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Original Article

# Comparison of the Accuracy of Five Intraoral Scanners

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**Abstract**

**Introduction:** In recent years, the use of digital techniques such as computer-aided design and computer-aided manufacturing (CAD/CAM) has increased significantly in dentistry This study aimed to compare the accuracy (trueness and precision) of five intraoral scanners (IOSs).

**Methods:** A mandibular dental model with lower first molar teeth was scanned 12 times with several IOSs, including Medit i500, Medit i700, Carestream 3600, 3Shape 3SHAPE 3, and Einscan SE. In addition, the reference dataset was obtained using an Identica T500 laboratory scanner. Then, all intraoral scans were superimposed onto the reference model using EXOCAD software to assess trueness, while precision was determined by comparing the 12 repeated scans for each scanner.

**Results:** Significant differences in precision were observed only in the mesial region of the preparation ($P=0.004$). Pairwise comparisons revealed that the Carestream 3600 had significantly lower precision than the Medit i700 ($P=0.04$), Medit i500 ($P=0.03$), or 3Shape 3SHAPE 3 ($P=0.01$). Moreover, trueness significantly differed among scanners in the lingual ($P=0.02$), buccal ($P=0.02$), and mesial ($P<0.01$) regions. The Medit i700 displayed significantly lower trueness in the mesial area compared to the Carestream 3600 and Shining scanners ($P=0.021$ and $P=0.001$, respectively).

**Conclusion:** Among the tested scanners, the 3Shape 3SHAPE 3 demonstrated the highest precision, while the Einscan SE showed superior trueness across all evaluated regions.

**Keywords:** Intraoral scanners, Trueness, Precision, Accuracy, CAD/CAM, Fixed prosthodontics

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## Introduction

Digital technologies, such as computer-aided design and computer-aided manufacturing (CAD/CAM), have transformed restorative dentistry by enabling the fabrication of highly accurate and durable prostheses. CAD/CAM systems allow the use of advanced materials (e.g., alumina and zirconia ceramics), which cannot be processed through conventional casting techniques (1). Intraoral scanners (IOSs) represent a key innovation within CAD/CAM workflows, offering a digital alternative to traditional impression methods (2). Compared with conventional techniques, digital impressions reduce patient discomfort, eliminate the need for impression materials, and shorten clinical chair time (3).

The accuracy of IOSs is a critical factor in ensuring the clinical success of restorations, as errors in digital impressions can lead to ill-fitting prostheses. According to ISO Standard 5725, accuracy comprises trueness and precision, indicating the closeness of a measurement to the true value and the consistency among repeated measurements, respectively (4-6).

New IOSs annually enter the market, claiming improved speed and accuracy. Despite the rapid advancement of digital scanning technology, comparative data on the latest models remain limited. Previous studies have focused on the older generations of scanners, leaving a gap in the literature regarding the performance of newer devices, such as the Medit i700 and Einscan SE.

Therefore, this in vitro study aims to comprehensively evaluate and compare the trueness and precision of five IOSs, including Medit i500, Medit i700, Carestream 3600, 3Shape 3SHAPE 3, and Einscan SE, using a laboratory scanner as a reference. This comparison provides clinicians with updated evidence to guide the selection of IOSs for digital prosthodontic workflows.

## Methods

### *Study Model*

A complete dental model of a first molar tooth was designed using EXOCAD DentalCAD 3.2 Elefsina (EXOCAD GmbH, Germany) to simulate preparation for a full-ceramic restoration. The standardized preparation

parameters were tooth height after preparation of 5 mm, preparation depth of 1.5 mm, preparation taper of 6°, and occlusal clearance of 2 mm. This model served as the reference for all scanning procedures.

### *Study Design*

This in vitro study evaluated the accuracy of five IOSs: 3SHAPE 3 (3Shape), Einscan SE (Shining 3D), i700 (Medit), i500 (Medit), and CS 3600 (Carestream Dental). It should be noted that accuracy was assessed in terms of trueness and precision, following ISO 5725 guidelines.

Moreover, the tabletop scanner Identica T500 (Medit, Korea) was used as the reference for trueness assessment. A sample size of 12 scans per scanner was calculated using a 95% confidence level and a 5% margin of error. This sampling strategy is supported by previous research, demonstrating its adequacy for obtaining statistically significant outcomes (7).

The sample size (12 per group) was determined using the formula $n = (Z^2 \times \sigma^2) / d^2$, where $Z = 1.96$ (for 95% confidence), $\sigma = 0.04$ (estimated standard deviation from pilot data), and $d = 0.02$ (desired precision), ensuring adequate power for detecting inter-scanner differences.

All scans were performed by a single experienced operator trained in digital dentistry and proficient in using all scanners included in the study. To reduce operator fatigue and ensure measurement reliability, scanning was conducted in a randomized sequence with rest intervals. Additionally, the selection of the scanner for each scan was randomized to mitigate operator bias. Blinding was also applied during data analysis; the evaluator was unaware of which scanner produced each scan.

Operator calibration was verified by repeating five random scans per scanner and confirming that intra-operator variation did not exceed 5 µm, ensuring consistency.

Each scanner captured 12 digital impressions of the master model using a consistent scanning protocol. The scan data were then aligned and processed using EXOCAD software. In addition, a standardized cutting template was employed to segment each mesh before export. In total, 12 surface meshes were obtained and analyzed for each scanner.

### *Trueness Evaluation*

Trueness was determined by comparing the scan data to the original STL file of the digital model. First, the Identica T500 scans of the master model were aligned with the original STL using Exocad's fine alignment and best-fit algorithms. Subsequently, the 12 scans from each intraoral scanner were aligned and cut in the same manner.

Measurements were taken from four defined areas on the tooth surface: buccal surface, buccal cusp, mesial surface, and lingual surface (Figure 1).

For each scan, the deviation from the reference model was calculated, and the mean and standard deviations were recorded to evaluate trueness.

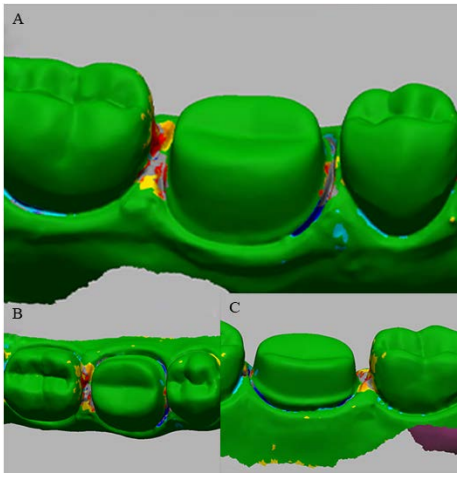


**Figure 1.** Evaluion in A:Buccal Area, B:Mesial,Distal and buccal cusp area, C:Lingual Area

### *Precision Evaluation*

Precision was assessed by superimposing the 12 repeated scans from each scanner. The closeness of these repeated scans to one another was used to estimate the scanner's precision.

In addition, a one-way analysis of variance (ANOVA) was conducted using SPSS (version 26; IBM Corporation, Armonk, NY, USA) to compare precision across scanners. All pairwise comparisons were performed using the Tukey's post hoc test with a significance level set at 0.05. Prior to ANOVA, the normality of data distribution was tested using the Shapiro–Wilk test, and homogeneity of variances was assessed using Bartlett's test. These tests ensured the statistical assumptions for ANOVA were met.

## Results

### *Precision*

The precision results for the five IOSs across four anatomical regions are summarized in Table 1. No statistically significant differences in scanner precision were found for the buccal, lingual, or buccal cusp regions ($P > 0.05$). However, the mesial region showed a statistically significant difference among scanners ($F = 5.07$, $P = 0.004$), indicating variability in measurement repeatability in this area.

Post hoc comparisons of scanner precision in the mesial region are presented in Table 2. The Carestream 3600 demonstrated significantly lower precision compared to the Medit i700, Medit i500, and 3Shape scanners.

### *Trueness*

The trueness of each scanner in different anatomical regions is provided in Table 3. Significant differences in trueness were observed in the lingual, buccal, and mesial areas ($P < 0.05$), while there was no significant difference in the buccal cusp region.

Figure 2 presents a visual summary of the trueness results, showing the mean values and 95% confidence intervals for each scanner. Key findings are as follows:

- In the mesial region, the Medit i700 exhibited significantly lower trueness than both the Carestream

**Table 1.** Mean Values and Comparison of Scanner Precision Across Anatomical Regions

| Area of Scan | Scanner | Mean ± SD (in mm) | *P*-Value |
|---|---|---|---|
| Lingual surface | Medit i700 | 0.14 ± 0.11 | F = 1.09 *P* = 0.382 |
| | Medit i500 | 0.10 ± 0.06 | |
| | Shining | 0.08 ± 0.05 | |
| | 3shape | 0.10 ± 0.04 | |
| | Carestream 3600 | 0.06 ± 0.04 | |
| Buccal surface | Medit i700 | 0.08 ± 0.06 | F = 1.08 *P* = 0.385 |
| | Medit i500 | 0.08 ± 0.05 | |
| | Shining | 0.05 ± 0.03 | |
| | 3shape | 0.04 ± 0.04 | |
| | Carestream 3600 | 0.09 ± 0.07 | |
| Buccal cusp | Medit i700 | 0.04 ± 0.04 | F = 0.72 *P* = 0.589 |
| | Medit i500 | 0.04 ± 0.02 | |
| | Shining | 0.02 ± 0.01 | |
| | 3shape | 0.04 ± 0.02 | |
| | Carestream 3600 | 0.04 ± 0.03 | |
| Mesial surface | Medit i700 | 0.07 ± 0.04 | F = 5.07 *P* = 0.004 |
| | Medit i500 | 0.08 ± 0.04 | |
| | Shining | 0.14 ± 0.02 | |
| | 3shape | 0.06 ± 0.05 | |
| | Carestream 3600 | 0.16 ± 0.07 | |

*Note*. SD: Standard deviation. *Statistically significant at $P < 0.05$

**Table 2.** Pairwise Comparisons of Scanner Precision in the Mesial Region (Tukey's Test)

| | Scanner | *P*-Value |
|---|---|---|
| Medit i700 | Medit i500 | >0.99 |
| | Shining | 0.159 |
| | 3shape | 0.992 |
| | Carestream 3600 | 0.034* |
| Medit i500 | Shining | 0.205 |
| | 3shape | 0.976 |
| | Carestream 3600 | 0.047* |
| Shining | 3shape | 0.066 |
| | Carestream 3600 | 0.943 |
| 3shape | Carestream 3600 | 0.012* |

*Note*. *Statistically significant at $P < 0.05$.

**Table 3.** Mean Values and Comparison of Scanner Trueness Across Anatomical Regions

| Area of Scan | Scanner | Mean ± SD (in mm) | *P*-Value |
|---|---|---|---|
| Lingual surface | Medit i700 | 0.14 ± 0.01 | F = 4.62 *P* = 0.023 |
| | Medit i500 | 0.09 ± 0.07 | |
| | Shining | 0.00 ± 0.00 | |
| | 3shape | 0.08 ± 0.06 | |
| | Carestream 3600 | 0.03 ± 0.02 | |
| Buccal surface | Medit i700 | 0.13 ± 0.01 | F = 4.51 *P* = 0.024 |
| | Medit i500 | 0.07 ± 0.05 | |
| | Shining | 0.01 ± 0.01 | |
| | 3shape | 0.09 ± 0.06 | |
| | Carestream 3600 | 0.05 ± 0.01 | |
| Buccal Cusp | Medit i700 | 0.05 ± 0.04 | F = 1.10 *P* = 0.407 |
| | Medit i500 | 0.03 ± 0.02 | |
| | Shining | 0.01 ± 0.00 | |
| | 3shape | 0.04 ± 0.03 | |
| | Carestream 3600 | 0.02 ± 0.02 | |
| Mesial surface | Medit i700 | 0.04 ± 0.03 | F = 9.43 *P* = 0.002 |
| | Medit i500 | 0.02 ± 0.02 | |
| | Shining | 0.01 ± 0.00 | |
| | 3shape | 0.02 ± 0.02 | |
| | Carestream 3600 | 0.09 ± 0.02 | |

*Note*. *Statistically significant at $P < 0.05$.

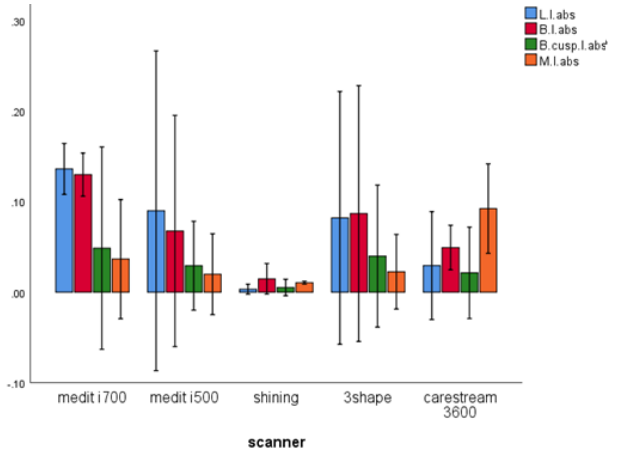


**Figure 2.** Comparison of Trueness Across Intraoral Scanners (Mean ± 95% CI). *Note*. CI: Confidence interval

3600 ($P = 0.021$) and Shining scanners ($P = 0.001$).

- In the buccal area, the Medit i700 displayed significantly lower trueness than the Carestream 3600 ($P = 0.003$) and Shining scanners ($P = 0.001$).
- The Carestream 3600 had significantly lower trueness than all other scanners in the mesial area ($P = 0.021$) and underperformed compared to Shining in the buccal region ($P = 0.044$).

## Discussion

IOSs provide multiple advantages for clinicians, patients, and laboratories by improving communication, reducing chairside time, and eliminating the need for physical impression materials. The clinical success of digital impressions largely depends on precision (repeatability) and trueness (closeness to the actual anatomy), as both directly affect restoration fit and longevity (8). Clinically acceptable marginal gaps range between 50 µm and 120 µm, with deviations above 200 µm considered unacceptable. For digital workflows, the trueness and precision thresholds of approximately 50 µm and 10 µm are generally recommended, respectively (9). Although digital impressions are increasingly adopted, concerns persist regarding their accuracy compared to conventional methods. Prior studies have shown that implant-supported restorations fabricated from traditional impressions can exhibit discrepancies up to 38 µm, depending on arch

span (10). However, digital workflows potentially reduce error by bypassing intermediate fabrication steps, thereby improving final prosthetic accuracy. Several studies have also demonstrated the superiority of digital impressions in fabricating fixed restorations for both natural teeth (11, 12) and partially edentulous cases(13,14).

In this study, significant differences were observed in scanner performance. The 3Shape TRIOS 3 scanner demonstrated the highest overall precision, particularly in the mesial and buccal regions. In contrast, the Carestream 3600 showed lower precision, especially in the mesial region. Regarding trueness, the Shining 3D illustrated the highest accuracy across most evaluated surfaces, while the Carestream 3600 displayed lower trueness values in the mesial and buccal areas. These results indicated that while 3Shape achieved superior consistency between repeated scans, the the Shining 3D produced scan data closest to the true reference dimensions.

Our precision findings for the 3Shape scanner align with those of Amornvit et al and Renne et al, demonstrating that 3Shape devices offer greater repeatability and scanning speed compared with competitors (7, 15). Similarly, Hack and Patzelt (16) concluded that 3Shape ranked the highest in a study of six IOSs for molar preparations. The poor mesial precision observed with Carestream 3600 in our study also conforms to the findings of Hack and Patzelt. However, Winkler and Gkantidis (17) found no significant differences in precision between 3Shape and Carestream scanners under clinical conditions, suggesting that laboratory and clinical outcomes may differ due to intraoral factors.

In terms of trueness, the present study identified the Einscan SE as the top performer, which is consistent with the results of Róth et al (18), emphasizing that newer-generation scanners tend to outperform earlier models. Our observation of lower trueness in Carestream 3600 also corroborates the findings of Hack and Patzelt (16) and Nagy et al (19), demonstrating inferior trueness compared to 3Shape and Medit scanners.

A consistent trend across studies, including the present one, is that scanning smaller areas yields higher accuracy. Winkler and Gkantidis (17) reported that single-tooth scans achieved greater precision than full-arch scans. The reduced trueness observed in the mesial region, particularly for Carestream and Medit i700, may be related to scanning angle limitations and access restrictions. Nagy et al (19) further noted that, in full-arch scanning, all IOSs produced less accurate results than indirect impression methods, though 3Shape consistently performed best among digital systems.

While this investigation was conducted under controlled laboratory conditions to isolate device-specific performance, clinical accuracy can be affected by environmental and operator-related factors, including saliva, limited access, patient movement, and user experience (20). Therefore, in vitro results should be interpreted as indicative rather than absolute representations of in vivo performance.

It should be noted that the present study evaluated a single tooth preparation under laboratory conditions, which may not perfectly replicate intraoral variables. Hence, future research should include clinical validation across different tooth types, arch spans, and operator skill levels in order to confirm the applicability of these findings.

## Conclusion

This in vitro study investigated the precision and trueness of five IOSs by analyzing four key regions on a prepared molar tooth. While scanner precision displayed no significant differences in most regions, a statistically significant difference was observed in the mesial area, with the 3Shape 3SHAPE 3 demonstrating the highest precision overall.

Regarding trueness, significant differences were found across the lingual, buccal, and mesial regions, with the Shining 3D scanner depicting superior trueness in most areas. The Carestream 3600 scanner consistently illustrated lower performance in both precision and trueness in critical areas.

These findings highlight that scanner performance can vary depending on the anatomical region and device brand, which has important clinical implications for selecting scanners based on the clinical case and scan area.

Accordingly, future studies should examine scanner accuracy in real-world clinical settings, accounting for operator variability, saliva, patient movement, and lighting conditions. Additionally, evaluating the long-term clinical outcomes of restorations fabricated from digital impressions can validate scanner selection in clinical practices.

### Authors' Contribution

Conceptualization: Siavash Bagheri Shirvan, Hamidreza Rajati Haghi, Davood Nodehi
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Formal analysis: Siavash Bagheri Shirvan
Funding acquisition:
Investigation: Siavash Bagheri Shirvan, Alireza Peighon, Davood Nodehi
Methodology: Siavash Bagheri Shirvan, Alireza Peighon, Hamidreza Rajati Haghi
Project administration: Hamidreza Rajati Haghi, Davood Nodehi
Resources: Hamidreza Rajati Haghi, Davood Nodehi
Software:
Supervision: Hamidreza Rajati Haghi, Davood Nodehi
Validation: Siavash Bagheri Shirvan, Alireza Peighon, Hamidreza Rajati Haghi, Davood Nodehi
Visualization: Siavash Bagheri Shirvan
Writing–original draft: Siavash Bagheri Shirvan
Writing–review & editing: Siavash Bagheri Shirvan, Alireza Peighon, Hamidreza Rajati Haghi, Davood Nodehi

### Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Ethical Approval

This in vitro experimental study used only one dental model while not involving human participants, animals, or identifiable biological

materials. Therefore, no ethical approval was required. However, the study followed institutional and international ethical guidelines for laboratory research integrity and data handling.

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