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# Evaluating the accuracy of intraoral scanners used in single-unit implant prosthesis construction

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## Abstract

**Aim:** This study aims to evaluate and compare the scanning accuracy of various intraoral scanners when taking digital impressions of single-implant-supported prostheses.

**Methodology:** A partially edentulous model with a single implant was produced, and a scan body was fixed on the model. The control model was created by scanning the model using Ineos X5 (CM). The model was also scanned (n = 3) using three different intraoral scanners (IOS) [(Helios (H), TRIOS 3 (T3), Medit (M)]. GOM Inspect software was used for comparison. The data were analyzed with a Shapiro-Wilk test, resulting in a nonnormal distribution, and Kruskal-Wallis test was employed for intergroup parameter comparisons.

**Results:** There were significant differences in the devices' accuracy values ($p < 0.05$). Accuracy [M (19.1 µm), T3 (25.3 µm), H (33.9 µm)] and sensitivity values [M (10 µm), T3 (19.05 µm), H (25 µm)] are similarly listed from high to low as M, T3, and H.

**Conclusion:** IOS can be used to create digital impressions for single-unit implant crowns. Clinicians should be cautious and selective when choosing IOS for more successful and accurate impressions. More comprehensive and clinical studies using different brands are needed on this subject.

**Keywords:** Intraoral scanner, digital impression, data accuracy, trueness, precision, dental implants

## Introduction

Digital workflow use is increasingly widespread in today's world and eliminates clinic-and laboratory-related shortcomings with traditional impressions using intraoral scanners (IOS). Implant-supported prosthesis measurements can be obtained using digital methods, followed by production using computer-aided design/computer-aided manufacturing (CAD/CAM) systems. Digital measurements can be taken either in the dental laboratory or directly in the oral cavity. To initiate the digital workflow with digital measurements in the laboratory, a traditional impression is taken from a patient's mouth and used to create a model. This model is then scanned by laboratory scanners and transferred to a digital environment. Another digital method involves intraoral scanners (with which digital measurements can be obtained from directly inside the mouth (1, 2).

Intraoral scanners acquire consecutive photos of the patient's dental arches using structured light and/or laser, enabling three-dimensional (3D) reconstruction of their surface using advanced reconstruction software. These software tools create triangulated point clouds, which are then used to build surface reconstructions (meshes) or virtual models of the patient's dental arches (3). IOS directly captures digital images of teeth and oral cavity tissues. They capture precise images using technologies such as optical and light scanning. In implant-supported prosthesis intraoral scans, the scan bodies are attached to the implants. These scan bodies are then scanned to obtain a digital model (3, 4).

The advantages of using IOS to obtain digital implant measurements include reducing processing times and costs. Additionally, from a clinical perspective, IOSs offer ease of use and patient comfort, especially for patients with strong gag reflexes, as their use removes the need to place impression materials in the patient's mouth. Digital measurements can be transferred directly to the laboratory technician without the risk of distortion. These features also enhance the process's efficiency (1, 5).

The accuracy of intraoral scanners during the fabrication of single-unit prostheses has been proven, leading to their widespread use in the production of implant-supported single crowns and bridges. The proliferation of IOS has resulted in the development of numerous intraoral scanner brands with various features and capabilities. This can pose a challenge for clinicians when selecting an appropriate scanner (6-9).

The scanners' mathematical quality is defined as "accuracy," which reflects the IOS's ability to capture a detailed and precise digital oral cavity model. Accuracy encompasses two fundamental aspects: "do trueness" and "precision" (10-12). Do trueness is the ability to match measurements with the actual surface. The scanner should create a digital impression that closely resembles the target area without significant deviations. To assess trueness, a control scan should be performed and digitally compared in space (13).

Trueness is a critical factor for IOS success; it is insufficient for a successful digital impression. High precision values must also accompany this concept. Precision is the IOS's ability to consistently generate similar or nearly identical measurements in the same measurement area in repeated scans. In other words, precision indicates the IOS's measurement consistency. No control measurement is required to assess precision; comparing the IOS's measurements among themselves is sufficient (12, 14).

Numerous studies in the literature compare the IOS's accuracy and precision for implant-supported prostheses (1, 2, 6, 7, 11, 13). However, no study has been found that evaluates the trueness and precision of different brands of IOS, specifically in posterior single-implant-supported digital measurements with a laboratory scanner as a reference. Our study assesses the trueness and precision of different brand IOS devices commonly encountered in clinical practice for digital measurements of posterior single-implant-supported prostheses.

The aim of this study was to evaluate and compare the scanning accuracy of various intraoral scanners when taking digital impressions of single-implant-supported prostheses. The null hypothesis was that no differences in trueness and precision would be found between the various scanners.

## Materials and Methods

This in vitro study assessed the accuracy of three different IOS (Trios 3, Medit i700, Helios) and a laboratory scanner (Ineos X5). The characteristics of the investigated scanners are presented in Table 1. The STL files were compared using GOM Inspect software (Carl Zeiss Industrielle Messtechnik, Graz, Austria).

**Table 1.** IOS systems compared in the study.

| Scanner model | Manufacturer | Technology of acquisition | Current version |
|---|---|---|---|
| Trios 3® | 3-Shape, Copenhagen, Denmark | Structured light | 3.2.1 |
| Helios 600 | Eighteeth, Changzhou, China | Structured light | 1.1.4.1 |
| Medit i700 | Medit, Seoul, South Korea | 3D-in-motion video technology | 1.3.2 |
| Ineos X5 | Dentsply Sirona, York, PA, USA | Optical Blue Structured Light | 4.2.5 |

A full-arch mandibular model (KaVo Basic Working Model; KaVo Dental GmbH, Bismarckring, Germany) was used as the reference model. Tooth 46 was removed from the model. Impressions were taken using polyvinyl siloxane (Affinis Putty Heavy Body; Coltène) impression material. Type IV dental hard plaster (GC Fujirock EP OptiXscan; GC Corp.) was used for the cast. A Dyna implant analog 4.2 mm (Dyna Dental, Bergen op Zoom, Hoorne, Netherlands) was placed with the help of a parallelometer (Paraflex, BEGO GmbH, Bremen, Germany), and the gaps between the extraction socket and the dental implant analogues were filled with the same plaster. The scan body was hand-tightened on the analog to proceed to the scan stage (Fig. 1).

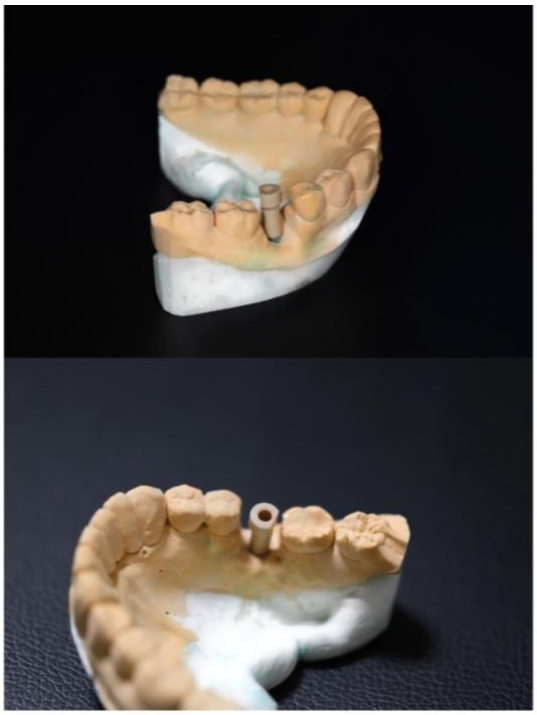

**Figure 1.** The model used in the study.

In the in vitro study, .stl files obtained from each intraoral and laboratory scanner were imported into GOM Inspect (Carl Zeiss Industrielle Messtechnik, Graz, Austria) for comparison. The .stl file from the laboratory scanner was imported using the "import" and "CAD body" commands. The model scanned using the intraoral scanner was imported using the "import" and "mesh" commands. Initially, three points were selected for alignment, and the models were superimposed. Subsequently, a best-fit alignment process was performed using the scan body as a reference. The results obtained from the best-fit alignment were saved. It's important to note that GOM Inspect is a software used for aligning and comparing scanned models, ensuring precision and accuracy in the study. In this in vitro study, strict protocols were followed to maintain consistency and reliability, including environmental conditions (temperature, humidity, air pressure), the expertise of the dentist performing the scans, and visual inspections to confirm scan quality and coverage.

The limit values for the study were determined based on Specification No. 19, as published by the American Dental Association, which provides guidelines on the properties of elastomeric impressions (16). This meticulous approach ensures the validity and comparability of the results obtained from different scanner systems, ultimately contributing to the reliability of the study's findings. Standard Deviation values were examined.

## Statistical analysis

For statistical analyses, the relevant data were tested using IBM SPSS V24 software (IBM Corp., Armonk, NY, USA).

The normal distribution assumption was assessed using the Shapiro-Wilk test and the parameters did not follow a normal distribution. The Kruskal-Wallis test was employed for intergroup parameter comparisons. The analysis results for quantitative data were presented as mean ± standard deviation and median (minimum-maximum). A $p < 0.05$ level was considered statistically significant.

# Results

The devices' accuracy values are presented in Table 2 and Figure 2, while their sensitivity values are displayed in Table 3 and Figure 3. Statistically, numerical values close to zero indicate that a device exhibits high accuracy and sensitivity.

The Kruskal-Wallis test was used to compare the trueness values that did not follow a normal distribution among the groups. The trueness values among the devices were statistically significantly different ($p = 0.027$; Table 1).

**Table 2.** Trueness examination by device.

| | Trueness (µm) | |
|---|---|---|
| | Mean + SD | Med. (Min.-Max) |
| Helios | 35.73 ± 7.91 | 33.9 (28.9-44.4) |
| Medit | 20.07 ± 1.94 | 19.1 (18.8-22.3) |
| Trios | 25.37 ± 2.6 | 25.3 (22.8-28.0) |
| p | 0.027 | |

**Table 3.** Precision examination by device.

| | Precision (µm) | |
|---|---|---|
| | Mean + SD | Med. (Min.-Max.) |
| Helios | 25 ± 2.52 | 25 (22.5-29.2) |
| Medit | 11.48 ± 2.28 | 10.6 (9.2-15.3) |
| Trios | 20.53 ± 4.10 | 19.05 (16.3-26.6) |
| p | 0.002 | |

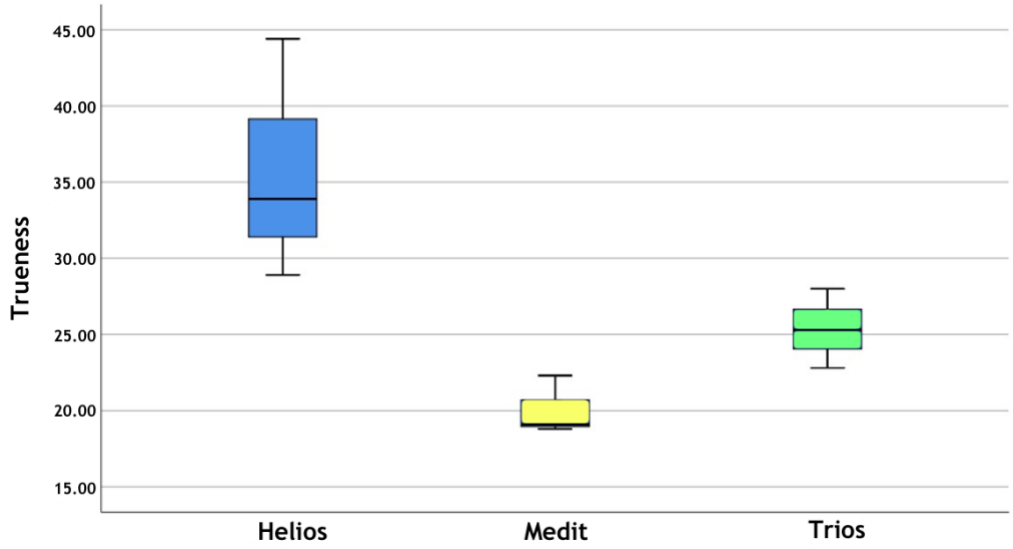


Figure 2. Trueness values by device.

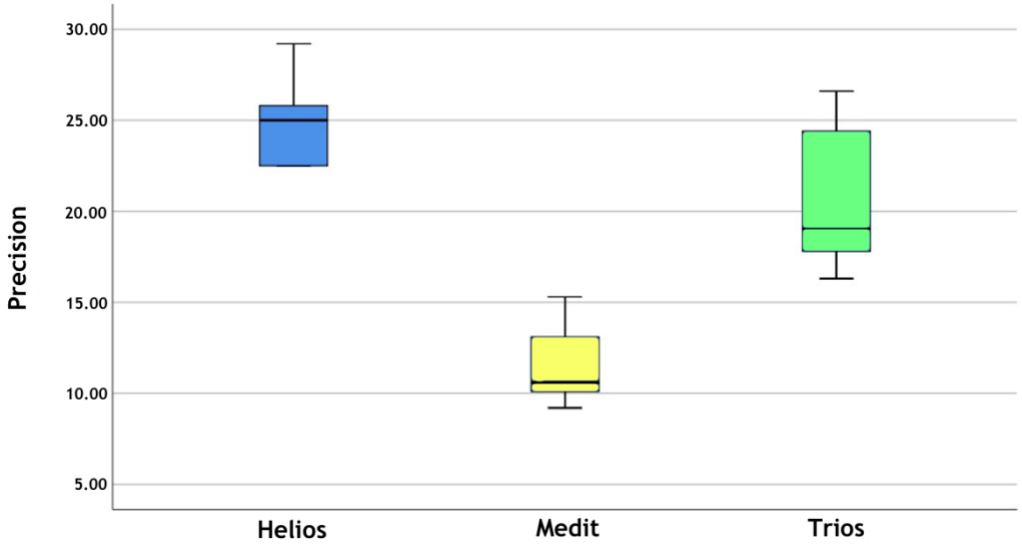


Figure 3. Precision values by device.

## Discussion

In this study, T3, M, and H devices performed scans for single posterior implant restorations, and their trueness and precision were compared. Our null hypothesis was rejected, and differences in trueness and precision were observed among the devices. Trueness values for M (19.1 µm), T3 (25.3 µm), and H (33.9 µm), as well as precision values for M (10 µm), T3 (19.05 µm), and H (25 µm) followed a similar trend, with M showing the highest values and H showing the lowest.

In previous studies, Roig et al. compared intraoral scanners to elastomeric impressions and reported that intraoral scanners provided more accurate results when measurements were taken from two neighboring implants (17). Zimmermann et al. evaluated the accuracy and precision of the M and T3 intraoral scanners for single-crown and inlay preparations (6). The accuracy and precision values for both restorations were similar. Çakmak et al. (1) compared the Primescan, Omnicam, Virtiovivo, and T3 intraoral scanners using combined healing abutment-scan bodies for single-implant scans. They reported no significant differences in the IOS

devices' accuracy. Yilmaz et al. assessed partial and full arch scans for anterior single-implant restorations using T3 scans and a laboratory scanner (Ceramill Map 600) as a reference (8). They observed no significant differences in accuracy and precision values among operators. In contrast, Mangano et al. compared five different scanners, including the T3, for single- and multiple-implant restorations and concluded that the scanners had accuracy and precision differences. Additionally, mathematical errors increased when transitioning from single-unit to multi-unit prostheses (2).

Nulty et al. compared the accuracy and precision of nine intraoral and laboratory scanners, including the T3 and Ineos X5, for full arch scans. They reported that the intraoral scanners they compared were successful in full arch scans, and none achieved accuracy comparable to the Ineos X5 (18). In our study, similar to Nulty's study, we used the Ineos X5 laboratory scanner as a reference model.

While numerous studies compare the accuracy and precision of intraoral and laboratory scanners for fully edentulous cases (10, 19-21), few studies compare single-implant-supported restorations. According to the research, discrepancies >30 µm are acceptable, while those greater than <150 µm are the limit to avoid long-term complications (2). In studies where the Trios 3 and M i500 were compared for accuracy and precision, the Trios3 reportedly provided better accuracy and precision results (19, 20). Kaya et al. found that the T3 (40.3 µm) had higher accuracy values than the M i500 (89.8 µm) (19). Revell et al. analyzed the accuracy of the M i500 and T3, among other IOS systems, in a five-implant human cadaver maxilla (20). They reported that the T3 (40 µm) showed higher accuracy than the M i500 (57 µm). However, due to study method differences, it is impossible to numerically compare deviations (19). Our study showed that the T3 had lower trueness (25.3 µm) and precision (19.05 µm) values than the M i700's trueness (19.01 µm) and precision (10 µm) values. This difference is attributable to the fact that the mentioned studies evaluated the i500 M scanner model, while our study used the newer i700 model. Furthermore, the studies mentioned were conducted in fully edentulous cases with numerous implants, whereas our study used a single implant-supported model. No study in the literature specifically evaluates the M i700's accuracy or compares the H scanner with other machines; therefore, we could not make direct comparisons in this regard.

This study's limitations include the absence of a reference measurement—the Ineos X5 scanner's accuracy was not evaluated—and the assumption that the Ineos X5 scans were accurate. During image alignment, the use of nested alignment and surface comparisons rather than same-point comparisons may have introduced distortions in the results. All scans were performed in a laboratory environment if it mimicked the oral environment. Therefore, factors such as the patient's tongue, saliva, and mouth opening, which could affect the scan results, were absent. In the presence of these conditions, we cannot predict how the accuracy results of the intraoral scanners used in our study would be affected.

## Conclusion

We observed significant accuracy and precision differences among the compared devices. The M i700 scanner had the highest accuracy values. However, further in vitro and in vivo studies evaluating a wider range of devices are required to support these findings. It is advisable for clinicians to exercise caution in choosing appropriate devices when taking intraoral digital measurements.

## Disclosures

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Conception – E.G.S.; Design – E.G.S., B.K.E.; Supervision – B.K.E.; Materials – E.G.S., B.K.E.; Data Collection and/or Processing – E.G.S., B.K.E.; Analysis and/or Interpretation – B.K.E.; Literature Review – E.G.S., B.K.E.; Writer – E.G.S., B.K.E.; Critical Review – E.G.S., B.K.E.

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