster models representing different implant systems: BioInfinity (UMG Medical, Turkey), Meisinger (Hager & Meisinger, Germany), and Mode (Mode Medical, Turkey). The selected implant systems were associated with scan bodies of different geometric designs. Implant 3, the reference implant, was positioned perpendicular to the ridge crest at the midline of the arch. Implants 1 and 2 were positioned to the right of the reference implant with an interimplant distance of 10 mm. Implant 2 was angled at 5°, whereas implant 1 was angled at 10° relative to implant 3. Similarly, implants 4 and 5 were positioned to the left of the reference implant with an interimplant distance of 5 mm. Implant 4 was angled at 5°, and implant 5 at 10° relative to implant 3. The experimental design, including implant positions, angulations (5° and 10°), and interimplant distances (5 mm and 10 mm), is illustrated in **Figure 1**. The corresponding scan bodies were attached to the implants using a dynamometric key and tightened to 5 N·cm according to the manufacturer's recommendations. All scans were performed by a single operator under standardized conditions.

Digital impressions of the models were obtained by scanning the scan bodies of each implant system using an intraoral scanner (TRIOS 5 Wired). Each model was scanned 10 times, and each scan was treated as an individual observation for statistical analysis. The number of repeated scans was determined in accordance with previous in vitro studies on digital implant scanning accuracy [48]. For each implant system, the 10 repeated scans were acquired during the same experimental session and on the same day by a single operator under standardized conditions. No predetermined time interval was established between consecutive scans. A combined scanning strategy based on commonly recommended scanning protocols was used. Scanning was initiated from the occlusal surfaces from right to left, followed by a buccal scan from left to right, and completed with a palatal scan from right to left using a continuous zig-zag motion. This scanning strategy was intended to promote a more homogeneous distribution of stitching errors along the arch [34].

After each scan, only the scan bodies were removed and reattached, while the implant analogs remained fixed in the plaster models throughout the study. This procedure was performed to reduce potential positional bias. The experimental unit was the individual scan, and each STL dataset was included separately in the statistical analysis (n = 10 per group) without averaging repeated scans. All scan data were exported in STL format and transferred to a computed-aided design (CAD) software program (exoCAD 3.2 Elefsina; exocad GmbH, Germany). **Figures 2-4** illustrate the interimplant distance and angulation measurements performed on the models of each implant system using ExoViewer3D (exoCAD 3.2 Elefsina). Implant 3, the non-angulated (0°) implant, served as the reference implant for all measurements. Linear distances (mm) between the most mesial point of each implant and the most distal point of the reference implant, as well as angular measurements (°) relative to implant 3, were obtained from each STL dataset and analyzed separately. Because implant 3 served as the internal reference within each model, no separate reference STL file or best-fit registration procedure was required.

Statistical Analysis

Prior to statistical analysis, the assumptions of normality and homogeneity of variances were assessed. Normal distribution was evaluated using the Shapiro-Wilk test, while homogeneity of variances was assessed using the Levene test. Data meeting these assumptions were analyzed using 1-way analysis of

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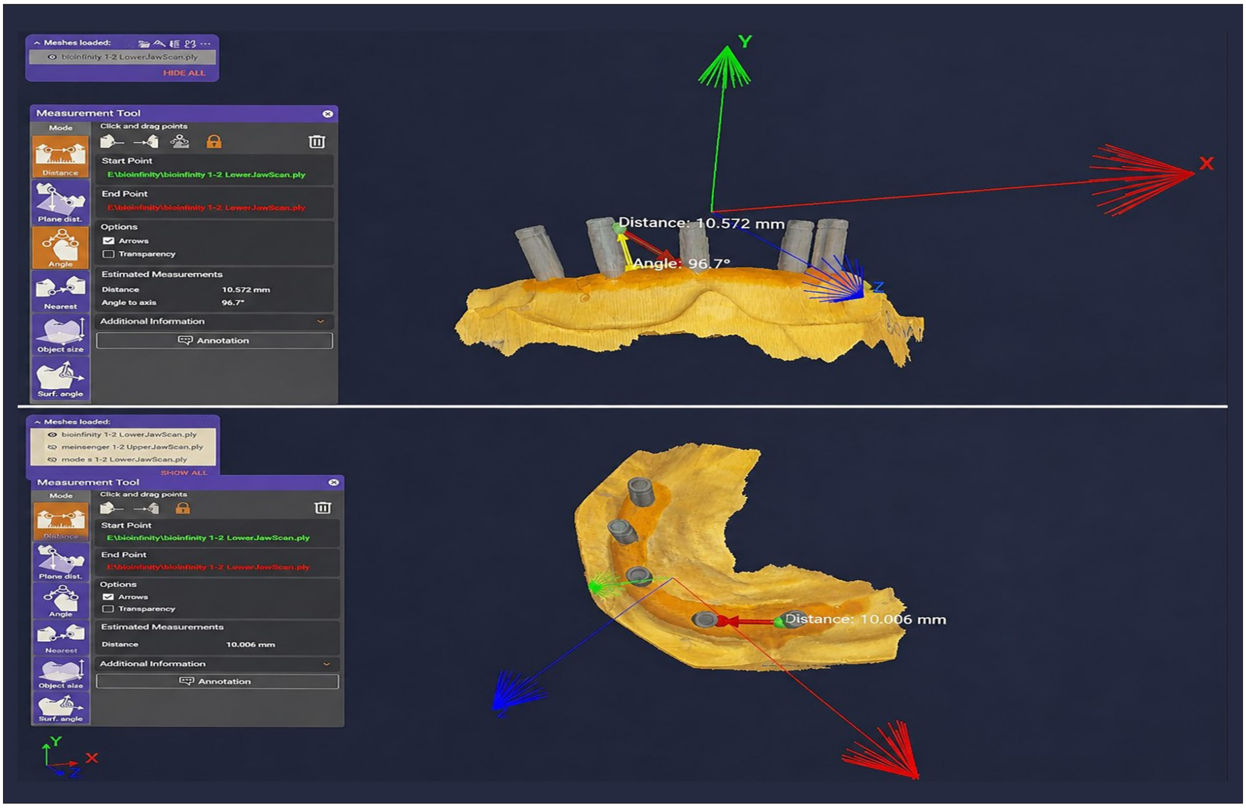

Figure 2. Angle and interimplant distance measurements relative to the reference implant in the Bioinfinity group.

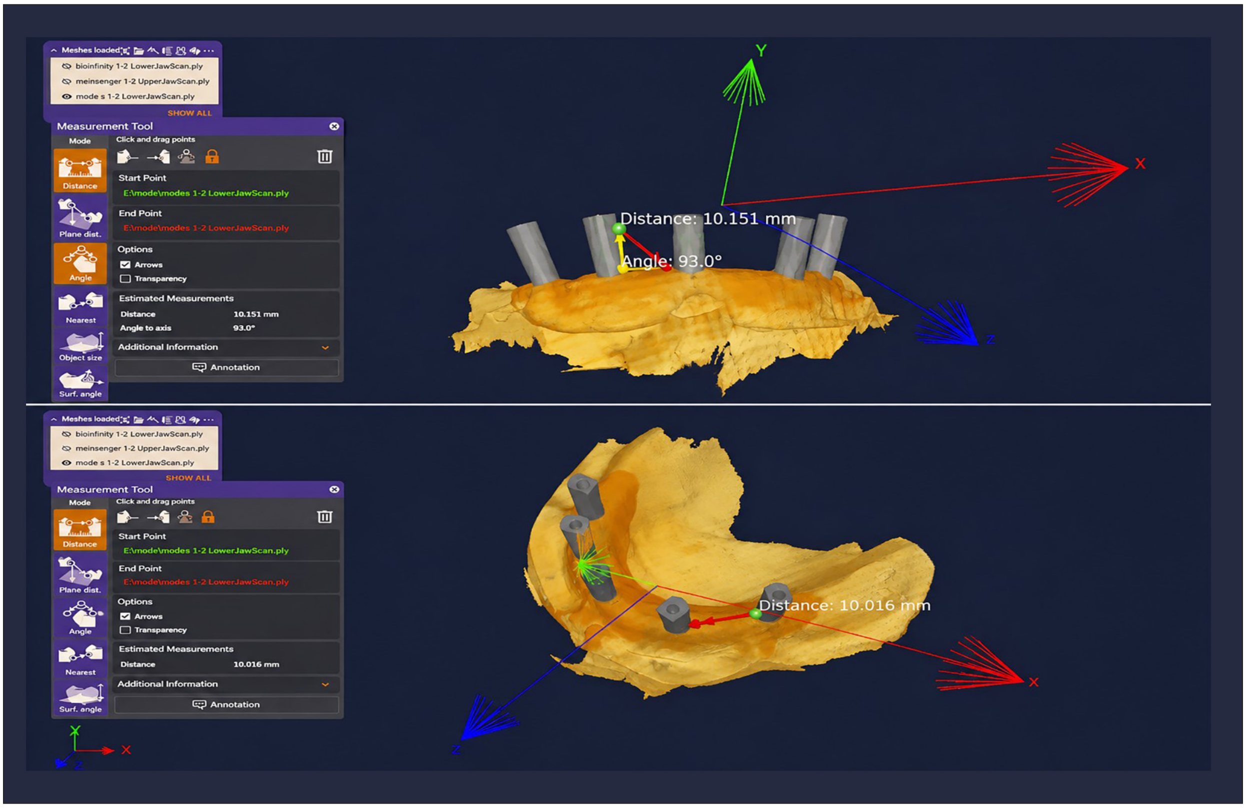

Figure 3. Angle and interimplant distance measurements relative to the reference implant in the Mode group.

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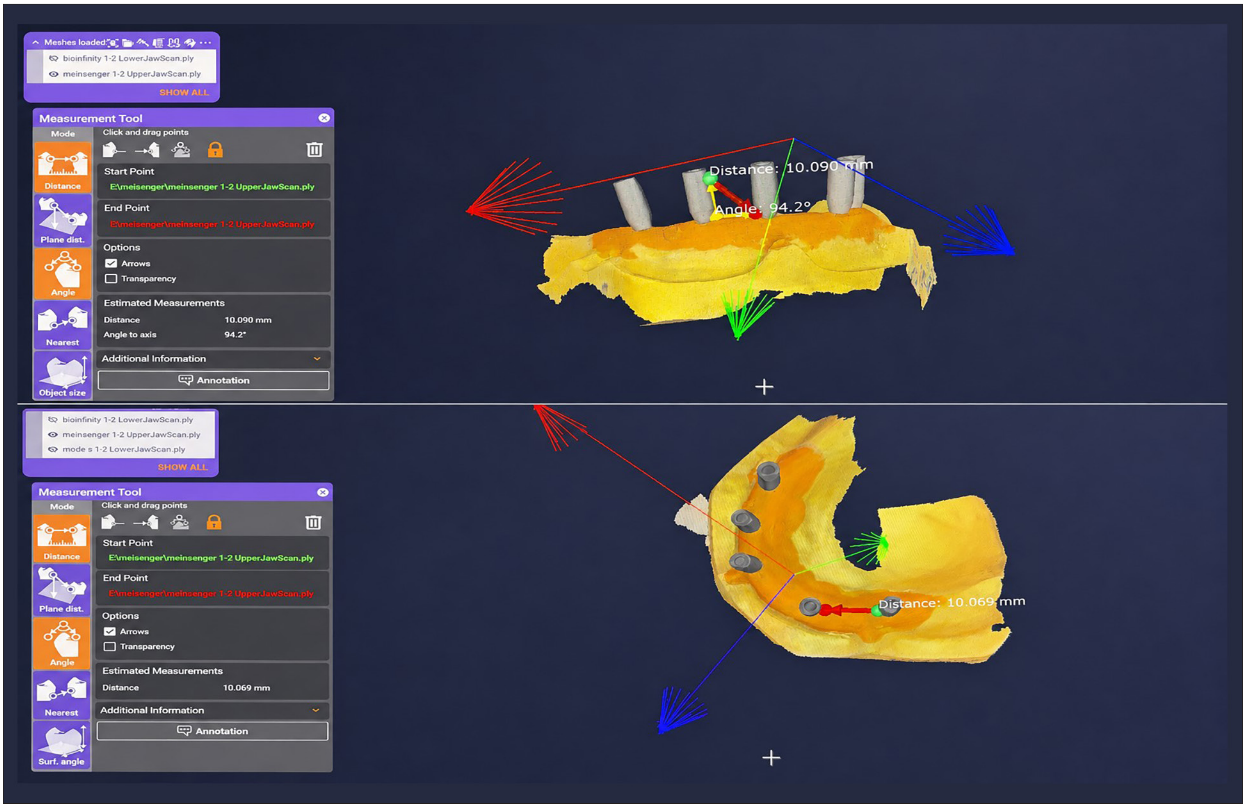

Figure 4. Angle and interimplant distance measurements relative to the reference implant in the Meisinger group.

variance (ANOVA). When statistically significant differences were identified, pairwise comparisons were performed using the Tukey honestly significant difference (HSD) post hoc test. Pearson correlation analysis was used to assess the consistency of deviation patterns among the scan body systems under different implant angulation and interimplant distance conditions. All analyses were performed using jamovi (the jamovi project). A P value of <0.05 was considered statistically significant.

Results

For implants placed at 10°, statistically significant differences were observed among the implant systems. At implant 1 (10°), a significant difference was found between the groups ($F=6.815$, $P=0.004$), with Bioinfinity showing significantly higher deviation values than both Mode and Meisinger. No significant difference was detected between Mode and Meisinger. At implant 5 (10°), a significant difference was also observed ($F=8.995$, $P=0.001$). Meisinger demonstrated significantly higher deviation values than both Bioinfinity and Mode, while no significant difference was found between Bioinfinity and Mode.

In contrast, for implants placed at 5°, no statistically significant differences were found among the groups. Both implant 2 (5°) ($F=1.083$, $P=0.353$) and implant 4 (5°) ($F=1.188$, $P=0.320$) showed comparable deviation values across all implant systems ($P>0.05$). The effect of implant angulation on 3-dimensional (3D) deviation values is presented in **Table 1**, and the distribution of these values is shown in **Figure 5**.

For implants with a 10-mm interimplant distance, statistically significant differences were observed among the implant systems. At implant 1 (10 mm), a significant difference was found ($F=14.842$, $P<0.001$), with Bioinfinity demonstrating significantly lower deviation values than both Mode and Meisinger. No significant difference was observed between Mode and Meisinger. Similarly, at implant 2 (10 mm), a significant difference was detected ($F=15.380$, $P<0.001$). Bioinfinity showed significantly lower deviation values than both Mode and Meisinger, while the difference between Mode and Meisinger was not statistically significant.

In contrast, for implants with a 5-mm interimplant distance, the results varied by implant position. At implant 4 (5 mm), no statistically significant difference was found among the groups ($F=0.690$, $P=0.510$). However, at implant 5 (5 mm), a significant difference was observed ($F=27.822$, $P<0.001$). Meisinger exhibited the highest deviation values, followed by Mode, while Bioinfinity showed the lowest values, with all pairwise comparisons being statistically significant. The effect of interimplant distance on 3D deviation values is presented in **Table 2**, and the distribution of these values is shown in **Figure 6**.

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Table 1. Comparison of 3-dimensional deviation values according to implant angulation.

Implant position	Group	Mean ± SD	Min-Max	Multiple comparisons (Tukey HSD)
Implant 1 (10°) F = 6.815 *P* = 0.004	(1) Bioinfinity	9.960 ± 1.180	8.500-12.200	(2)(3)
	(2) Mode	8.670 ± 0.941	7.300-9.900	(1)
	(3) Meisinger	8.420 ± 0.855	6.300-9.400	(1)
Implant 2 (5°) F = 1.083 *P* = 0.353	(1) Bioinfinity	5.350 ± 0.980	3.300-6.600	ns
	(2) Mode	4.940 ± 0.587	3.700-5.600	ns
	(3) Meisinger	4.850 ± 0.814	3.600-6.700	ns
Implant 4 (5°) F = 1.188 *P* = 0.320	(1) Bioinfinity	5.150 ± 0.784	3.600-6.200	ns
	(2) Mode	5.490 ± 0.486	4.900-6.500	ns
	(3) Meisinger	5.670 ± 0.955	3.900-6.800	ns
Implant 5 (10°) F = 8.995 *P* = 0.001	(1) Bioinfinity	10.140 ± 1.479	7.600-12.100	(3)
	(2) Mode	9.360 ± 0.698	8.100-10.100	(3)
	(3) Meisinger	11.410 ± 0.947	9.90-12.90	(1)(2)

One-way ANOVA was used for statistical analysis, followed by Tukey honestly significant difference (HSD) post hoc test for multiple comparisons. Values are presented as mean ± standard deviation (SD). Numbers in parentheses indicate groups with statistically significant differences according to Tukey HSD test ($P < 0.05$). n = 10 per group. "ns" indicates no statistically significant difference ($P > 0.05$).

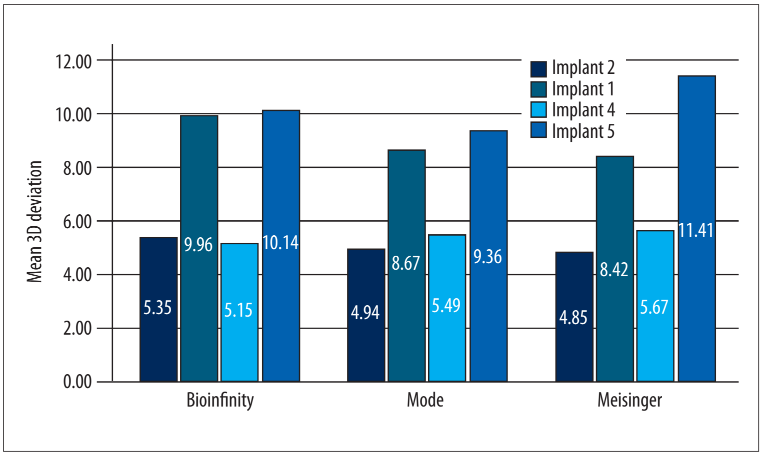

Figure 5. Distribution of 3-dimensional deviation values among different implant systems according to implant angulation.

When evaluated within each implant system, deviation values increased significantly with implant angulation in all groups ($P \leq 0.004$). Interimplant distance showed a variable effect: while no consistent significant differences were observed within the same angulation for Bioinfinity and Mode, higher deviations were generally observed at 10 mm. In contrast, the Meisinger system demonstrated significant differences related to both angulation and interimplant distance across conditions ($P < 0.001$). For reporting purposes, descriptive statistics were rounded to 3 decimal places.

Pearson correlation analysis was performed to evaluate the consistency of deviation patterns among the scan body systems under different angulation and interimplant distance conditions. No significant correlations were observed among the scan body systems under different implant angulation conditions at any implant position (all $P > 0.05$). Correlation coefficients ranged from -0.569 to 0.346, with the strongest, albeit nonsignificant, correlation observed between the Bioinfinity and Meisinger groups at implant 2 ($r = -0.569$, $P = 0.086$). Under different interimplant distance conditions, no significant correlations were observed among the scan body systems at

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Table 2. Comparison of 3-dimensional deviation values according to interimplant distance.

Implant position	Group	Mean ± SD	Min-Max	Multiple comparisons (Tukey HSD)
Implant 1 (10 mm) F = 14.842 *P* < 0.004	(1) Bioinfinity	9.875± 0.766	8.463-10.879	(2)(3)
	(2) Mode	11.108± 0.429	10.328-11.695	(1)
	(3) Meisinger	10.895± 0.326	10.354-11.283	(1)
Implant 2 (10 mm) F = 15.380 *P* < 0.001	(1) Bioinfinity	10.536± 0.549	9.222-11.023	(2)(3)
	(2) Mode	11.182± 0.331	10.729-11.711	(1)
	(3) Meisinger	11.542± 0.309	10.843-11.829	(1)
Implant 4 (5 mm) F = 0.690 *P* = 0.510	(1) Bioinfinity	6.016± 0.778	4.917-7.380	ns
	(2) Mode	6.187± 0.292	5.731-6.736	ns
	(3) Meisinger	6.264± 0.105	6.128-6.470	ns
Implant 5 (5 mm) F = 27.822 *P* < 0.001	(1) Bioinfinity	5.543± 0.703	4.314-6.623	(2)(3)
	(2) Mode	6.536± 0.296	6.043-6.863	(1)(3)
	(3) Meisinger	6.995± 0.108	6.796-7.163	(1)(2)

One-way ANOVA was used for statistical analysis, followed by Tukey honestly significant difference (HSD) post hoc test for multiple comparisons. Values are presented as mean ± standard deviation (SD). Numbers in parentheses indicate groups with statistically significant differences according to Tukey HSD test ($P < 0.05$). n = 10 per group. "ns" indicates no statistically significant difference ($P > 0.05$).

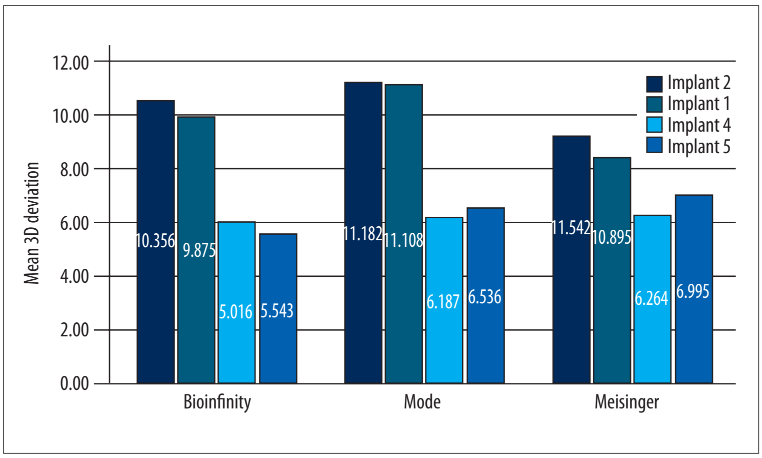

Figure 6. Distribution of 3-dimensional deviation values among different implant systems according to interimplant distance.

implants 1, 2, and 4 (all $P > 0.05$). A significant positive correlation was identified only between the Mode and Meisinger groups at implant 5 ($r = 0.641$, $P = 0.046$).

Discussion

The findings of this study indicate that implant angulation and interimplant distance influenced digital implant scanning accuracy, and that the differences observed among the 3 implant systems with different scan body geometries varied according to implant position. Statistically significant differences were identified only at specific implant positions.

At 5° angulation, no statistically significant differences were observed among the implant systems, suggesting that lower angulations may not substantially affect the performance of different scan body designs. In contrast, significant differences emerged at 10° angulation, although the direction of these differences varied according to implant position. Bioinfinity exhibited higher deviation values at implant 1, whereas Meisinger showed higher deviation values at implant 5. These findings suggest that increased angulation accentuates differences among scan body designs rather than consistently favoring a particular implant system. This may be attributed to reduced scan body distinguishability and increased image stitching errors under more challenging geometric conditions.

In full-arch intraoral scanning, errors are known to accumulate as the scan advances, due to sequential image stitching, with greater deviations often occurring in regions scanned last [49,50]. Therefore, the increased deviations in the left posterior region may be attributed to cumulative errors related to the scanning sequence. According to an in vitro study, parallel implant configurations were associated with higher accuracy (trueness and precision) values compared with implants with angulations of up to 30° [51]. A systematic review and meta-analysis reported that implant angulation may reduce digital scanning accuracy; however, this difference was not statistically significant [52]. In contrast, several studies have demonstrated a significant decrease in intraoral scanning accuracy when implant angulation exceeds 15° [30] or 30° [29,45]. The findings of the present study are consistent with these observations, suggesting that higher implant angulation may accentuate differences among implant systems with different scan body geometries, particularly at specific implant positions.

When evaluated in terms of interimplant distance, differences among implant systems were more pronounced under the 10-mm condition, although significant differences were also observed at specific implant positions under the 5-mm condition. As the interimplant distance increases, the expansion of the scanning area makes the data acquisition and stitching process more complex, which may accentuate performance differences among systems [53,54].

At a 5-mm interimplant distance, the results varied depending on implant position. While no significant differences were observed among the groups at implant 4, statistically significant differences were found at implant 5, where all groups differed from each other. Multiple comparisons revealed that the Meisinger group exhibited significantly higher deviation values than the Mode group, and the Mode group showed significantly higher values than the Bioinfinity group. These findings suggest that not only interimplant distance but also the position along the arch may influence the accuracy of digital implant scans. Previous studies have consistently demonstrated that increasing interimplant distance negatively affects the accuracy of digital implant scans [53]. In an in vitro study, it was reported that, as the interimplant distance increased from 7 mm to 14 mm and 21 mm, accuracy decreased, with the highest 3D deviations observed at the longest distance [54]. Consistent with these findings, increased interimplant distance has been associated with higher 3D deviation values, indicating reduced accuracy with increasing edentulous span.

This effect has been attributed to cumulative stitching errors during long-span digital acquisition and has been reported to become more pronounced at longer interimplant distances, including the 10-mm condition [8,53-56]. In line with this, error accumulation may be more pronounced in distal regions of the arch, potentially leading to greater deviations in certain implant systems. Moreover, the higher 3D deviation values observed for the Meisinger system at implant 5 under both the 10° angulation and the 5-mm interimplant distance conditions may indicate that this scan body design is more susceptible to challenging scanning conditions in distal regions. However, the absence of significant correlations among most scan body systems indicates that these effects were not consistent across all designs and may be influenced by scan body-specific geometric characteristics.

The higher 3D deviations observed under greater implant angulation and longer interimplant distance suggest that error accumulation becomes more pronounced under challenging scanning conditions. However, the different deviation patterns observed among implant positions indicate that scanning accuracy is influenced not only by interimplant distance but also by the implant location within the arch. This finding is consistent with previous studies reporting that long edentulous spans and a reduced number of reference points may negatively affect scanning performance [57]. The differences observed among implant systems under higher angulation and greater interimplant distances further suggest that scan body geometry may become more important under demanding conditions. Nevertheless, this effect did not appear to be uniformly distributed across all implant sites and showed position-dependent variability.

Consistent with previous studies, scan body geometry has been reported to influence digital impression accuracy by affecting the availability of reference features during image stitching [35,58,59]. In the present study, the differences observed among implant systems were not consistent across all conditions but varied according to implant position under different angulation and interimplant distance conditions, indicating a condition-dependent effect of scan body geometry.

The predominantly cylindrical design of the Bioinfinity scan body may provide fewer distinct reference features, potentially contributing to increased deviations under certain challenging conditions, such as higher angulation. Similarly, the hybrid cylindrical geometry of the Meisinger scan body, with localized bevel features, may lead to a non-uniform distribution of reference landmarks, which could explain its higher deviations at specific implant positions. In contrast, the Mode scan body, featuring a reverse conical geometry with partially defined flat surfaces, may offer more distinguishable features; however, its performance remained condition-dependent.

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These interpretations are based on qualitative assessments rather than quantitative measurements and should therefore be considered hypothesis-driven. Previous studies support this view, indicating that not only the presence of geometric features but also their spatial distribution and surface continuity may influence scanning accuracy [59].

Excessively complex scan body geometries may introduce noise into point cloud data and reduce mesh accuracy, whereas overly simple designs may lack sufficient reference features for reliable image alignment. Thus, an optimal balance between geometric simplicity and distinctiveness is essential for accurate digital scanning [58]. Previous studies have suggested that scan body geometry may influence digital impression accuracy by affecting feature recognition and image stitching [24,32]. Therefore, the differences observed among implant systems may be related to variations in scan body design characteristics. However, this relationship was not directly evaluated in the present study and should be interpreted with caution.

Overall, the findings of this study indicate that the accuracy of digital implant scanning is multifactorial and cannot be attributed to a single parameter. In addition to implant angulation and interimplant distance, scanning accuracy was influenced by implant position within the arch. Differences among implant systems became more pronounced under more challenging conditions, suggesting that the influence of scan body geometry is condition-dependent rather than consistent across all scenarios. From a clinical perspective, increased implant angulation and extended interimplant distances should be considered during digital scanning, as differences among implant systems and scan body designs may become more pronounced under these challenging scanning conditions. The absence of significant correlations among the scan body systems suggests that the effects of implant angulation and interimplant distance varied according to scan body design.

This study has several limitations. First, it was conducted under in vitro conditions, and clinical factors such as saliva, soft tissue dynamics, and patient-related variables were not simulated. In addition, only a single intraoral scanner was used, which may limit the generalizability of the findings. Another limitation is the use of a plaster model instead of a 3D-printed resin model, which may facilitate greater standardization and reproducibility. Future studies incorporating different scanner systems, 3D-printed models, and clinical conditions are needed to validate these results. Furthermore, quantitative analyses of scan body geometric parameters under different implant positions, angulations, and interimplant distances would provide a more comprehensive understanding of their role in digital scanning accuracy.

Conclusions

Within the limitations of this in vitro study, we conclude the following. (1) Digital implant scanning accuracy was influenced by implant angulation, interimplant distance, and implant position. (2) Significant differences among implant systems emerged under higher angulation and varied according to implant position, particularly in distal regions. (3) Increased interimplant distance was associated with higher deviations, while shorter distances showed position-dependent variability. (4) No implant system demonstrated consistently superior performance across all conditions.The observed differences among implant systems may be associated with scan body design characteristics, although this relationship was not directly evaluated in the present study.

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Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

References:

1. Pjetursson BE, Thoma D, Jung R, et al. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res. 2012;23(6):22-38
2. Oh JH, Pyo SW, Chang JS, Kim S. Up to a 15-year survival rate and marginal bone resorption of 1780 implants with or without microthreads: A multicenter retrospective study. J Clin Med. 2023;12(6):2425
3. Assunçao WG, Gomes EA, Rocha EP, Delben JA. Three-dimensional finite element analysis of vertical and angular misfit in implant-supported fixed prostheses. Int J Oral Maxillofac Implants. 2011;26:788-96
4. Kim JH, Kim KR, Kim S. Critical appraisal of implant impression accuracies: A systematic review. J Prosthet Dent. 2015;114:185-92
5. Papaspyridakos P, Gallucci GO, Chen CJ, et al. Digital versus conventional implant impressions for edentulous patients: Accuracy outcomes. Clin Oral Implants Res. 2016;27:465-72
6. Siqueira R, Galli M, Chen Z, et al. Intraoral scanning reduces procedure time and improves patient comfort in fixed prosthodontics and implant dentistry: A systematic review. Clin Oral Investig. 2021;25(12):6517-31
7. Vitai V, Németh A, Sólyom E, et al. Evaluation of the accuracy of intraoral scanners for complete-arch scanning: A systematic review and network meta-analysis. J Dent. 2023;137:104636
8. Jeong M, Ishikawa-Nagai S, Lee JD, Lee SJ. Accuracy of impression scan bodies for complete arch fixed implant-supported restorations. J Prosthet Dent. 2025;134:425-32

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

9. Abduo J, Judge RB. Implications of implant framework misfit: A systematic review of biomechanical sequelae. Int J Oral Maxillofac Implants. 2014;29(3):608-21
10. Katsoulis J, Takeichi T, Gaviria AS, et al. Misfit of implant prostheses and its impact on clinical outcomes. Definition, assessment and a systematic review of the literature. Eur J Oral Implantol. 2017;10(Suppl. 1):121-38
11. Palma-Carrio C, Macconi A, Rubert Aparici A, et al. Prosthetic complications of single screw-retained implant-supported metal-ceramic fixed prostheses: A retrospective observational study. Int J Dent. 2024;2024:9242928
12. Mizumoto RM, Yilmaz B. Intraoral scan bodies in implant dentistry: A systematic review. J Prosthet Dent. 2018;120:343-52
13. Sim JY, Jang Y, Kim WC, et al. Comparing the accuracy (trueness and precision) of models of fixed dental prostheses fabricated by digital and conventional workflows. J Prosthodont Res. 2019;63(1):25-30
14. International Organization for Standardization. ISO 5725-1: 2023. Accuracy (trueness and precision) of measurement methods and results – Part 1: General principles and definitions. Accessed Jan 25, 2026. https://www.iso.org
15. International Organization for Standardization. ISO 20896-1: 2019. Dentistry – Digital impression devices – Part 1: Methods for assessing accuracy. Accessed Jan 25, 2026. https://www.iso.org
16. Iturrate M, Minguez R, Pradies G, Solaberrieta E. Obtaining reliable intraoral digital scans for an implant-supported complete-arch prosthesis: A dental technique. J Prosthet Dent. 2019;121(2):237-41
17. Tan JZH, Tan MY, Toh YLS, et al. Three-dimensional positional accuracy of intraoral and laboratory implant scan bodies. J Prosthet Dent. 2022;128:735-44
18. Revell G, Simon B, Mennito A, et al. Evaluation of complete-arch implant scanning with 5 different intraoral scanners in terms of trueness and operator experience. J Prosthet Dent. 2022;128:632-38
19. Canullo L, Colombo M, Menini M, et al. Trueness of intraoral scanners considering operator experience and three different implant scenarios: A preliminary report. Int J Prosthodont. 2021;34:250-53
20. Ochoa-López G, Revilla-León M, Gómez-Polo M. Impact of color temperature and illuminance of ambient light conditions on the accuracy of complete-arch digital implant scans. Clin Oral Implants Res. 2024;35:898-905
21. Gómez-Polo M, Cascos R, Ortega R, et al. Influence of scanning pattern on accuracy, time, and number of photograms of complete-arch implant scans: A clinical study. J Dent. 2024;150:105310
22. Oh KC, Park JM, Moon HS. Effects of scanning strategy and scanner type on the accuracy of intraoral scans: A new approach for assessing the accuracy of scanned data. J Prosthodont. 2020;29:518-23
23. Gómez-Polo M, Donmez MB, Çakmak G, et al. Influence of implant scan body design (height, diameter, geometry, material, and retention system) on intraoral scanning accuracy: A systematic review. J Prosthodont. 2023;32:165-80
24. Lawand G, Ismail Y, Revilla-León M, Tohme H. Effect of implant scan body geometric modifications on the trueness and scanning time of complete arch intraoral implant digital scans: An in vitro study. J Prosthet Dent. 2024;131(6):1189-97
25. Azevedo L, Marques T, Karasan D, et al. Effect of splinting scan bodies on the trueness of complete-arch digital implant scans with 5 different intraoral scanners. J Prosthet Dent. 2024;132:204-10
26. Retana L, Nejat AH, Pozzi A. Effect of splinting scan bodies on trueness of complete-arch implant impression using different intraoral scanners: An in vitro study. Int J Comput Dent. 2023;26:19-28
27. Kim RJY, Benic GI, Park JM. Trueness of intraoral scanners in digitizing specific locations at the margin and intaglio surfaces of intracoronal preparations. J Prosthet Dent. 2020;126(6):779-86
28. Gómez-Polo M, Piedra-Cascon W, Methani MM, et al. Influence of rescanning mesh holes and stitching procedures on the complete-arch scanning accuracy of an intraoral scanner: An in vitro study. J Dent. 2021;110:103690
29. Arcuri L, Pozzi A, Lio F, Rompen E, et al. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: A randomized in vitro trial. J Prosthodont Res. 2020;64(2):128-36
30. Pereira ALC, Medeiros VR, Carreiro AFP. Influence of implant position on the accuracy of intraoral scanning in fully edentulous arches: A systematic review. J Prosthet Dent. 2021;126(6):749-55
31. Moon YG, Lee KM. Comparison of the accuracy of intraoral scans between complete-arch scan and quadrant scan. Prog Orthod. 2020;21(1):36
32. Mizumoto RM, Yilmaz B, McGlumphy EA, et al. Accuracy of different digital scanning techniques and scan bodies for complete-arch implant-supported prostheses, J Prosthet Dent. 2020;123:96-104
33. Gómez-Polo M, Alvarez F, Ortega R, et al. Influence of the implant scan body bevel location, implant angulation and position on intraoral scanning accuracy: An in vitro study. J Dent. 2022;121:104122
34. Revilla-León M, Lanis A, Yilmaz B, et al. Intraoral digital implant scans: Parameters to improve accuracy. J Prosthodont. 2023;32(S2):150-64
35. Pan Y, Tsoi JKH, Lam WYH, et al. Does the geometry of scan bodies affect the alignment accuracy of computer-aided design in implant digital workflow: An in vitro study. Clin Oral Implants Res. 2022;33:313-21
36. Lee JH, Bae JH, Lee SY. Trueness of digital implant impressions based on implant angulation and scan body materials. Sci Rep. 2021;11:21892
37. Althubaitiy R, Sambrook R, Weisbloom M, Petridis H. The accuracy of digital implant impressions when using and varying the material and diameter of the dental implant scan bodies. Eur J Prosthodont Restor Dent. 2022;30:305-13
38. Pozzi A, Arcuri L, Lio F, et al. Accuracy of complete-arch digital implant impression with or without scanbody splinting: An in vitro study. J Dent. 2022;119:104072
39. Sequeira V, Harper MT, Lilly CL, Bryington MS. Accuracy of digital impressions at varying implant depths: An in vitro study. J Prosthodont. 2023;32:54-61
40. Diker E, Terzioglu H, Gouveia DNM, et al. Effect of material type, torque value, and sterilization on linear displacements of a scan body: An in vitro study. Clin Implant Dent Relat Res. 2023;25:419-25
41. Kim J, Son K, Lee KB. Displacement of scan body during screw tightening: A comparative in vitro study. J Adv Prosthodont. 2020;12:307-15
42. Kato T, Yasunami N, Furuhashi A, et al. Effects of autoclave sterilization and multiple use on implant scanbody deformation in vitro. Materials (Basel). 2022;15:7717
43. Moslemion M, Payaminia L, Jalali H, Alikhasi M. Do type and shape of scan bodies affect accuracy and time of digital implant impressions? Eur J Prosthodont Restor Dent. 2020;28:18-27
44. Farah RI, Alresheedi B, Alazmi S, Al-Haj Ali SN. Evaluating the impact of scan body angulation and geometric attachments on the accuracy of complete-arch digital implant impressions: A comparison of two intraoral scanners. J Prosthodont. 2023;34(3):174-81
45. Lin WS, Harris BT, Elathamna EN, et al. Effect of implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: An in vitro comparative study. Int J Oral Maxillofac Implants. 2015;30(1):102-9
46. Zhang YJ, Qiao SC, Qian SJ, et al. Influence of different factors on the accuracy of digital impressions of multiple implants: An in vitro study. Int J Oral Maxillofac Implants 2021;36(3):442-49
47. Sicilia E, Lagreca G, Papaspyridakos P, et al. Effect of supramucosal height of a scan body and implant angulation on the accuracy of intraoral scanning: An in vitro study. J Prosthet Dent. 2024;131(6):1125-34
48. Li Y, Fang H, Yan Y, Geng W. Accuracy of intraoral scanning using modified scan bodies for complete arch implant-supported fixed prostheses. J Prosthet Dent. 2024;132:994.e1-e8
49. Mangano FG, Hauschild U, Veronesi G, et al. Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: A comparative in vitro study. BMC Oral Health. 2019;19(1):101
50. Yahya MA, Selléus M, Hadi DJ, et al.The effects of different scanning protocols on precision and trueness of intraoral scanning: A pilot trial. J Clin Exp Dent. 2024;16(10):e1299-e306
51. Gómez-Polo M, Ortega R, Sallorenzo A, et al. Influence of the surface humidity, implant angulation, and interimplant distance on the accuracy and scanning time of complete-arch implant scans. J Dent. 2022;127:104307
52. Papaspyridakos P, Vazouras K, Chen YW, et al. Digital vs conventional implant impressions: A systematic review and meta-analysis. J Prosthodont. 2020;29(8):660-78
53. Flügge TV, Att W, Metzger MC, Nelson K. Precision of dental ımplant digitization using ıntraoral scanners. Int J Prosthodont. 2016;29:277-83
54. Thanasrisuebwong P, Kulchotirat T, Anunmana C. Effects of inter-implant distance on the accuracy of intraoral scanner: An in vitro study. J Adv Prosthodont. 2021;13(2):107-16
55. Alikhasi M, Siadat H, Nasirpour A, Hasanzade M. Three-dimensional accuracy of digital impression versus conventional method: Effect of implant angulation and connection type. Int J Dent. 2018:3761750
56. Tan MY, Yee SHX, Wong KM, et al. Comparison of three-dimensional accuracy of digital and conventional implant impressions: Effect of interimplant distance in an edentulous arch. Int J Oral Maxillofac Implants. 2019;34:366-80

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

57. 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
58. Mohajerani R, Djalalinia S, Alikhasi M. The effects of scan body geometry on the precision and the trueness of ımplant ımpressions using ıntraoral scanners: A systematic review. Dent J. 2025;13(6):252
59. Alvarez C, Dominguez P, Jimenez-Castellanos E, et al. How the geometry of the scan body affects the accuracy of digital impressions in implant supported prosthesis. In vitro study. J Clin Exp Dent. 2022;14:e1008-e14