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# Accuracy of Two Digital Scanners (Intraoral, Extraoral) Compared to Conventional Impression Using Implant with Different Angulations (Zero, 15°, 25°) "In-Vitro Study"

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## ABSTRACT

***Background:*** Achieving passive fit for implant-supported restorations on multiple abutments with varied implant angulations is challenging with conventional impressions due to distortion. Digital scanning offers the potential for greater accuracy in such cases. ***Aim of the study:*** To evaluate intraoral and extraoral scanners' accuracy compared to conventional impressions across different implant angulations (0°, 15°, 25°). ***Materials and Methods:*** Three epoxy models with implants at various angles were scanned by InEos X5 for reference. Conventional PVS impressions (n=15), scanning with intraoral Primescan (n=15), and extraoral Trios 3shape (n=15) were tested. Impressions were converted to STL format and analyzed for trueness and precision using digital control surface matching software GeoMagic Control X. Statistical analysis was conducted using two-way ANOVA. ***Results:*** Significant statistical differences were found among the groups, with the Trios desktop scanner exhibiting the best trueness and precision ($p<0.001$), followed by Primescan IOS and PVS impressions. Implant angulation significantly influenced trueness ($p<0.001$), with higher deviations at 25°, followed by 15° and 0°, except for Primescan IOS, where no statistically significant difference was found between 15° and 0° angulations. ***Conclusion:*** parallel implants have the best accuracy in terms of trueness and precision. The use of desktop scanners offers the highest accuracy regardless of the implant angulations.

***Keywords:*** accuracy, angulated implant, digital impressions, scanners, conventional impressions.

## INTRODUCTION

In the era of increasing technology in dentistry, dental implants have shown a high success rate due to better knowledge about the nature of Osseo-integration and the accuracy of the techniques used nowadays.[1] Implants have become the most favorable treatment option in restoring a missing single tooth concerning function and esthetics. Best results are achieved depending on many factors such as the condition of soft tissue and alveolar ridge, the teeth adjacent to the missing site, precise planning for implant position and angulation, and proper final prosthesis.[2,3]

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In an ideal situation, the implant is to be inserted parallel to the teeth adjacent to it. However, the morphology of the alveolar ridge or the presence of vital structures may not allow for achieving this parallelism. There are different treatment options to resolve this situation. Ridge augmentation for the planned site, inserting an implant in a different site, or inserting an implant with different angulation.[1,4]

There are many advantages to inserting implants with different angulations. First, inserting an implant with larger dimensions in height and width. Second, its versatility allows more patients to be treated since it has fewer restrictions than parallel implants. Third, it aids in overcoming complex procedures such as guided bone regeneration.[5,6] Although distortion of the impression, due to lack of parallelism may occur, leading to an inaccurate model and an ill-fitting final restoration, and since the restoration will not fit passively over the implant, more stresses fall on the implant and restoration.[7]

For many decades, the gold standard has been the conventional impression. Nevertheless, conventional impressions have many drawbacks. The materials need many preparations in the patient's mouth, which may lead to patient discomfort and increase time and cost of the procedure. There is an unavoidable degree of distortion to the impression material while recording undercuts of teeth and surrounding structures. Moreover, impression distortion may occur during storage or casting, causing inaccurate final results.[8]

The emergence of digital dentistry facilitated the fabrication of dental prosthesis through computer-aided designing and computer-aided manufacturing (CAD/CAM) technology. Digital impressions have a significant impact on many steps during the fabrication of crowns on implants.[9–11] Dentists have omitted many chairside and laboratory steps, which has led to the fabrication of final restoration in less time and at a reduced cost. Digital scanning has improved operator communication with the patient and the lab through a virtual 3D model. These models also simplified the prosthetic designing.[12,13]

The accuracy of the digital impressions is assessed by trueness and precision of the digital scanners. According to the ISO international standard 5725, trueness is the ability of a measurement or a measuring device to match the actual value of the quantity being measured. Precision is the ability of a measurement or a measuring device to consistently repeat a particular measurement.[14–16] Although many studies[17–20] have been conducted for the accuracy (trueness and precision) of digital impressions, there is minimal evidence regarding the accuracy of the prosthesis over implants, especially angled ones.

This study aims to evaluate the accuracy (trueness and precision) of two scanning techniques (intraoral and extra-oral) compared to conventional impression techniques using different implant angles (zero°, 15°, 25°). The null hypotheses of this study are a) there will be no significant differences in the trueness of conventional (PVS) and digital (intraoral and extraoral) impression techniques at different implant angulations (zero, 15, 25). b) There will be no significant differences in the precision of conventional (PVS) and digital (intraoral and extraoral) impression techniques at different implant angulations (zero, 15, 25). And finally, c) there will be no difference in accuracy (trueness, precision) between different implant angulations (zero°, 15°, 25°).

## MATERIALS AND METHODS

### Sample size calculation:

This power analysis used trueness deviations as the primary outcome. The effect size ($f = 0.938$) was calculated based on the results of Malik J et al. (2018).[21] Using alpha ($\alpha$) level of (5%) and Beta ($\beta$) level of (20%) i.e. power = 80%; the minimum estimated sample size was 5 specimens per group, giving a total of 15 specimens. Sample size calculation was performed using G*Power Version 3.1.9.2.

A modified typodont was duplicated into three epoxy models to receive two implants in each one; each model received the implants in different angulations (0°,15°,25°). The implants were inserted in the canine and first molar regions to replace the missing canine, premolars, and first molar. Then, the models were scanned by InEos X5 to obtain reference scans to which the accuracy of different impression techniques was compared. The tested groups include conventional PVS impressions, digital impressions using intraoral Primescan, and extraoral Trios 3shape.

### Sample grouping:

Three epoxy models were divided according to the angulation of implants used in this study. **Group 0**: implants with angle zero°, **Group 15:** Implants with angle 15°, and **Group 25:** Implants with angle 25°.

Each group was further subdivided into three equal subgroups according to the type of impression technique, where five impressions were taken by each technique for every implant angle (n=5). **Subgroup C:**

Conventional PVS, **Subgroup I:** Intraoral scanner (CEREC Primescan), and **Subgroup E:** Extraoral scanner (Trios 3shape).

**Model preparation:**

The process involved duplicating three epoxy models from a modified typodont model. The typodont model was modified by removing the upper right canine, first premolar, second premolar, and first molar and filling the gaps with base plate wax. A silicon mold was created from this modified model to capture all details. The silicon mold was then used to create a negative impression; then epoxy resin was poured and left to set for 24 hours. After setting, the epoxy models were inspected for imperfections and trimmed as needed to prepare for implant drilling. **(Figure 1)**

**Figure (1):** modified typodont model and duplicated epoxy casts.

**Implant insertion:**

Each epoxy model received two implants, one in the location of the upper right canine and one in the upper right first molar. The model was oriented on the Parallelometer platform with the occlusal surface facing upwards and the labial aspect of anterior teeth facing the operator to drill the 0° implants. Then, the base was tilted towards the edentulous span side at angles 15° and 25° to drill both, respectively.

The epoxy model was secured to the base of a Parallelometer using screws; the handpiece was attached to the vertical arm of the Parallelometer. The angle was adjusted on the Parallelometer away from the midline to position the implant drills at the desired angle (0°, 15°, 25°). Sequential drilling was conducted according to manufacturer instructions, starting with a pilot drill and followed by three additional drills until reaching the desired size. After preparing the implant sites, a torque ratchet was used to insert the dental implants into the epoxy cast, ensuring they were threaded securely to the crestal level.

**Obtaining reference dataset (REF):**

To reduce reflections on transparent epoxy models, a scan spray (Cerec Optispray) was applied according to manufacturer instructions at varying angles to ensure full coverage. Each surface was sprayed once to avoid excessive thickness. This process was repeated before scanning with each scanner (inEos X5, Primescan, and 3shape). Scan bodies were attached to the implants; then the scanner was calibrated following manufacturer instructions using the inLab software. The models were secured to a model holding plate on a rotating disk, and automatic scanning mode was chosen for accuracy. InEos X5 reference scanner was used to scan the models and obtain a reference STL file.

**Impression and data acquisition:**

**Conventional PVS:**

Two impression copings were attached to implants using a screwdriver, and a metal stock tray was cut open to allow room for the copings. Elite HD+ putty soft and light body silicone impression material was used in a one-step-two-viscosity approach. Putty and light body materials were mixed and loaded into the tray. Light body material was injected around the copings and over the arch before seating the tray over the epoxy cast. After setting (6 minutes), screws were removed from the copings, and the tray was carefully removed and inspected for defects. Implant analogues were attached to the copings, and base plate wax was used as a gingival mask before casting. This process was repeated five times for each implant angulation (0°,15°,25°), resulting in a total of 15 impressions. The 15 impressions were then poured with type IV extra hard stone (Elite Rock). The 15 models were scanned using inEos X5 reference scanner to obtain STL files. **(Figure 2)**

**Intraoral scanner (Primescan):**

For digital acquisition, the intraoral scanner, Cerec Primescan was used, with

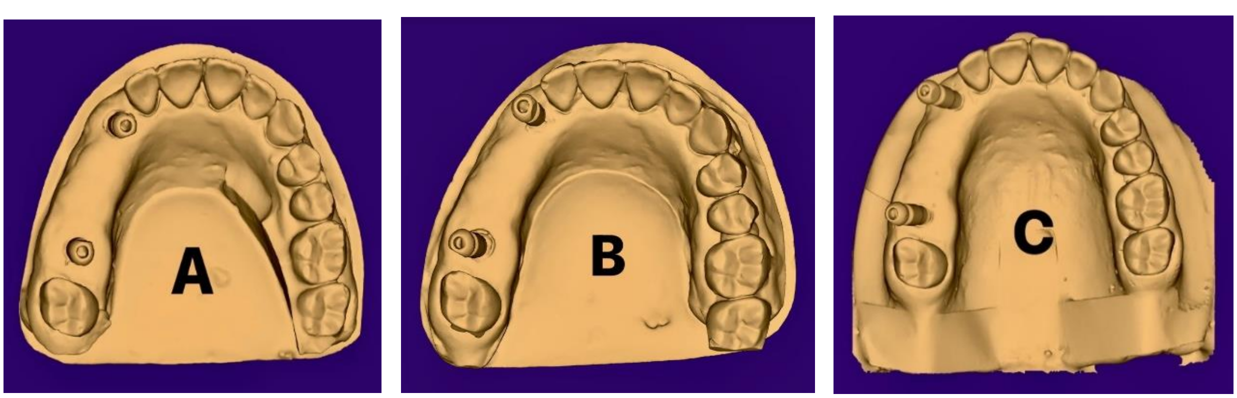


**Figure (2):** Digitized stone model with **A):** angle 0, **B):** angle, 15, **C):** angle 25.

Cerec software version 5.0.0. The scanning process involved three phases: administrative, acquisition, and model phases. Sequential scanning was carried out starting from the occlusal surface of the upper left second molar, progressed towards the incisal surface of the anterior teeth, extended to the right second molar, and then the camera (automatically positioned at a 60° angle) was rotated. This rotation covered the palatal and interproximal regions, and another rotation recorded the buccal surface of the arch, following the sequence of occlusal, palatal, and then buccal.

During scanning, the camera was positioned according to manufacturer instructions, capturing various surfaces of the epoxy models. The scanning time averaged 2.5 minutes per scan. After completion, STL files were exported and saved. This procedure was repeated five times with the same trained operator for each of the three groups (angle 0°, angle 15°, and angle 25°), resulting in 15 STL files in total, as presented in **figure (3)**.

**Extraoral scanning (3 shape trios):**

For the second digital acquisition, a 3Shape extraoral scanner with Exocad scan software was employed. Before scanning, the scanner was calibrated according to the manufacturer's recommendation. The epoxy models were then secured in the scanner's model holding plate, and information about the models was entered into the software. The scanning process began automatically after activating the start button, and once complete, the scan model was rendered. Finally, the scans were exported as STL files. This process was repeated five times for each of the three groups (angle 0, angle 15, and angle 25), resulting in 15 STL files in total. **(Figure 4)**

**Accuracy assessment:**

Accuracy measurement focuses on trueness and precision. Trueness is assessed using reverse engineering software to align reference and measurement data, segment, and merge areas of interest for precise comparison, and calculate Root Mean Value (RMS) for deviation. Precision measurement

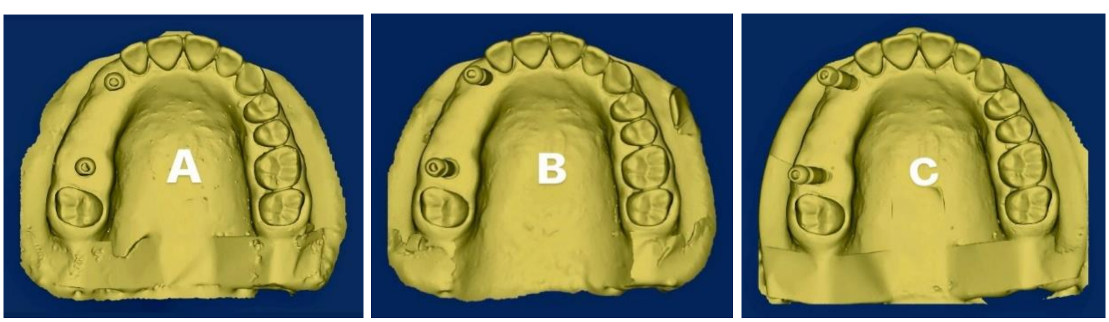


**Figure (3):** Extraoral trios 3shape scan with **A):** angle 0, **B):** angle, 15, **C):** angle 25.

involves multiple scans within each group, with each scan serving as a reference to assess the precision of the others. Both trueness and precision involve aligning data, comparing scans, and generating reports.

$$RMS = \sqrt{\frac{\sum_{m=1}^{n}\left(X_{1,m} - X_{2,m}\right)^2}{n}}$$

Where n is the sum of points measured, X1, m is the measurement of the reference model and X2, m is the measurement of the tested model.

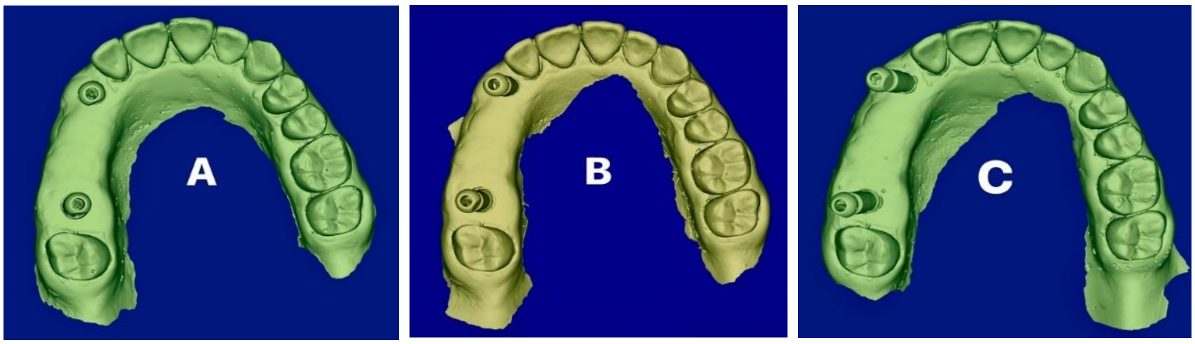

**Figure (4):** Intraoral prime scan with **A):** angle 0, **B):** angle, 15, **C):** angle 25.

**Trueness:**

The reference scanner STL file of each group was superimposed on each STL file of the five obtained from every subgroup.

The reference (InEos X5 files) and measurement (impression technique files) data were imported to the geomagic window and trimmed to remove any data that was not related to the desired scan. Two alignment features are available when using the Geomagic Software (initial and best-fit alignment). A 3D comparison was then performed. The distances between all corresponding points were calculated by using the RMS formula, where the mean distance between corresponding points was calculated, corresponding to the mean value of errors, by using the following formula:

A high computed RMS value denotes a significant error, while a low RMS value denotes a small error or deviation. A colored heat map was drawn with a maximum deviation range of 0.5 mm and a -0.5 mm minimum deviation with no specific tolerance. The green color region meant a perfectly matching surface, the red color region (positive error) indicated that the test model was located above the reference model (model expansion), and the blue color region (negative error) meant that the model was located below the reference model; (model shrinkage). (**Figure 5)**

**Precision**

For the precision measurement, the calculation was done inside each group,

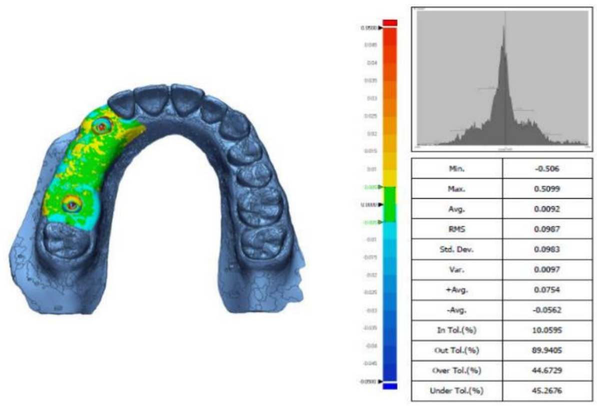


**Figure (5):** The 3D comparison of implants represented with a color difference map and RMS report.

where each scan in every subgroup was considered as the reference model and the 4 other scans were superimposed on it to produce a total of 10 reports in every subgroup, 30 reports in every group and 90 reports in total. Precision was measured in the same way trueness was calculated from data alignment to report generation.

## RESULTS

### Trueness:

Intergroup comparisons, mean and standard deviation values of trueness (RMS) (µm) for different acquisition techniques showed statistically significant difference between various groups. The highest deviation was reported with conventional impression, while the lowest deviation was reported with Trios 3 shape, as shown in.

On the other hand, intergroup comparisons, mean and standard deviation values of trueness (RMS) (µm) for different implant angulations showed statistically significant difference between various groups. The highest deviation was reported with 25°, while the lowest deviation was reported with 0°, except for Primescan IOS, where 15° and 0° showed no statistically significant difference, as shown in **Table (1)** and **Figure (6)**.

**Table (1):** Intergroup comparisons, mean and standard deviation (±SD) values of trueness (RMS) (µm) for different acquisition techniques.

| Angle | Trueness (RMS) (µm) (Mean±SD) | | | p-value |
|---|---|---|---|---|
| | 3Shape | Primescan | Conventional | |
| **0º** | 53.13±2.68$^{C}$ | 133.58±27.29$^{B}$ | 312.04±18.14$^{A}$ | **<0.001*** |
| **15º** | 68.30±1.46$^{C}$ | 153.80±30.72$^{B}$ | 349.74±9.12$^{A}$ | **<0.001*** |
| **25º** | 89.78±8.96$^{B}$ | 390.70±78.91$^{A}$ | 365.66±66.11$^{A}$ | **<0.001*** |

*Values with different superscript letters within the same horizontal row are significantly different.*
**; significant (p≤ 0.05). RMS; Root Mean Square. µm; Micrometer SD; Standard Deviation.*

### Precision:

Intergroup comparisons, mean and standard deviation values of precision (RMS) (µm) for different acquisition techniques showed statistically significant difference between various groups. The highest deviation was reported with conventional impression, while the lowest deviation was reported with Trios 3 shape.

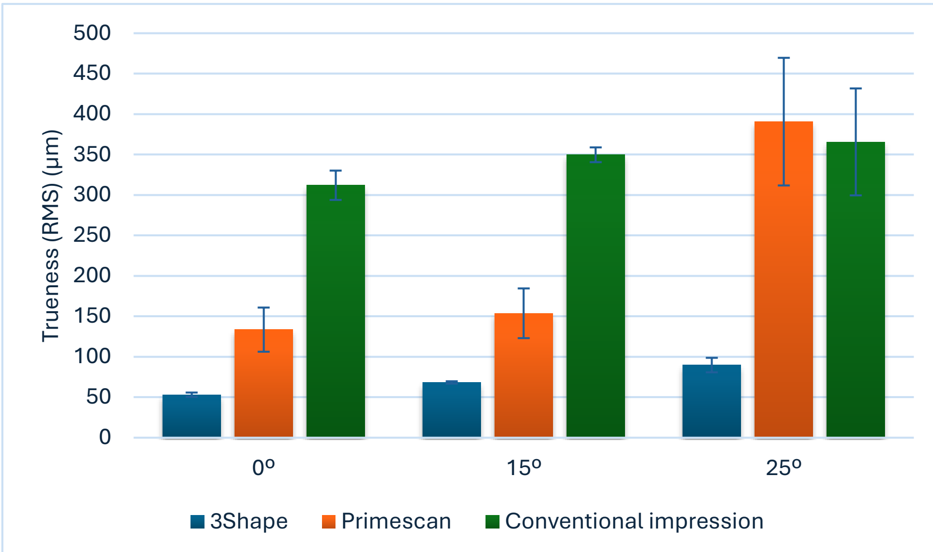


**Figure (6):** Bar chart showing mean and standard deviation values of trueness (RMS) (µm) for different acquisition techniques.

On the other hand, intergroup comparisons, mean and standard deviation values of precision (RMS) (µm) for different implant angulations showed statistically significant difference between various groups. The highest deviation was reported with 25°, while the lowest deviation was reported at 0°, except for Primescan IOS and Trios 3 shape desktop scanner, the implant

angulation of 15° and zero° showed no statistically significant difference, as shown in **Table (2)** and **Figure (7)**.

**DISCUSSION**

The advancement of prosthetic dentistry, particularly with implant-supported restorations, relies heavily on accurately capturing three-dimensional relationships among implants, teeth, and surrounding oral tissues. Achieving precise impressions is crucial for creating restorations that fit passively and reflect clinical conditions accurately. Various factors affect impression accuracy, including different techniques and implant angles.[22–25]

Traditional physical impressions, while effective, have drawbacks such as time consumption and distortion susceptibility. Digital impressions offer potential advantages in accuracy and patient comfort. Studies suggest digital scanners can effectively capture implants at various angles, but challenges arise with severe angles, potentially impacting restoration accuracy. To address these concerns, this study aims to evaluate the accuracy of conventional and digital scanning techniques on implants with different angulations.[26–28]

scanner accuracy with a setup resembling an in vivo environment.[29,30]

Implant-level impressions were

**Table (2):** Intergroup comparisons, mean and standard deviation (±SD) values of precision (RMS) (µm) for different angles.

| Technique | Precision (RMS) (µm) (Mean±SD) | | | p-value |
|---|---|---|---|---|
| | 0º | 15º | 25º | |
| **3Shape** | $15.56\pm1.75^{B}$ | $17.48\pm3.97^{B}$ | $23.53\pm4.97^{A}$ | **<0.001*** |
| **Primescan** | $120.24\pm29.78^{B}$ | $132.65\pm20.36^{B}$ | $271.71\pm51.94^{A}$ | **<0.001*** |
| **Conven.** | $340.36\pm26.30^{B}$ | $383.43\pm73.51^{AB}$ | $426.06\pm90.67^{A}$ | **0.034*** |

*Values with different superscript letters within the same horizontal row are significantly different.*
**; significant (p≤ 0.05). RMS; Root Mean Square. µm; Micrometer SD; Standard Deviation.*

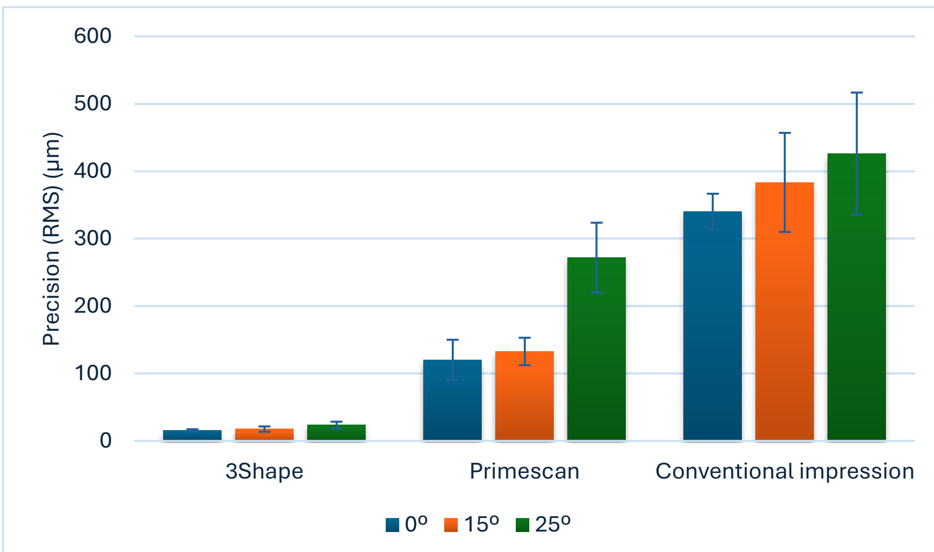


**Figure (7):** Bar chart showing mean and standard deviation values of precision (RMS) (µm) for different angles.

The study was conducted in vitro to standardize the experimental setting, as achieving such standardization in vivo can be challenging due to the complex intraoral environment. Assessing trueness parameter in vivo lacks a reference master geometry thus in vitro studies offer insights into digital

conducted to exploit their advantages, and a direct pick-up open tray technique was chosen for its accuracy with multiple implants[8]. A polyvinyl siloxane (PVS) impression material was selected for its accuracy and stability, using a one-step technique adhering to ADA specifications.[31]

Elite Rock extra hard type IV dental stone was chosen for its precision in impression pouring.[32]

To enhance accuracy, digital impressions were performed using Cerec Primescan with scan bodies and powder coating.[33] Reverse engineering software was utilized for trueness evaluation, with Root Mean Square (RMS) error values calculated. Superimposition of STL files allowed for trueness and precision evaluation, with RMS values indicating average error. Positive values suggest model expansion, while negative values suggest shrinkage. Overall, meticulous methodology was employed to assess the accuracy of different impression techniques in implant dentistry.[34]

In the current study, the first and second null hypotheses were rejected based on the 3D analysis of the accuracy of various impression techniques. The findings indicated that the 3Shape Trios desktop scanner exhibited the highest levels, followed by the Primescan IOS and PVS conventional impression, in descending order. These differences were statistically significant.

These findings are consistent with previous studies, including one by Abduo et al.,[35] which evaluated the accuracy of digital impressions compared to conventional impressions for recording the position of parallel and divergent implants. Similar results were observed, with significantly higher trueness and precision achieved with optical impressions than conventional ones. The lower trueness and precision values associated with conventional impressions may be attributed to the multi-step nature of the process, where each step from impression material setting to digitization could introduce discrepancies.

Additionally, a study by Fathi et al.,[7] demonstrated similar findings. They compared the accuracy of five tooth-implant impression techniques, including intraoral scanning, occlusal matrix, wax relief, closed-tray, and open-tray techniques. The study concluded that intraoral scanning exhibited the highest accuracy, followed by open-tray, occlusal matrix, closed-tray, and wax relief techniques, in descending order. Consequently, the authors recommended the adoption of digital impressions as a more precise alternative to conventional methods for implant impressions.

Furthermore, a systematic review by Alikhasi et al.,[36] evaluated eight studies comparing digital and conventional impression techniques. The review found that five of the studies recommended the adoption of optical impressions for dental implants using intraoral scanners. These findings align with the results of the present study regarding the accuracy of dental implant impression techniques.

Moreover, a systemic review conducted by Alkadi et al.,[37] attributed the high trueness and precision of Primescan IOS to several features. These include Primescan's utilization of new scanning technology with the CEREC 5 software, as well as ongoing advancements in both software and hardware within the digital dentistry field. Primescan employs a high-frequency contrast photo-based dynamic depth scan capable of reaching depths of up to 20mm. It utilizes both video and photo-based imaging systems, with video scanners showing superior accuracy for long-span areas compared to single-image scanners. Additionally, Primescan employs over- scanning technology instead of the cut-out-rescan method, leading to more accurate scans by acquiring data from previously unscanned regions.

Contradictory results were reported by Revilla-León et al.,[38] in their comparison of conventional, photogrammetry, and intraoral scanning accuracy for complete-arch implant impression procedures. Their findings indicated that the conventional technique exhibited the lowest 3D discrepancy, followed by IOS optical scans, with the photogrammetry method showing the least accuracy. However, it's important to note that differences in the conventional impression technique may account for the disparity between their results and those of the current study. Specifically, they utilized a 3D printed customized open tray and printed splint for the conventional impression, which may have contributed to its higher accuracy than the conventional techniques used in the current study.

Additionally, Kernen et al.,[39] pointed out that errors in digital impressions can be attributed to scanning surface accuracy and the stitching between different images, accumulating errors with each step. One noticeable error pattern is the inter-implant distance deviation observed in some intraoral scanning (IOS) systems. Another potential source of error is the mathematical conversion of the scanned surface of the scan body to the parametric scan body and implant surfaces.

In the current study, the third null hypothesis was partially accepted. The 3D analysis of trueness concerning different implant angulations revealed higher deviation results with implants placed at 25°, followed by 15° and 0°, with statistically significant differences observed except for Primescan IOS, where no statistically significant difference was found between 15°

and 0°. Similarly, in the analysis of precision, higher deviation results were observed with implants placed at 25°, followed by 15° and 0°, with statistically significant differences noted except for Primescan IOS and Trios 3Shape desktop scanner, where no statistically significant difference was found between 15° and 0°.

These results align with previous studies, such as the one conducted by Abduo et al.,[35] which also highlighted the higher accuracy of digital impressions, particularly with divergent implants exceeding a 15° angle. This discrepancy was attributed to the deformation of the impression material surrounding the impression copings upon removal from the model, with some deformation not fully recovering, resulting in decreased accuracy.

However, several limitations were present in our study. Firstly, artificial models were used, lacking the biological variability observed in clinical settings. Additionally, these simplified models may not fully represent the complexity of real clinical scenarios. Moreover, the study was conducted extra orally, thus not accounting for variables such as saliva, soft tissue, humidity, and patient movement within the oral environment.

## CONCLUSIONS

1- Parallel implants have the best accuracy in terms of trueness and precision.

2- The greater the implant angulation, the less accuracy of the conventional or digital impression.

3- Desktop scanners provide the highest accuracy for tissue level dental impressions.

## FUNDING

This research received no external funding.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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