Journal of Dental Sciences 20 (2025) 2189–2194

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Original Article

Impact of scan body splinting on the accuracy of complete-arch digital implant impressions

Hale Arikan Kalayci [a], Sema Merve Uzel [b], Ilser Turkyilmaz [c*], Mackenzie Hunt [d], Mustafa Baris Guncu [e]

[a] *Department of Prosthodontics, Faculty of Dentistry, Başkent University, Ankara, Turkey*
[b] *Private Practice, Ankara, Turkey*
[c] *Department of Comprehensive Care, Case Western Reserve University School of Dental Medicine, Cleveland, OH, USA*
[d] *Case Western Reserve University School of Dental Medicine, Cleveland, OH, USA*
[e] *Department of Prosthodontics, School of Dentistry, Hacettepe University, Ankara, Turkey*

Received 30 June 2025; Final revision received 1 July 2025
Available online 11 July 2025

KEYWORDS
Accuracy;
Digital dentistry;
Digital impression;
Implant;
Scan body

Abstract *Background/purpose:* The accuracy of intraoral scanners in capturing complete-arch implant impressions remains a subject of ongoing investigation. This study aimed to evaluate the influence of different scanning strategies and the effect of splinting scan bodies on the accuracy of complete digital scans of the mandible.
Materials and methods: A master model of an edentulous mandible with four dental implants was used. The implants were positioned bilaterally in the regions of the mandibular lateral incisors and second premolars. A laboratory scanner was utilized to digitize the reference model. Three experimental groups were used to evaluate the effects of different scanning strategies and auxiliary reference methods on scan accuracy: Group A (single-stage scan), Group B (two-stage scan without additional references), and Group C (two-stage scan with additional reference points).
Results: A total of 45 digital scans were analyzed. To evaluate scan accuracy, linear deviations were measured at the four implant sites and compared against the digital reference model. Group A consistently demonstrated the highest accuracy, with the lowest overall mean linear deviation of 39.57 ± 8.69 μm across all implant positions. Group B recorded a marginally higher mean deviation of 42.80 ± 24.24 μm. Group C showed the greatest linear deviation (70.60 ± 17.69 μm), and the differences were statistically significant when compared with both Groups A and B ($P < 0.05$).

* Corresponding author. Department of Comprehensive Care, Case Western Reserve University School of Dental Medicine, 9601 Chester Avenue, Cleveland, 44106, OH, USA.
E-mail address: ilserturkyilmaz@yahoo.com (I. Turkyilmaz).

https://doi.org/10.1016/j.jds.2025.07.002

Conclusion: The findings of this study indicate that single-stage scanning yields superior accuracy, whereas the incorporation of poorly designed or improperly positioned reference markers may inadvertently compromise scan precision.

Introduction

Dental implants have significantly revolutionized dental treatment in many ways. Implants provide a long term solution for both single tooth replacement as well as long edentulous spans and full edentulous arches.[1–3] There are several benefits for patients, including better aesthetics, greater comfort, natural tooth-like function, long-term durability and biocompatibility, preservation of bone, no harm to surrounding teeth, and overall reliability. One disadvantage of implants is the necessity to accurately replicate the three-dimensional position of the implant through either conventional or digital scanning impressions. Both of these impression methods can be technique sensitive and require a precise replication of the implant to ensure proper fit of the restorations.[4,5]

While conventional impressions have long been recognized as the gold standard method of impression taking, digital scanning impressions have continued to evolve and have become more widely used across the dental field.[6,7] Using these intraoral scanners (IOSs) provide a variety of benefits to both the clinician and patient. They are more patient-friendly, hygienic and time-efficient. The clinical procedures are simple and can be evaluated in real time. However, the digital workflow is not error-free and there are many factors that affect scanning accuracy. Dental literature has analyzed different operator and patient related factors of IOSs and, therefore, the accuracy of digital implant scans.[8–10] These factors include IOS technology, operator experience, ambient light illumination, scanning field, scanning pattern and strategy, rescanning techniques, arch width, and oral surface characteristics.

Intraoral scanning accuracy is typically high for single-unit and short-span implant sites, with clinically acceptable deviations in virtual implant positioning.[11,12] However, some studies have shown conflicting results in cases with large edentulous spans between implants in completely edentulous patients.[13,14] Flugge et al., found that scanning accuracy decreased as the distance between implant scan bodies (ISBs) increased.[14]

IOS produces images through stitching and mathematical interpolation, where the stitching process is critical for accuracy and depends on the scanning field and implant spacing.[15–17] The absence of anatomical reference points makes it difficult to align and stitch multiple images accurately.[15–17] Several studies have explored different techniques to overcome these problems and create a reference point that can increase digital impression accuracy.

While conventional open-tray implant impressions with splinted copings remain the gold standard for full-arch impressions due to their high accuracy, recent studies also suggest that splinting scan bodies can similarly improve accuracy by increasing the number of reference points.[15,18,19] Huang et al., reported that new scan bodies with an extensional structure (vs. without an extensional structure) improved scanning accuracy.[18] Kao et al., found that connecting scan bodies with power chains and flowable resin also enhanced accuracy in complete arch scans.[19]

The scan pattern or scanning strategy is another factor affecting IOS accuracy. Different IOS manufacturers recommend different scanning strategies based on the different technologies.[20,21] Motel et al., tested single-stage and two-stage scanning methods, with and without a scan body, concluding that single-stage scanning provided better accuracy.[20] In this study, three implants located in the same quadrant were scanned. Further studies on full-mouth scans, including larger areas and arch curvatures, are necessary for comprehensive analysis.

The purpose of this study was to assess the impact of the scanning strategy used and the effect of splinting scan bodies, on accuracy in complete mandibular digital scans.

Materials and methods

This in vitro study was conducted using an epoxy resin master model of an edentulous mandible with a soft tissue replica, incorporating four dental implants. The implants (4.2 mm $\times$ 10 mm; OneQ, Dentis, Daegu, South Korea) were placed bilaterally in the mandibular lateral incisor (#42 and #32) and second premolar (#44 and #34) regions. The implants at positions #42 and #32 were placed parallel to each other, while the implant at position #44 was angulated distally at 30°, and the implant at position #34 was placed lingually at 15°. Titanium multiunit abutments were seated on the implants and torqued to 25 Ncm.

Polyetheretherketone (PEEK) intraoral scan bodies (ISBs) were utilized for digital scans and torqued to 5 Ncm. A laboratory scanner (D900L, 3Shape, Copenhagen, Denmark) was used to scan the reference model, generating a digital reference model, which was saved as an STL file and imported into Exocad DentalCAD software.

Three experimental groups were established to evaluate different scanning techniques and the incorporation of additional reference points or splinting strategies (Fig. 1):

Group A (single-stage scan): The master model, with ISBs in place, was scanned in a single step without additional references (Fig. 2).

Group B (two-stage scan without additional references): The master model was first scanned without ISBs to capture the emergence profile. The initial scan was imported into

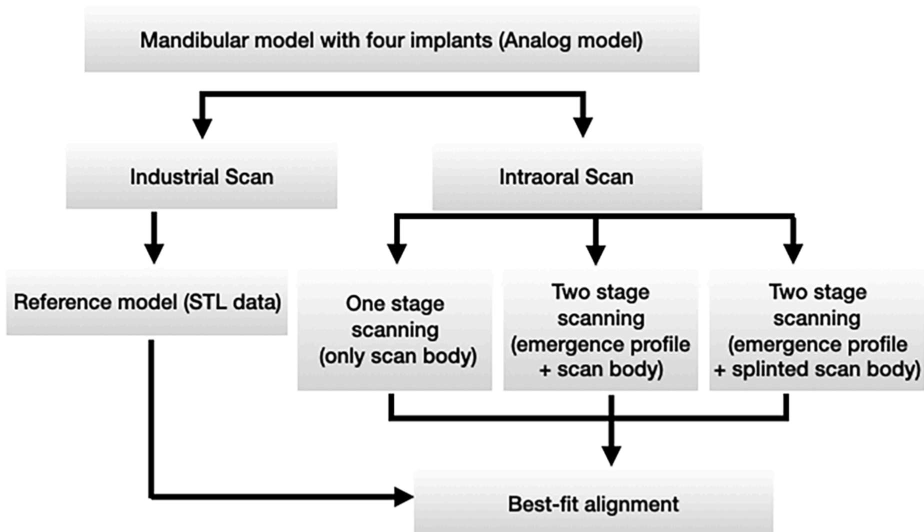

Figure 1 Study design with three experimental groups.

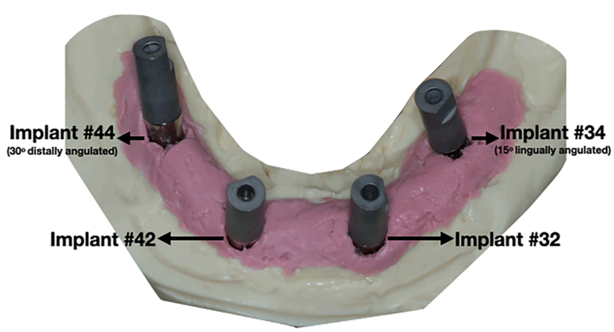

Figure 2 The master model with implant scan bodies in place was scanned in a single step without additional references.

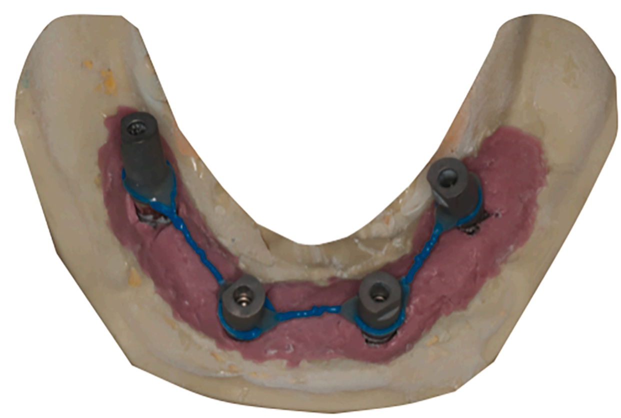

Figure 3 The master model with implant scan bodies and rubber buccal reference markers in place.

the design software, and implant positions were manually marked. The software subsequently recognized and removed the virtual implant surfaces. ISBs were then seated, and a second scan was performed. The TRIOS software aligned and merged the two scans into a single file.

Group C (two-stage scan with additional reference points): The scanning protocol followed that of Group B; however, rubber buccal reference markers were placed between the scan bodies before the second scan to establish continuous reference points (Fig. 3). The TRIOS software then aligned and merged the two scans.

An intraoral scanner (Trios 3, 3Shape, Copenhagen, Denmark) was used to obtain the virtual models. All scans were performed by a single experienced operator with five years of intraoral scanning experience, adhering to the manufacturer's recommendations.

To ensure statistical validity, each scanning strategy was repeated 15 times, yielding a total of 45 test scans ($n = 15$ per group). Each scan was saved as an stereolithography (STL) file and imported into Exocad DentalCAD. The digital reference model (one STL file) and the test scans (45 STL files) were analyzed using a best-fit registration method with a software program (GOM Inspect Professional 2017, Braunschweig, Germany) to assess deviations between the scanning strategies.

The root mean square (RMS) and angular deviation values were calculated to assess the accuracy of the implant positions. RMS is a commonly used quantitative metric in surface deviation analysis and digital dentistry to evaluate the overall geometric discrepancy between two three-dimensional surfaces. Specifically, RMS represents the square root of the average of the squared distances between corresponding points on the reference model and the test model. These distances are calculated point-to-point across the entire surface, thus providing a comprehensive measure of how closely two datasets align spatially.

In the context of implant placement, RMS values offer critical insights into the precision of digital workflows, particularly in comparing planned versus actual implant positions. A lower RMS value denotes a high degree of congruence between the two surfaces, indicating minimal deviation and therefore greater accuracy. Conversely, higher RMS values signify increased differences between the compared surfaces, which may be indicative of errors or discrepancies in the digital design or clinical execution.

Angular deviation, on the other hand, measures the difference in orientation between the long axes of the implants in the reference and test models. This parameter is particularly important for evaluating rotational alignment, which can significantly influence the fit and function of prosthetic components. Together, RMS and angular deviation provide a comprehensive assessment of both translational and rotational deviations, offering a robust evaluation of the accuracy of implant placement in digitally guided procedures.

The statistical analysis of the data was performed by using an open-source R software (version 4.1.2) and Turcosa software (www.turcosa.com.tr). Compliance of numerical variables with normal distribution was evaluated by using graphical approaches (Q—Q plot) and hypothesis tests (Shapiro—Wilk normality test) together. In the comparisons between groups, the condition that the normal distribution assumption was not provided, and the number of groups compared was evaluated using the Kruskal—Wallis test, and the groups that created the difference were determined by the Conover paired comparison test. Statistical significance level was accepted as $P < 0.05$.

Results

A total of 45 digital scans were analyzed, with each of the three groups comprising 15 scans (n = 15 per group). Linear deviations were measured at four implant sites (#32, #34, #42, and #44) to assess scan accuracy in comparison to the reference model (Table 1).

Group A (single-stage scan) exhibited the lowest mean deviation values across all implant locations, with an overall mean deviation of 39.57 ± 8.69 μm, indicating the highest level of accuracy among the groups. Group B (two-stage scan without additional reference points) demonstrated slightly higher deviations (42.80 ± 24.24 μm); however, the difference was not statistically significant when compared to Group A ($P > 0.05$), suggesting a comparable level of accuracy. In contrast, Group C (two-stage scan with additional reference points) showed the greatest deviation (70.60 ± 17.69 μm), and the differences were statistically significant when compared with both Groups A and B ($P < 0.05$), indicating a decline in accuracy despite the use of additional reference markers.

At the individual implant level, the smallest mean deviation was observed at implant site #34, while the highest deviation was recorded at site #44. Statistically significant differences between groups were found at each implant location ($P < 0.05$). Specifically, a single statistically significant intergroup difference was observed at sites #32, #34, and #42. However, at site #44, all three groups differed significantly from one another.

Discussion

This study aimed to assess the impact of different intraoral scanning protocols—single-stage scanning, two-stage scanning without auxiliary references, and two-stage scanning with supplemental reference markers—on the accuracy of complete-arch digital implant impressions. The results revealed that the single-stage scanning approach (Group A) yielded the lowest mean linear deviation (39.57 ± 8.69 μm), thereby demonstrating superior accuracy compared to the two-stage methods. Group B (two-stage scanning without additional reference points) exhibited slightly higher deviations (42.80 ± 24.24 μm), while Group C (two-stage scanning with added buccal rubber markers) produced the highest deviations (70.60 ± 17.69 μm), significantly differing from both Groups A and B ($P < 0.05$). These findings indicate that, in this experimental setup, the addition of flexible auxiliary reference markers did not enhance, and may have compromised scan accuracy.

Interestingly, this outcome contradicts several previously published studies that emphasize the benefits of incorporating geometric references or auxiliary devices during digital scanning. For instance, Kao et al.,[19] investigated the accuracy of digital impressions in edentulous spans restored with implant-supported prostheses and reported improved angular and linear accuracy when a continuous geometric aid (a power chain and flowable resin) was applied. Their study demonstrated a significant reduction in angular deviation (0.01 ± 0.11°) and increased linear precision (3.10 ± 2.14 mm) when compared to the non-assisted group (0.20 ± 0.15° and 11.14 ± 6.35 mm, respectively), reinforcing the potential role of geometric stabilization.

Similarly, Arikan et al.,[15] found that auxiliary geometric devices significantly improved accuracy in full-arch digital implant scans. Their results showed a reduced marginal gap

Table 1 Overall linear deviation values (mean ± standard deviation in microns) measured at lateral incisor and first premolar implant sites.

Implant Location	Group A	Group B	Group C	Overall
#34	29.9 ± 2.23 $^{a, T}$	38.6 ± 11.98 $^{c, T}$	60 ± 12.11 $^{e, U}$	42.83 ± 16.03 $^{g, T}$
#32	39.4 ± 5.64 $^{b, V}$	34.4 ± 18.17 $^{c, V}$	70.4 ± 11.67 $^{e, Y}$	48.06 ± 20.42 $^{g, V}$
#42	43.6 ± 4.78 $^{b, W}$	34.5 ± 16.46 $^{c, W}$	68.1 ± 20.08 $^{e, ,Z}$	48.73 ± 20.60 $^{g, W}$
#44	45.4 ± 10.4 $^{b, P}$	63.7 ± 33.81 $^{d, R}$	83.9 ± 18.50 $^{f, S}$	64.33 ± 27.39 $^{h, R}$
Overall	39.57 ± 8.69 $^{b, L}$	42.8 ± 24.24 $^{c, L}$	70.6 ± 17.69 $^{e, M}$	50.99 ± 22,71 $^{g, L}$

Identical lowercase letters within each column indicate no statistically significant differences between groups at a given implant site ($P > 0.05$); differing lowercase letters indicate statistically significant differences ($P < 0.05$). Similarly, identical uppercase letters within each row denote no significant differences across implant sites within the same group ($P > 0.05$), whereas differing uppercase letters represent statistically significant differences ($P < 0.05$).

(49.16 ± 32.37 μm) when AGDs were used, compared to unaided scans (80.86 ± 50.06 μm). Huang et al., (2020) further confirmed this trend, reporting that scan bodies incorporating extensional structures improved both trueness (28.45 μm) and precision (27.30 μm), performing similarly to conventional impressions. These collective findings suggest that structural enhancements to scan bodies or the use of auxiliary guides can facilitate more consistent data capture and improve overall scan quality.

Contrary to these favorable outcomes, our study observed a decline in scan accuracy with the inclusion of buccal rubber markers in the two-stage approach. The likely explanation for this discrepancy lies in the physical characteristics and positioning of the markers used. Unlike rigid and geometrically defined auxiliary devices in other studies, the rubber markers applied here may have lacked sufficient stability and structural continuity. These deficiencies could have disrupted the software's stitching algorithms during image reconstruction, resulting in greater deviation and lower trueness. This interpretation aligns with findings by Lawand et al.,[22] who evaluated how modifications to implant scan bodies influence accuracy. They demonstrated that subtractive geometric changes (e.g., grooves) enhanced scan trueness and angular precision, while additive elements (e.g., flexible PEEK beads) led to higher deviations. Their findings reinforce the idea that the design integrity and material rigidity of auxiliary elements are critical determinants of scanning accuracy.

In addition to auxiliary structure design, other factors such as the type of intraoral scanner (IOS) and the spatial configuration of the implants must also be considered. Azevedo et al.,[17] compared five IOS systems using three scanning protocols (conventional, splinted, and artificial landmarks) and found that while scanning technique did not significantly influence accuracy ($p = 0.06$), the scanner model had a notable effect. For instance, Cerec Primescan demonstrated superior trueness (27 ± 4 μm) compared to other systems, with Trios 4 performing less favorably (up to 107 ± 13 μm). Moreover, they emphasized that implant angulation, especially in cases with wide inter-implant divergence, can adversely affect scan body alignment and stitching. In the present study, implant site #44 exhibited the highest deviation values across all groups, which may be attributed in part to the 30° distal tilt of this implant, supporting the hypothesis that implant angulation significantly affects scan accuracy.

While it could be hypothesized that two-stage scanning offers a more controlled environment for capturing specific implant features, our findings do not support a significant improvement in accuracy with this approach. Group B (two-stage scanning without reference markers) did not demonstrate statistically better performance than Group A. This observation is consistent with the conclusions drawn by Motel et al.,[20] who reported improved outcomes with single-stage scanning over more complex multi-stage protocols in short-span implant cases. The anticipated benefit of two-stage scanning may be undermined by increased potential for alignment discrepancies between scan phases, which could accumulate and result in greater overall error.

When comparing our findings with existing literature, a central distinction emerges regarding the nature of the auxiliary features used. Previous studies that observed improved accuracy typically employed rigid, precisely designed, and geometrically continuous aids. In contrast, the flexible rubber markers in our study may have lacked the necessary structural integrity and placement consistency to effectively aid in scan alignment. These results emphasize that not all auxiliary elements are inherently beneficial; their effectiveness is heavily dependent on material properties, geometry, and integration into the scan protocol.

In conclusion, this study underscores the importance of scan protocol selection and the design quality of auxiliary references in determining the accuracy of complete-arch digital implant impressions. While multiple factors influence scan precision, including scanner model, implant angulation, and scan body design, our findings support the clinical use of single-stage scanning as the most accurate method. Moreover, poorly designed or improperly applied auxiliary markers may compromise rather than enhance scan accuracy, highlighting the need for further research into optimal strategies for improving full-arch digital impression fidelity.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This study was approved by Baskent University Institutional Review Board (Project no: D-KA24/03) and supported by Baskent University Research Fund.

References

1. Uzel SM, Guncu MB, Aktas G, Arikan H, Reiss N, Turkyilmaz I. Influence of the implant scan body modifications on trueness of digital impressions. *J Dent Sci* 2023;18:1771—7.
2. Kirman EA, Asar NV, Erdem B, Turkyilmaz I. Effects of abutment length and platform size on the retention of implant-supported CAD/CAM crowns using six different cements. *J Dent Sci* 2022;17:601—3.
3. Turkyilmaz I, Benli M, Schoenbaum TR. Clinical performance of 11,646 dental implants using surgical guides and two different surgical approaches: a systematic review and meta-analysis. *Int J Oral Maxillofac Implants* 2023;38(suppl):16—29.
4. Pereira ALC, de Luna Gomes JM, Campos MFTP, et al. Device trueness in passivity and misfit of CAD-CAM frameworks: conventional versus printed casts. *J Prosthet Dent* 2025;133: 1495—502.
5. Turkyilmaz I, Unsal GS. Full-mouth rehabilitation of an elderly patient with Sjogren'S syndrome by using implant-supported fixed dental prostheses including CAD/CAM frameworks. *J Dent Sci* 2019;14:428—9.
6. Rojas-Rueda S, Robles M, Pagan-Banchs M, et al. Accuracy of digital impressions for veneer restorations: a narrative review and case illustration. *J Clin Med* 2025;14:3859.
7. Guncu MB, Aktas G, Turkyilmaz I, Gavras JN. Performance of high-translucent zirconia CAD/CAM fixed dental prostheses using a digital workflow: a clinical study up to 6 years. *J Dent Sci* 2023;18:44—9.

8. 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.
9. Alkadi L. A comprehensive review of factors that influence the accuracy of intraoral scanners. *Diagnostics* 2023;13:3291.
10. Revilla-Leon M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans. Part 1: operator factors. *J Esthetic Restor Dent* 2023;35:230—40.
11. Turkyilmaz I, Wilkins GN, Varvara G. Tooth preparation, digital design and milling process considerations for CAD/CAM crowns: understanding the transition from analog to digital workflow. *J Dent Sci* 2021;16:1312—4.
12. Liang S, Yuan F. High-accuracy digital model design for full crown tooth preparation. *Int J Comput Dent* 2019;22:331—42.
13. Robert N, Bechet E, Albert A, Lamy M. Influence of the scanning path on the accuracy of intraoral scanners in the implanted edentulous patient: an in vitro study. *Int J Comput Dent* 2025;28:117—27.
14. Flugge TV, Att W, Metzger MC, Nelson K. Precision of dental implant digitization using intraoral scanners. *Int J Prosthodont (IJP)* 2016;29:277—83.
15. Arikan H, Muhtarogullari M, Uzel SM, et al. Accuracy of digital impressions for implant-supported complete-arch prosthesis when using an auxiliary geometry device. *J Dent Sci* 2023;18: 808—13.
16. Eid HS, Zohdy MM, Nour M, Salah T. A comparative analysis of the passivity of fit of complete arch implant-supported frameworks fabricated using different acquisition techniques. *J Prosthet Dent* 2024;131:477.e1—8.
17. Azevedo L, Marques T, Karasan D, et al. Influence of implant scanbody material and intraoral scanners on the accuracy of complete-arch digital implant impressions. *Int J Prosthodont (IJP)* 2024;37:575—82.
18. Huang R, Liu Y, Huang B, Zhang C, Chen Z, Li Z. Improved scanning accuracy with newly designed scan bodies: an in vitro study comparing digital versus conventional impression techniques for complete-arch implant rehabilitation. *Clin Oral Implants Res* 2020;31:625—33.
19. Kao TY, Hsieh MC, Hsu CP, Liao CC, Chang CL. Accuracy of digital impressions for three-unit and four-unit implant supported fixed dental prostheses using a novel device. *J Dent Sci* 2023;18:702—8.
20. Motel C, Kirchner E, Adler W, Wichmann M, Matta RE. Impact of different scan bodies and scan strategies on the accuracy of digital implant impressions assessed with an intraoral scanner: an in vitro study. *J Prosthodont* 2020;29:309—14.
21. Alpkılıc-Issever DS, Tokuc M. Effect of scanning strategies on trueness and time efficiency of digital impression on paediatric models. *Int J Paediatr Dent* 2025;35:639—47.
22. Lawand G, Ismail Y, Revilla-Leon 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: 1189—97.