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Effect of Splinting Scan bodies on The Accuracy and Clinical Time Required for Completely Edentulous Arch Data Acquisition

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Aim: This study aimed to examine the influence of intraoral splinting of implant scan bodies on the trueness of data acquisition for fully edentulous arches using a simple technique to address dimensional discrepancies inherent in the stitching process of intraoral scanners.

Materials and Methods: Thirteen edentulous patients with All-on-4 implants were included. A verified master model, obtained from conventional splinted open-tray impressions, was digitized as the reference. Each patient received two intraoral scans (Medit I700): one with non-splinted and one with splinted scan bodies (using dental floss and composite resin). Data were analyzed with 3D metrology software (Geomagic Control X) and compared using an independent t-test.

Results: The splinted scan bodies (0.45 ± 0.07 mm) showed significantly higher deviation from trueness measurements compared to non-splinted scan bodies (0.12 ± 0.01 mm) as P = 0.0001.

The splinted scan bodies recorded a significantly higher total clinical time (13 ± 1.47 minutes) compared to non-splinted scan bodies (8.08 ± 0.86 minutes) as P = 0.0001.

Conclusion: Splinting of scan bodies using dental floss with composite resin has significantly decreased the scanning accuracy of the intraoral scans. Although splinting has decreased scan time, it has increased the total clinical time for full arch implant data acquisition.

Keywords: Full Arch scanning, Computer-Aided Design, Trueness, Scan body Splinting.

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Introduction

The swift advancements in digital dentistry are significantly enhancing the development of implant dentistry. Digital workflows in dentistry can be categorized as either direct or indirect.[1] The indirect method involves digitizing a traditional implant impression using an extraoral optical scanner and scan bodies. Conversely, the direct method uses an intraoral scanning (IOS) device to scan the scan bodies (ISBs) directly from the patient's mouth.[2] Both extraoral and intraoral optical scanners depend on structured light technology, which collects raw data as point clouds through various techniques, such as confocal microscopy, triangulation, and wavefront sampling. Differences in these technologies can lead to variations in accuracy.[3-5]

In one hand, in implant prosthodontics, intraoral scanners (IOSs) are frequently utilized to obtain optical impressions for short-span restorations, such as single crowns and fixed partial prostheses.[6-8] On the other hand, many studies and literature reviews reported how challenging it is to obtain accurate intraoral optical impressions for long-span implant-supported restorations, especially for completely edentulous patients.[9,10]

Intraoral scanners demonstrate trueness and precision, which together constitute "accuracy." Accuracy is defined as the extent to which measured values align with actual values. Trueness refers to the closeness of a measurement to the actual dimensions of the scanned object, while precision pertains to the consistency of the scan measurements.[11]

Edentulous alveolar ridges can exhibit varying degrees of general deficits and resorption, leading to the presence of non-attached movable mucosa. This variability may further affect the implant data acquisition in clinical settings.[12] In-vitro research has examined numerous factors that could influence the trueness of intraoral scanners (IOS), producing varied results. These factors include the operator's prior experience, the scanning pattern, the characteristics of the scan body material, implant depth, angulation, inter-implant distance and the intraoral scanner's technology.[13–15]

Obtaining accurate digital impressions in fully edentulous full-arch implant cases remains a significant challenge, primarily due to the limited presence of reference landmarks between scan bodies. Intraoral scanners rely on the sequential acquisition of images to reconstruct the complete arch—a process known as image stitching. However, this technique is susceptible to dimensional inaccuracies, which are inherently influenced by the scanner's field of view and the spatial arrangement of the implants.[16,17]

In theory, splinting scan bodies intraorally could increase the number of reference points for the scanner to recognize, improving image stitching and scanning accuracy and in turn decreasing scan time.[18,19] However, there is a scarcity of in vivo clinical research that assessed the effects of splinting scan bodies and the appropriate scanning technique to be used with fully edentulous arches on the scanning accuracy and clinical time required for data acquisition.

Thus, the objective of this clinical study was to evaluate the effect of intraoral splinting of implant scan bodies, using a straightforward simple technique involving dental floss and composite resin, on the trueness and clinical time required for implant data acquisition in completely edentulous arches. The first null hypothesis posits that there is no significant difference in accuracy between splinted and non-splinted scan bodies in completely edentulous maxillary arches. The second null hypothesis proposes that splinting the scan bodies will reduce the clinical time needed for full-arch implant data acquisition.

ASDJ Ain Shams Dental Journal

Materials And Methods

This study was conducted according to the Declaration of Helsinki guidelines and approved by the Institutional Review Board of Misr University for Science and Technology (MUST-IRB) with IRB Number: 2024/0016. It was retrospectively registered on https://clinicaltrials.gov/ with registration number NCT06669065. First registered on 01-11-2024. Informed consent was obtained from the participants.

I- Patients' selection and study design:

Based on the findings of a previous study as a reference,[20] the minimally accepted sample size was 13 full-arch implant impressions per group with a study power of 80 % & type I error probability equals 0.05. Sample size calculation was performed by using P.S. power 3.1.6.
Thirteen patients with completely edentulous maxillae were allocated and enrolled in the study from the Dental Implantology clinic, College of Oral and Dental Surgery – Misr University for Science and Technology. They were previously rehabilitated with four standard implants (Implant Swiss; Switzerland) following the "All-on-4" protocol (comprising two anterior vertical implants and two posterior angled implants). The multiunit abutments were placed on the surgery day and covered with healing caps. Participants were selected based on the following inclusion criteria: complete edentulism in the maxilla restored with four implants using a computer-guided stent; medium palatal vaults, absence of systemic conditions that could impair bone remodelling and osseointegration; and the presence of well-formed alveolar ridges with healthy keratinized mucosa. Exclusion criteria included patients with high palatal vault, non-compliance, smoking, systemic diseases affecting bone metabolism, and poor oral hygiene.

II- Data acquisition:

After 6 months post dental implant insertion in the maxillary arches, patients were assigned for the commencement of the study as follows:

1. Acquisition of the reference scan:

For every participant, an open-tray impression technique was carried out using polyvinyl siloxane (PVS) (Elite HD+; Zhermack) after splinting the impression copings using low shrinkage resin (GC Pattern Resin; GC America Inc) and sectioning the splint followed by re-splinting using the same low shrinkage resin to minimize the amount of shrinkage and guarantee an accurate impression. After the removal of the impression from the patient's mouth, the 4 multi-unit analogues (Implant Swiss; Switzerland) were secured to the impression copings. (Fig. 1-A) A silicone replica of the gingiva (Gingifast Elastic; Zhermack) was placed around the analogues.

The impression was then boxed and poured with Type IV stone (Elite Rock; Zhermack). For confirmation of the definitive cast, a verification jig was constructed by connecting the impression copings using pattern resin (GC Pattern Resin; GC America Inc). Verification of the jig was performed clinically using periapical radiographs and the one screw test known as the "Sheffield" test, for detection of any misfit between the verification device and the multiunit abutments.[26] If a misfit was noted through any of the above-mentioned verification methods, the final impression was repeated. Then, a new master cast was produced and verified with the same procedure.

Scan bodies (S-PMUSB, Implant Swiss, Switzerland) were hand-tightened onto each implant replica of the master cast and scanned using an extraoral optical scanner (E2, 3Shape; Denmark). The scanned cast was then saved as a standard tessellation language (STL) file to serve as the reference scan of each participant. This served as the control group. (Fig. 1-B)

ASDJ Ain Shams Dental Journal

2. Acquisition of the intraoral scans

Intraorally, the scan bodies (S-PMUSB, Implant Swiss, Switzerland) were hand-tightened onto each participant's multi-unit abutments. The intraoral scan bodies' seating was verified using periapical radiographs and direct visual examination. An intraoral scanner (Medit i700 wired; Medit, Korea) was used to record the implants' positions. This scan was saved as an STL/PLY file and represented the first test group (non-splinted Scan Group [NS]) (Fig. 1-C).

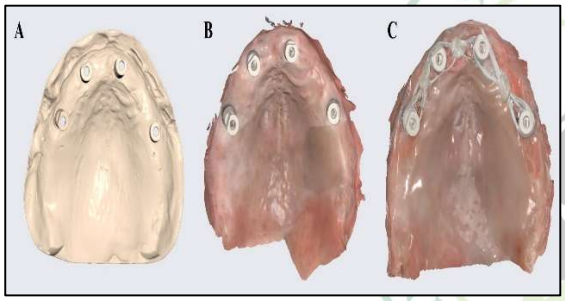

Figure 1: A. The optical scan of the verified master model for open tray full arch conventional impression. B. The intraoral optical scan of the non-splinted scan bodies group. C. The intraoral optical scan of the splinted scan bodies group.

For the splinted scan bodies group, all scan bodies were splinted using dental floss and flowable composite resin material (3m Espe, USA). Dental floss was positioned around the scan bodies to form small scaffolds located away from the scanning region of the scan body. Subsequently, composite resin was applied in irregularly shaped blobs to serve as reference markers between the implants. The intraoral scan was then acquired using the same intra-oral scanner and the scan was then saved as an STL/PLY file and represented the second test group (Splinted Scan Group [S]) (Fig. 1-D).

All scans were acquired by a single experienced operator, who was not involved as an examiner in the study. Before each scan, the edentulous ridge was thoroughly cleansed, and saliva was carefully eliminated, and scans were carried out under the same light conditions. The intraoral scan was consistent and performed according to the scanner's manufacturer's recommendations starting from the rugae and incisive papillae area, all the way occlusal on both sides, palatal then buccal.[39] A scan was complete once all maxillary arch was captured with no major deficiencies such as holes or artifacts. The scan time and the time of the total clinical steps for each scan were recorded, starting from placing the scan bodies, splining and adding composite, scanning procedure, removing the scan bodies, and torquing the healing caps.

3. The digital comparison of trueness

The scan bodies were virtually transformed into a custom abutment using a prosthesis design software program (Exocad, Dental CAD). The software depends on the best-fit algorithm matching of the scan body flat surface and the CAD scan body design present on the virtual software library to determine the implant position, angulation, and orientation, followed by custom abutment designing.[21,22]

For the trueness measurement of each optical scanning technique, a special 3D metrology software program (Geomagic Control X 2020; 3D systems) was used, and the verified master model obtained from the conventional impression (control group) was marked as a reference for all the following comparisons.

Using the software region tools, the reference model was 3D segmented into two main parts: the custom abutments (comparator area) and the edentulous alveolar ridge with palatal areas. The edentulous alveolar ridge with palatal areas was used for the superimposition step between the two studied groups and the control group. The superimposition was performed depending on the initial alignment and the best-fit alignment software algorithms.[21,23]

The trueness values represented by deviation in custom abutments from the

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control group were recorded in mm and measured by the root mean square (RMS.) which represents the degree of all-over deviation between the custom abutments constructed from both the optical intraoral impression and the conventional one. The 3D segmentation method used ensures research results' standardization by neglecting the irrelevant data from incorporation into the comparison and comparing the trueness only in the abutment area. (Figs. 2 & 3)

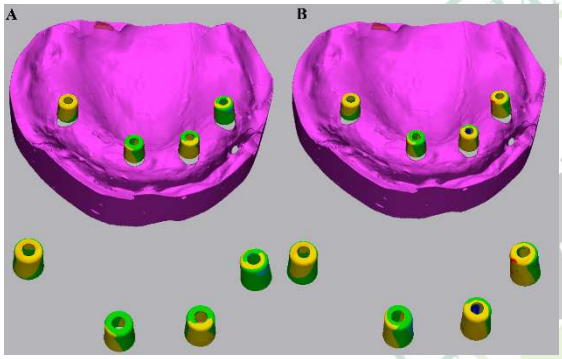

Figure 2: A. colour map representing the trueness of the non-splinted scan body group.
B. colour map representing the trueness of the splinted scan body group.

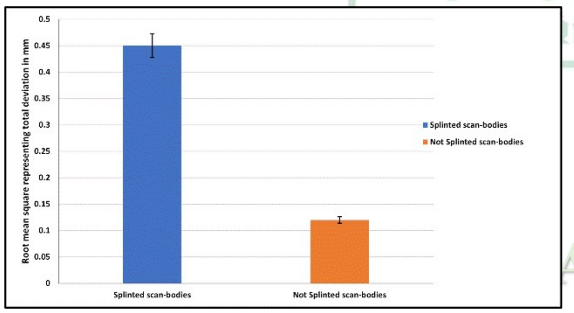

Figure 3: Bar chart of root mean square in (mm) comparing the deviation from trueness between the splinted and non-splinted scan body groups.

Results

Statistical analysis

Statistical analysis was performed with SPSS 20®, Graph Pad Prism®, and Microsoft Excel 2016. All quantitative data were presented as minimum, maximum, means, and standard deviation (SD) values and explored for normality by using the Shapiro-Wilk Normality test and Kolmogorov test, which revealed that all data were normally distributed; accordingly, comparison between splinted and non-splinted scan-bodies was performed by using the independent t-test. The significance level was set to be at $P \leq 0.05$. All data were presented in (3) tables & (1) graph.

1. Evaluation of Accuracy:

A comparison between the trueness of splinted and non-splinted scan bodies was presented in Table 1 and Figure 4. An Independent t-test was used and revealed that: The R.M.S. for splinted scan bodies (0.45 ± 0.07 mm) showed significantly higher deviation measurements compared to non-splinted scan bodies (0.12 ± 0.01 mm) as P= 0.0001.

Table 1: The trueness of splinted and non-splinted scan bodies represented in R.M.S.:

	R.M.S. (Deviation from reference in mm)				Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		P value
	Min.	Max.	Mean	Standard Deviation			Lower	Upper	
Splinted scan-bodies	0.35	0.55	0.45	0.07	0.33	0.02	0.29	0.37	0.0001*
Not Splinted scan-bodies	0.11	0.13	0.12	0.01					

***Significant difference as P ≤ 0.05.**

2. Evaluation of time spent in each scan:

A comparison between the time spent in each scan of splinted and non-splinted scan bodies was presented in Table 2. An Independent t-test was used and revealed that: The splinted scan bodies recording (2.88 ± 0.66 minutes) showed significantly lower time compared to non-splinted scan bodies recording (4.74 ± 0.54 minutes) as P= 0.0001.

Table 2: Comparison between splinted and non-splinted scan bodies regarding time spent in each scan:

	Time spent on each scan in minutes				Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		P value
	Min.	Max.	Mean	Standard Deviation			Lower	Upper	
Splinted scan-bodies	2.00	4.00	2.88	0.66	-1.86	0.24	-2.35	-1.38	0.0001*
Not Splinted scan-bodies	4.00	5.60	4.74	0.54					

***Significant difference as P ≤ 0.05.**

ASDJ Ain Shams Dental Journal

3. Evaluation of total clinical time spent on each scanning technique:

A comparison between the total clinical time required for data acquisition in both splinted and non-splinted scan bodies was presented in Table 3. An Independent t-test was used and revealed that: The splinted scan bodies recording a total clinical time of (13 ± 1.47 minutes) showed significantly higher time compared to non-splinted scan bodies recording a total clinical time of (8.08 ± 0.86 minutes) as P= 0.0001.

Table 3: Comparison between splinted and non-splinted scan bodies regarding total clinical time required for data acquisition:

	Time spent on each procedure from the beginning of scan body installation/splinting till the end of the scan in minutes				Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		P value
	Min.	Max.	Mean	Standard Deviation			Lower	Upper	
Splinted scan-bodies	11.00	16.00	13.00	1.47	4.92	0.47	3.95	5.90	0.0001*
Not Splinted scan-bodies	7.00	10.00	8.08	0.86					

***Significant difference as P ≤ 0.05.**

Discussion

With the advent of CAD/CAM technology in implant dentistry and significant advancements in intraoral scanner software, it may become feasible to fabricate implant-supported prostheses entirely through digital means, gradually avoiding the need for a physical cast. However, practitioners continue to seek the most accurate methods to address the challenges associated with digital workflow in full arch implant prostheses.

To the authors' knowledge, clinical studies on full arch scanning techniques for implant prostheses are scarce, particularly those evaluating methods to enhance scanning accuracy with intraoral scanners. This study examined the accuracy, scan time, and the total clinical time using proprietary scan bodies, comparing splinted versus non-splinted techniques with a single intraoral scanner. The splinting versus non-splinting methods significantly affected the trueness results represented by deviation from the verified open tray conventional impression, leading to the rejection of the initial null hypothesis. The splinting method significantly reduced the scan time compared to the non-splinted method on the other hand the splinting method increased the total clinical time required for full arch data acquisition.

The verified master cast was scanned as the reference scan in this study as it has been proven by previous studies that the conventional splinted open tray impression technique is the gold standard for accurate full arch implant impressions.[24,25] Also, the technique used for splinting impression copings enhances accuracy by minimizing micromovement during impressions.[26]

The digitization of the verified master model using extra-oral scanners has a high accuracy of up to 4 microns therefore it could be used as a reliable reference for the final acquisition of edentulous jaws to construct full arch implant prosthesis.[27]

Given that scan bodies possess a one-sided flat surface (i.e. the scan region), the orientation of this surface relative to the maxillary edentulous jaw may vary with each scan acquisition. To facilitate the comparison of different scanning procedures, customized cylindrical abutments were designed on the CAD software for each jaw scan before accuracy measurement.[21] Additionally, these custom virtual abutments enable accurate evaluation of scanning inaccuracies that arise after splinting, by comparing the scan body with its virtual counterpart during the matching process in the CAD software. Furthermore, creating custom abutments for each jaw scan simulates the actual clinical scenario in the laboratory aligning with the standard digital workflow.[13]

The 3D metrology software (Geomagic control X) was used as a valid method for comparing the accuracy of optical scans in many previous studies, also the 3D segmentation method introduced by the software allows for only comparing the accuracy of the area of interest (scan body or virtual abutments) and neglects non-

ASDJ Ain Shams Dental Journal

important regions such as soft tissue or palatal region.[21,23]

Previous studies indicated that the inter-implant distance, the depth of the implant, the scan body visibility, and the operator's experience can affect the accuracy of digital implant scans with multiple scan bodies.[28,29] In addition to the scan body itself regarding its design and material and the scanning technology used by the intraoral scanner software.[30,31]

In the present study, although the inter-implant distance could not be standardised due to variations inherent to each clinical case, measures were taken to minimise other sources of variability. All scans were performed by an experienced operator, independent from the study, to reduce bias. Furthermore, a uniform scanning protocol was strictly followed, and the intraoral scanner software was calibrated prior to each scanning session to minimise operator- and technology-related discrepancies.

There is no consensus regarding the clinically acceptable accuracy range of intraoral scanners; however, the threshold misfit that does not induce clinical complications ranges between 50 and 226 µm in fixed restorations.[32] Other studies showed that for complete-arch implant digital scans, higher amounts of inaccuracy have been shown, ranging in distance deviations of 47 to 226 µm.[3,33] The literature indicates that 150 µm is an acceptable level of misfit for full-arch implant-supported restorations.[34]

In fully edentulous cases, stitching of the images is challenging for the intraoral scanner due to the absence of enough landmarks, and this can lead to inaccurate image stitching and misunderstanding of scan data as duplicates.[28] To address this issue, researchers have proposed various techniques and methods of splinting the scan bodies to increase the number of reference spots.[30,35-37]

In the present study, splinting of the scan bodies was achieved using dental floss and composite resin, which resulted in higher deviation values compared to the non-splinted group. This outcome may be attributed to the optical properties and thickness of the floss, which could interfere with the intraoral scanner's performance, particularly in the presence of salivary moisture and the surrounding soft tissue coloration. Furthermore, in some cases, the close proximity of the floss to the scanning region of the scan body may have compromised the scanner's ability to accurately capture and digitize the surface details of the scan body.

The results of the current study revealed that the splinted scan bodies showed a statistically significant increase in deviation measurements compared to the non-splinted scan bodies, measuring 450 µm and 120 µm, respectively, representing nearly a four times difference and highlighting the potential impact of the type of splinting technique on the scan precision and clinical accuracy.

The results of the study are consistent with the findings of Mizumoto et al[30] and Nedelcu et al[38] that used different techniques of splinting to add different landmarks. One of them was splinting the scan bodies with dental floss, which showed the highest deviation of all techniques. Another clinical study used the splinting technique between scan bodies with dental floss and pattern resin in mandibular edentulous arches, and it found that the splinted group did not significantly affect the trueness of complete arch digital scans in comparison with the non-splinted group.[39]

Eddin et al[40] reported in an in-vitro study that splinting scan bodies improved the stitching and trueness of the optical scans, they compared different splinting methods with the gold standard digitized impression of the open tray technique. They used dental floss with either pattern resin or composite resin, customized 3D printed scan body with lateral extensions and auxiliary apparatus attached to the scan body. The results revealed that the virtually designed scan aids yielded better trueness

ASDJ Ain Shams Dental Journal

than the other types. It attributed the findings to the fact that the scanner did not read the white composite properly which led to more light scattering and this part is consistent with our findings. Furthermore, another in-vitro study employing splinting with scan aids has reported that white-colored scan aids were associated with reduced trueness.[41] supporting the previous assumption, knowing that both studies were conducted using different intraoral scanners with different capturing technologies.

Another cause that may affect the trueness values is the scanning technology. The used intraoral scanner in the study was (Medit i700) which is based on the concept of active triangulation of optical imaging. Triangulation is based on the principle that an object's position can be calculated by recording the same surfaces and angles from two points of view. These two points are captured at two different points in time.[42] Active triangulation requires moving around the object (scan body), The vertical motion of the scanner head adversely influences scan accuracy, while the use of splinting may have further exacerbated the scanner's limitations in precisely capturing the areas adjacent to the scan bodies.

In contrast, the current study findings diverge from those reported in another in vivo study which compared splinted and non-splinted scan bodies using a specially designed scan aid and two different intraoral scanners: one based on active triangulation and the other on parallel confocal microscopy. The results showed that the trueness values were improved with splinted scan bodies using the intra-oral scanner working with the active triangulation concept and were insignificant with the other intraoral scanner.[43] Also, another in-vitro studies proved that splining of scan bodies has led to improved trueness whether it was by scan aids or specially designed scan bodies with extensions.[44]

Regarding the scanning time, the current study revealed that the splinted scan bodies group (2.88 ± 0.66) minutes had enhanced the scanning time in comparison with the non-splinted group (4.74 ± 0.54) minutes and the results were statistically significant. This came in consistent with other clinical studies and this could be attributed to the fact that increasing the landmarks has affected the stitching performance of the intra-oral scanner.[39] Although the splinting has decreased scanning time, it has increased the total clinical time for full arch data acquisition recording (11 ± 1.47) minutes in comparison to the non-splinting technique recorded (7 ± 0.86) minutes.

Any implant-supported prosthesis requires a perfect, distortion-free impression to provide a passive fit. While intraoral optical scanners may have resulted in prostheses with varied degrees of discrepancies, some of which may be clinically unsatisfactory, however, the current study did not seek to address this issue.

Limitations of this study are using dental floss with composite resin for splinting which has resulted in increased distance deviation due to direct contact with the scan body's unique region, potentially interfering with the intraoral scanner's capacity to digitize the surface, also, the study focused on evaluating the data-acquisition step of the workflow but did not examine the impact on subsequent steps like processing and manufacturing of the definitive restoration to assess the clinical influence of the examined intraoral scans. There are some variables that are hard to be controlled in the clinical studies, such as soft tissue thickness and depth of the palatal vault, Although the implant placement was performed using a computer guided stent , the inter-implant distance is difficult to be controlled due to patient related factors such as bone quantity and anatomic limitations.

Conclusions

Within the limitations of the current study, the following conclusions were drawn:

ASDJ Ain Shams Dental Journal

1. Splinting of scan bodies using dental floss with composite resin has significantly decreased the scanning accuracy of the intra-oral scans.
2. The concept of splinting the scan bodies has significantly enhanced the scanning time with the intra-oral scanner but increased the total clinical time required for full arch data acquisition
3. The introduced technique of using virtual custom abutments along with the 3D segmentation methods mimics a real clinical situation and controls over variables like saliva and light reflection during scanning also it considers the inaccuracies during the design step on the software.

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Ethics Approval and Consent to Participants: This study was conducted according to the Declaration of Helsinki guidelines and approved by the Institutional Review Board of Misr University for Science and Technology (MUST-IRB) with IRB Number: 2024/0016. Informed consent was obtained from all participants.

Data availability: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interest: The authors declare that they have no conflict of interest.
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ASDJ Ain Shams Dental Journal

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