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ACCURACY OF DIGITAL IMPRESSIONS OBTAINED BY DIFFERENT INTRAORAL SCANNERS COMPARED WITH THE LABORATORY SCANNER FOR IMPLANTS PLACED IN PARTIALLY EDENTULOUS MANDIBLE: AN IN VITRO STUDY

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ABSTRACT

Aim: The aim of this in vitro study was to evaluate the accuracy of three different intraoral scanners (Medit i700, 3Shape TRIOS 4 and Carestream CS3600) versus the desktop lab scanner for implants placed in Kennedy class II partially edentulous mandible.

Methodology: A 3D-printed resin cast simulating a Kennedy Class II mandibular arch with two implants, in the first premolar and first molar regions, was used. Each scan body and the mucosal part of the edentulous area were scanned once by a laboratory scanner to establish a reference standard. Then, they were scanned five times with each intraoral scanner. The scans were compared using Geomagic Control X software to measure the root mean square (RMS) deviation. Statistical tests were conducted to assess and compare trueness and precision between and within groups.

Results: For trueness, the One-Way ANOVA test showed no statistically significant differences among the three groups for anterior scan body, posterior scan body, and mucosal part (P-values: 0.14, 0.45, and 0.40 respectively). For precision, significant differences were found in the posterior scan body (P=0.03) and mucosal part (P=0.004), with the TRIOS 4 scanner demonstrating the highest precision. No significant differences between the three intraoral scanners were observed for the anterior scan body part (P=0.09).

Conclusions: The study revealed that intraoral scanners exhibit varying precision for different anatomical regions, despite comparable trueness. This underscores the necessity of carefully considering scanner selection based on clinical requirements to guarantee accurate digital impressions and optimal treatment outcomes.

KEYWORDS: Implants ; Trueness ; Precision ; Intraoral scanners ; Kennedy class II

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INTRODUCTION

Partially edentulous patients, defined as those who have lost one or more teeth within the dental arch, are common in dental practice due to various causes, including decay, periodontal disease, trauma, congenital absence of teeth, or systemic conditions. Proper restoration of the missing teeth is crucial to restoring both function and aesthetics. Dental implants, which have evolved significantly over the past century, are now a widely accepted treatment modality for replacing missing teeth. [1]

For dental implant placement, accurate impressions are critical to ensure the precise positioning of prosthetic restorations. Traditionally, conventional impression techniques have been employed, where an impression material is used to create a negative replica of the patient's dental arch, which is then used to fabricate the prosthesis. However, conventional methods are prone to several drawbacks, including distortion, material handling errors, and patient discomfort. These issues can lead to inaccuracies in the final prosthesis, necessitating adjustments or re-impressions. [2]

Intraoral scanners (IOS), a digital alternative to conventional impressions, have gained popularity due to their ability to eliminate impression materials, reduce chair time, and enhance patient comfort. IOS capture a 3D representation of the oral cavity through optical scanning, offering several advantages, including immediate visualization, digital storage, and a lower risk of impression distortion. [3],[4]

However, the key question remains: Can intraoral scanners provide the same level of accuracy as extraoral lab scanners, which have traditionally been considered the gold standard in digital dentistry?

This study investigates the accuracy of three intraoral scanners; Medit i700, TRIOS 4, and CS3600 compared to an extraoral scanner (InEos X5 Sirona) for Kennedy class II partially edentulous patients with dental implants.

MATERIALS AND METHODS

Study Design:

This in vitro study was conducted using a 3D-printed model of a Kennedy Class II partially edentulous mandible with two implants placed in the first premolar and first molar regions on the right side. The study aimed to assess the accuracy of three intraoral scanners compared to a reference extraoral scanner in terms of trueness and precision.

Construction of the Working Cast:

The working cast was designed digitally using Exocad software and printed using *MOGASSAM* 3D printer with high-precision dental resin. (Fig:1) The missing teeth on the right side included the first and second premolars and all molars. (Fig:2)

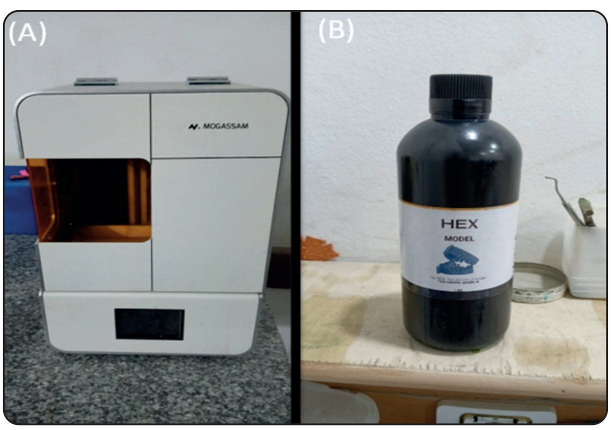

Fig. (1) (A) Mogassam 3D printer, (B) Hex dental resin

Fig. (2) The 3D printed Kenndy class I resin model

Identification of the Drilling Site and implant placement

The implant positions were determined based on the left collateral first premolar and first molar as references. (Fig:3) The desired positions for drilling were marked with a pencil, and implant placement was carried out in sequence using a 2.3 mm pilot drill, followed by 2.8 mm and 3.4 mm drills for final implant site preparation.

Fig. (3) Marking the drilling sites

Two implants *(Legacy 4, Implant Direct, USA)* were inserted in the right first premolar and right first molar regions. The first implant measured 3.7 mm in width and 10 mm in length, while the second implant was 4.7 mm in width and 10 mm in length. The drilling site was cleaned, and the fixture was secured in place using cement to ensure stability during the scanning process. (Fig:4)

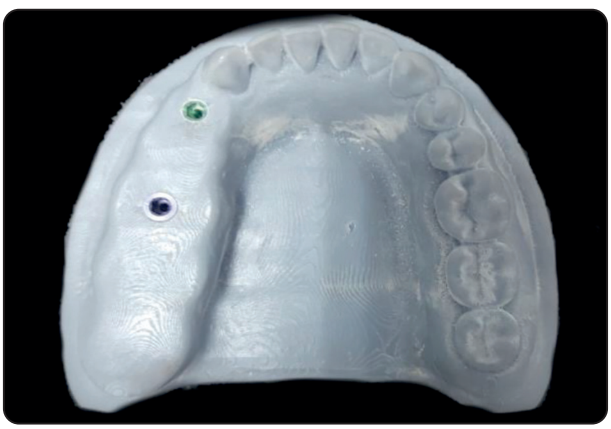

Fig. (4) Implant placement in the cast

Two scan bodies (*Implant Direct, USA)* were placed over each implant with the flat surfaces facing the buccal side for proper adaptation. They are manufactured from PEEK material with a titanium base interface. First one was 3.7 mm internal hexagonal connection for the first premolar area and the second one was 4.2 mm internal hexagonal connection for the first molar area. (Fig:5)

Fig. (5) Scan bodies installed over the implants.

Scanning Procedure:

Control Group (Desktop Lab Scanner):

The working cast was scanned using desktop lab scanner *(InEos X5 Sirona, 3Shape250, 3Shape*), to serve as the reference standard for the assessment of trueness and precision. The scan was saved as an STL file for comparison. (Fig:6)

Intervention Groups (Intraoral Scanners):

Three intraoral scanners (IOS) were evaluated in the study, the working cast was scanned five times with each IOS scanner to ensure reproducibility. The intraoral scanners used were: Group 1: 3Shape TRIOS 4

Group 2: Carestream CS3600.

Group 3: Medit i700

All scanning procedures were performed by the same experienced operator following a standardized scanning strategy, maintaining a consistent scanning distance of 10 mm to minimize operator-related variability.

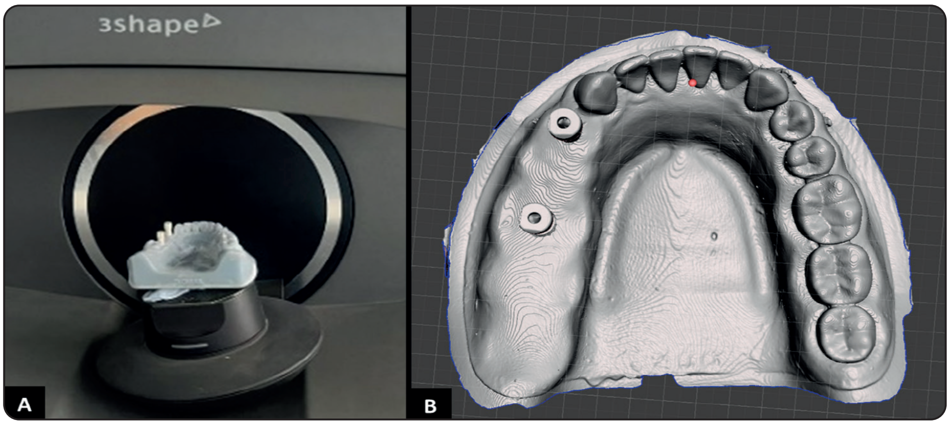

Fig. (6) (A) Scanning the cast using extraoral lab scanner, (B) The reference scan of the cast.

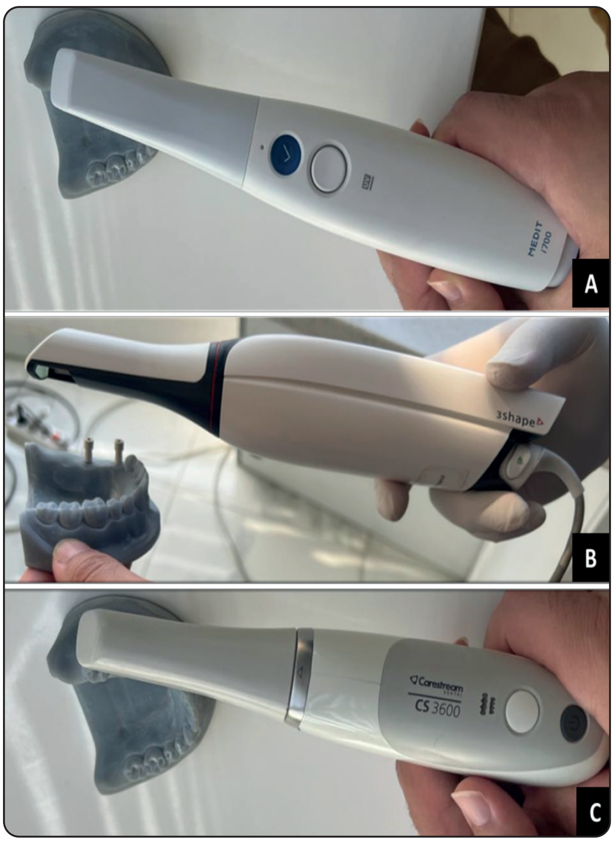

Fig. (7) (A) Medit i700 IOS, (B) TRIOS 4 IOS, (C) CS3600 IOS.

4) Accuracy Assessment:

The accuracy of the scans was evaluated using *Geomagic Control X*, an advanced metrology software for 3D inspection. The reference scan obtained from the desktop scanner was compared to the scans from the intraoral scanners. Each scan file is segmented into four parts. The first segment consists of the anterior scan body (comparative aspect), the second segment is the posterior scan body (comparative aspect), the third segment is the edentulous area (comparative aspect) and the fourth segment is the teeth, which were used for the superimposition procedure. (Fig:8)

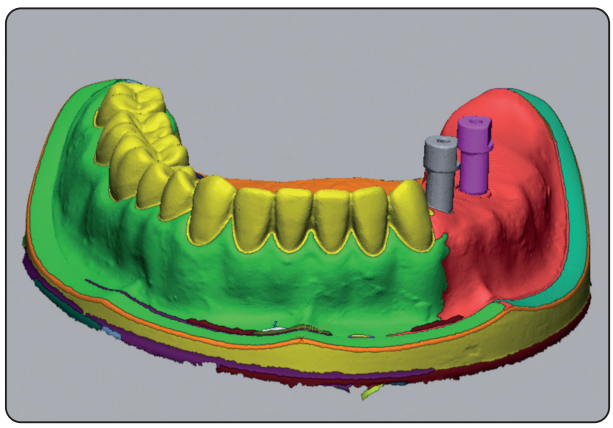

Fig. (8) Segmentation of the scan file of the working cast

Accuracy was assessed in terms of:

- **Trueness:** Defined as the closeness of a scan to the true dimensions of the object, measured by superimposing the scan data onto the reference scan and analysing deviations.
- **Precision:** The consistency and reproducibility of the scan data when repeated multiple times under the same conditions, measured by comparing scans within each group.

A color map was used to visualize deviations, with green representing no deviation, and red/blue indicating areas of positive/negative deviations, respectively.

5) Statistical Analysis:

Data were analysed using SPSS statistical software. Normality was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. One-way ANOVA followed by Tukey's Post Hoc test was used to compare trueness and precision across the three groups. Repetitive one-way ANOVA was employed to assess differences within the same scanner group for different anatomical areas (anterior scan body, posterior scan body, and mucosal part). Significance was set at $p < 0.05$.

RESULTS

Normality Tests:

The Shapiro-Wilk and Kolmogorov-Smirnov tests confirmed that the data for trueness and precision were normally distributed, with *P*-values > 0.05, allowing for parametric tests to be applied.

Trueness:

One Way ANOVA test followed by Tukey's Post Hoc test showed no significant differences in trueness among the three groups for anterior scan body, posterior scan body, and mucosal part (*P*-values: 0.14, 0.45, and 0.40 respectively). (Fig. 9) Mean (M) and standard deviation (SD) of RMS values in all groups were presented in table (1) and figure (8).

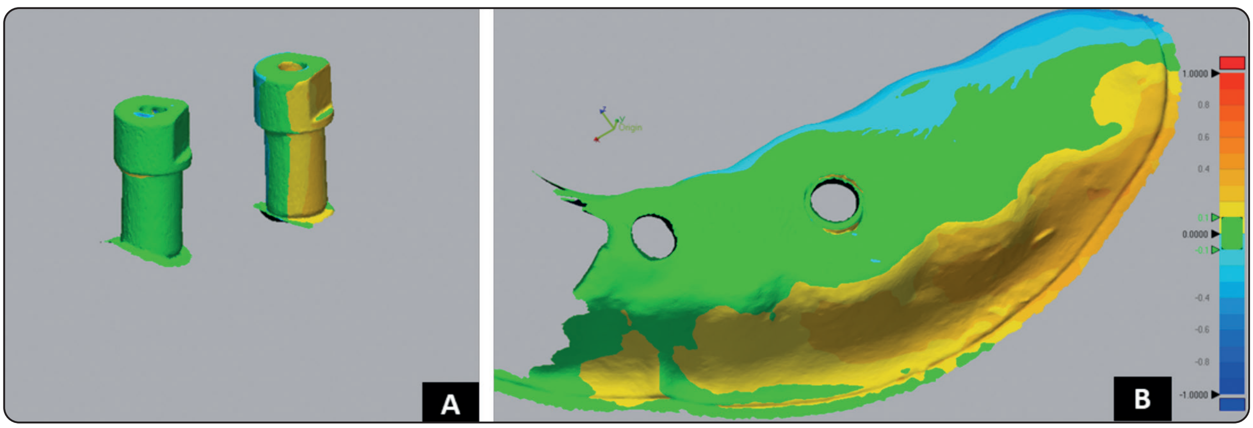

Fig. (9) Trueness of 2 scans superimposed on each other in (A) Anterior and posterior scan bodies, (B) Mucosal part.

TABLE (1) Comparison of Trueness in terms of mean and standard deviation of RMS values between different IOS groups for each scanned area using One Way ANOVA test.

The scanned area	Group 1 TRIOS 4	Group 2 CS3600	Group 3 Medit i700	P-value
	M ± SD	M ± SD	M ± SD	
Anterior Scan body	0.14 ± 0.06	0.08 ±0.02	0.08 ± 0.02	0.14
Posterior Scan body	0.16 ± 0.06	0.11 ± 0.05	0.12 ±0.04	0.45
Mucosal part	0.24 ± 0.11	0.26 ± 0.29	0.15 ± 0.07	0.40

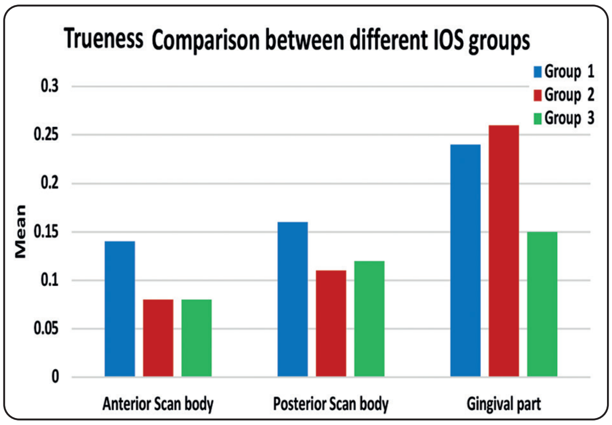

Fig. (8): Bar chart showing Comparison between trueness of different groups

Precision:

Significant differences in precision were observed between the three intraoral scanner groups:

- **Posterior Scan Body:** Group 1 (3Shape TRIOS 4) showed significantly higher precision compared to Group 2 (Carestream CS3600) ($P = 0.03$).
- **Mucosal Part:** Group 1 (3Shape TRIOS 4) again exhibited the highest precision (P=0.004), followed by Group 3 (Medit i700) and Group 2 (Carestream CS3600).
- **Anterior Scan Body:** No significant difference in precision was observed among the scanners for this area ($P = 0.09$).

Mean (M) and standard deviation (SD) of RMS values representing precision within all groups were presented in table (2) and figure (9).

TABLE (2) Comparison of precision in terms of mean and standard deviation of RMS values of each IOS for each scanned area using One Way ANOVA test.

The scanned area	Group 1 TRIOS 4	Group 2 CS3600	Group 3 Medit i700	P-value
	M ± SD	M ± SD	M ± SD	
Anterior Scan body	0.13 ± 0.05	0.16 ± 0.28	0.1 ± 0.02	0.09
Posterior Scan body	0.16 ± 0.04	0.11 ± 0.02	0.13 ± 0.05	0.03*
Mucosal part	0.27 ± 0.09	0.13 ± 0.05	0.18 ± 0.1	0.004*

**Significant difference as P<0.05.*

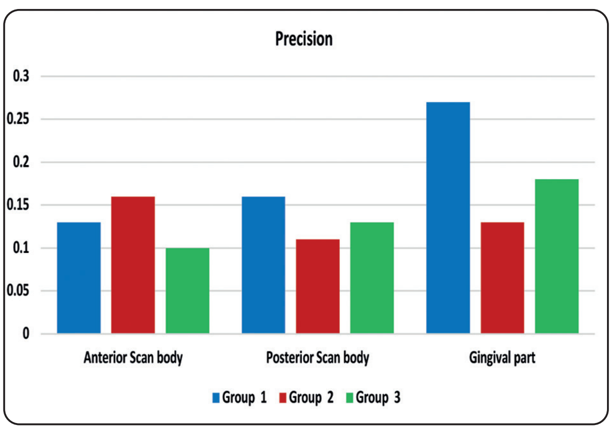

Fig. (9): Bar chart comparing the precision between the different IOS groups.

DISCUSSION

The current study assessed the accuracy of three intraoral scanners by comparing their trueness and precision to an extraoral desktop scanner. The study focused on a Kennedy Class II partially edentulous mandibular model with two implants.

Kennedy Class II cases, characterized by a free-end saddle, present unique challenges for accurate digital impressions. The lack of posterior support in these cases can lead to difficulties in stabilizing the scanning device, which may result in motion artifacts and inaccuracies. Additionally, the presence of both natural teeth and implant-supported restorations introduces varying surface textures and reflective properties that can complicate the scanning process. Ensuring accurate capture of these details is crucial for producing precise and reliable digital impressions. [5]

Using a desktop lab scanner as the reference standard provided a highly accurate benchmark for evaluating the accuracy of the intraoral scanners. The accuracy of each intraoral scanner was evaluated by overlaying the scans obtained from intraoral scanners and comparing them to those from an extraoral scanner, which some consider a gold standard in digital dentistry.[6] This method allows for assessing how closely the intraoral scans match a highly accurate reference scan. Therefore, incorporating the extraoral scanner in this study was essential to provide a baseline reference for superimposition and comparison. This approach helps to identify any deviations and assess the performance of the intraoral scanners comprehensively.[7],[8]

The findings of the current study revealed that there was no statistically significant difference in trueness among the three groups (TRIOS 4, CS3600 and Medit i700) in scanning the anterior scan body, posterior scan body, and mucosal part (P-values: 0.14, 0.45, and 0.40 respectively). This indicates that all three scanners provided similar levels of accuracy in replicating the true dimensions of the cast. These findings are consistent with prior research by Lee et al., which also demonstrated comparable trueness between intraoral scanners (Carestream CS3600 and Medit i500) in partially edentulous cases. [9]

On the other hand, precision, varied significantly across the scanners, particularly in the posterior scan body and mucosal regions. The TRIOS 4 scanner outperformed the Medit i700 and CS3600 scanners in these areas. This increased precision in complex anatomical regions could be attributed to the advanced imaging technology of TRIOS 4 and its ability to handle varying surface textures more effectively. [10]

Conversely, for the anterior scan body, no statistically significant difference was found among the intraoral scanner groups (P=0.09). This suggests that all three scanners performed similarly in terms of precision when capturing the anterior portion of the dental arch.

The primary reason for the increase in errors when addressing precision in Kennedy class II partially edentulous mandibular arches could be due to the image acquisition method of the intraoral scanners. These devices acquire scan data by stitching together images using a complex best-fit algorithm. To properly align the many images involved, it turns out to be advantageous for the scanned object to have a complex geometric shape. If the digitized item is too simple, an error may occur in the process of aligning the images. [11] Therefore, when scanning a relatively flat and smooth toothless region, errors in the alignment of scan data may be greater than when scanning an area having a much more complex shape, such as the occlusal surface of a tooth. [11] Perhaps, owing to these reasons, the deviations were more concentrated on the mucosal part and on the posterior scan body which is near to the edentulous areas and was non-significant in the anterior scan body which was close to the teeth.

Similar results were obtained in an in vitro study of repeatability of intraoral scanner for the partially edentulous models.[9] Additionally, an invitro study performed by Kim et al. reported that trueness and precision of intraoral scanner were improved using an artificial landmark in the long edentulous region. [12]

Moreover, the significant differences observed in the posterior scan body and mucosal part highlight that the precision of the scan results can vary according to the type of scanned area, irrespective of the type of intraoral scanner being used. However, potential strengths and weaknesses of each scanner model in specific anatomical regions should be considered. Clinicians may therefore prioritize the selection of an intraoral scanner based on its demonstrated precision in areas critical to the accuracy of digital impressions, such as the posterior scan body and mucosal edentulous areas.

Although these findings underscore the importance of considering precision as a critical factor when selecting an intraoral scanner for clinical use, it is essential to consider other factors such as trueness, ease of use, and overall clinical workflow integration when making informed decisions about intraoral scanner selection in dental practice. Future studies could explore these aspects further to enhance our understanding of intraoral scanner performance across various clinical applications and patient populations.

CONCLUSIONS

Within the limitations of this in vitro study, it can be concluded that all three intraoral scanners (TRIOS 4, CS3600 and Medit i700) demonstrated comparable trueness, indicating that they provide clinically acceptable accuracy for digital impressions. However, the 3Shape scanner showed superior precision, particularly in the posterior scan body and edentulous mucosal regions, making it a more suitable choice for cases that demand high precision. Clinicians should, therefore, consider both trueness and precision when selecting an intraoral scanner, especially paying attention to scanner performance in anatomically complex areas.

CONFLICTS OF INTEREST

The present study was self-funded, and the authors report no conflict of interest.

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