Assessing the Influence of Implant Scan Body Material on Desktop Scanner Accuracy: An In Vitro Study

Nurşen Şahin, DDS[1]*
Necati Kaleli, DDS, PhD[2]
Elif Nazlı Tekin, DDS[3]
Çağrı Ural, DDS PhD[4]

There are limited studies analyzing the accuracy of desktop scanners with scan bodies made of different materials but of the same design. The purpose of this in vitro study is to examine the effect of scan bodies made of titanium and polyetheretherketone (PEEK) on the accuracy of desktop scanners that have different scanning technologies (white light vs blue light). Two upper jaw models with a missing left second premolar were obtained. An implant (Bilimplant) was placed in the area where the missing tooth was located. The titanium and PEEK scan bodies were torqued, and an industrial scanner obtained reference data. A total of 40 scans were recorded using two desktop scanners (Dentium and Kivi). Ti-Dentium, Ti-Kivi, PEEK-Dentium, and PEEK-Kivi were identified as the four test groups. Each STL file was imported into Geomagic for reverse engineering. The deviation between the experimental scan and the reference data was analyzed using a best-fit algorithm to determine the accuracy of each scan. Deviation values were compared using nonparametric tests. The average deviation values ± standard deviation observed across the groups were 65 ± 4.5 μm, 81 ± 3.1 μm, 24 ± 5.4 μm, and 47 ± 9.1 μm, respectively. Group Ti-K exhibited the highest average deviation, whereas Group PEEK-D demonstrated the lowest. A statistically significant difference was found between all groups ($P < .05$). Within the limitations of this in vitro study, PEEK scan bodies and white light scanners demonstrated superior accuracy, which may be clinically relevant in high-precision implant restorations.

Key Words: accuracy of impression, dental implant, desktop scanner, digital impression, scanbody

INTRODUCTION

The long-term success and durability of implant-supported prostheses rely heavily on achieving a passive fit of the implant superstructure. Acquiring passive fit requires meticulous precision in clinical and laboratory procedures, beginning with the creation of an accurate impression. There is potential for human and material errors at each step in the process.[1]

The conventional process for dental implant impressions involves using screw-retained impression copings attached to the implant, along with impression trays loaded with impression material. Digital impressions, on the other hand, are an innovative technique for capturing implant positions. This approach leverages advanced optical technologies to precisely determine the placement of dental implants in a virtual model.[2]

A scan body is utilized to precisely capture the position and angulation of a dental implant within a digital workflow. In digital workflow for implant-supported prostheses, scan bodies are torqued to implants or analogs and scanned with an intraoral (IOS) or desktop scanner (DS).[3] Although IOS eliminates the need for impressions, patient discomfort, unpleasant taste, and stone model creation, it is affected by saliva, blood, and moisture contamination.[4,5] A DS scans the impression or stone model of the dental arch. Unlike iOS, DS have no field-of-view limitations, and stitching can be minimal during viewing.[6] The drawbacks of DS encompass dimensional alterations in impression materials and the final cast, the requirement for disinfecting the impression, and potential distortion of the tray or cast.[7] Different technologies, such as laser scanners, touch-probe scanners, blue LED, and white LED, can be used in desktop scanners.[8,9] However, despite the growing adoption of digital workflows, there is limited evidence comparing how the material composition of implant scan bodies affects the accuracy of desktop scanners with different technologies. Addressing this gap is essential for optimizing accuracy and achieving clinically reliable restorations.

Under a force of 500 g, the mobility in dental implants is approximately 13 μm, whereas the mobility in natural teeth is approximately 127 μm.[10] In most studies, the deviation values 100 μm and 0.4° are clinically acceptable levels for impression.[11] Previous studies comparing the deviation values of different intraoral scanners have reported values ranging from 24 to 176 μm.[12–14] The DS have demonstrated deviation values between 0 and 22 μm.[15–17] The clinically acceptable deviation value can be influenced by various factors, including the design of the scan body (geometry, height, diameter, material), implant angulation, and the scanning technology employed.[11,18–21] No consensus is

[1] Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Giresun University, Giresun, Turkey.
[2] Associate Professor, Dental Prosthesis Technology, Vocational School of Health Services, Ondokuz Mayıs Unıversity, Samsun, Turkey.
[3] Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Giresun University, Giresun, Turkey.
[4] Professor, Department of Prosthodontics, Faculty of Dentistry, Giresun University, Giresun, Turkey.
* *Corresponding author,* e-mail: nursen.sahin@giresun.edu.tr
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Figure 1. Titanium (left) and PEEK (right) implant scan bodies used in the study.

accepted about ideal geometry, material, and scanning technology.

The research question addressed in this study is whether differences in scan body material and scanning technology influence the accuracy of digital impressions obtained using desktop scanners. Therefore, this in vitro study aims to measure the effect of scanning bodies made of different materials (PEEK and titanium) on the scanning accuracy of two different desktop scanners with industrial 3D scanner data. Clarifying these effects may help guide clinicians in selecting scan body materials and scanners for high-precision digital workflows. The first null hypothesis was that scan bodies manufactured in different materials would not significantly impact the scanning accuracy. The second null hypothesis was that desktop scanners that have different scanning technologies do not significantly impact the scanning accuracy.

Materials and Methods

All experimental procedures were performed sequentially in the following order: implant positioned, scan body tightened, reference data acquisition using an industrial scanner, desktop scanning, STL alignment, and deviation analysis.

Two upper jaw resin models (3BFab Technology, Istanbul, Turkey) that have missing left second premolar were fabricated with a 3D printer (3BFab Technology) to allow testing of the desktop scanner systems. Two internal connection bone-level dental implants (4.1 $\times$ 10 mm; Bilimplant, Istanbul, Turkey) were positioned in the left second premolar region and 3 mm apical to the gingival margin of each model. The titanium (Ti) and PEEK scan bodies (Bilimplant) (Figure 1) were tightened to 15 Ncm with wrench, in accordance with the manufacturer's instructions and previous literature.[22,23] All procedures were carried out by a single clinician who was trained following the manufacturer's guidelines.

The jaw resin models were scanned using an industrial 3D scanner (Opentech3D, Rezzato, Italy), recorded as reference data (Ref Ti and Ref PEEK), and imported into the reverse engineering software program (Geomagic Control X, North Carolina, USA). The industrial 3D scanner from the manufacturer confirmed an accuracy of less than 5 μm.[24]

Then, both jaw models were scanned 10 times on two desktop scanners (dental laboratory 3D scanner Rainbow, Dentium, Korea; Dental laboratory 3D scanner Proxima L100, Kivi, Turkey) under identical environmental conditions (in a room with a temperature of 22C°, controlled ambient lighting of 1000 lux during the same day) according to the manufacturer's recommendations (n = 10). Both desktop scanners were calibrated prior to each scanning session using the manufacturer-supplied calibration blocks and software interfaces, in accordance with the official user manuals. Both groups were further divided into 2 subgroups based on the desktop scanner used: Ti (Ti-D and Ti-K subgroups) and PEEK (PEEK-D and PEEK-K subgroups). A total of 40 STL (standard tessellation language) files were obtained and were imported to same reverse engineering software (Geomagic Control X) for 3D analysis. Geomagic software enables the creation of a colorimetric map to visualize deviations across the surface of an STL mesh compared to the reference STL data, with deviations quantified at specific points. The color map displays inward deviations in blue and outward deviations in red, with green representing minimal deviation. The color scale spans from a maximum outward deviation of +100 μm (red) to a minimum inward deviation of $-$100 μm (blue)[25] (Figure 2).

In this study, for the accuracy evaluation of the Ti-D and Ti-K groups, 10 Ti-D and 10 Ti-K scans were superimposed with the Ref Ti data using the software. Similarly, for the accuracy evaluation of the PEEK-D and PEEK-K groups, 10 PEEK-D and 10 PEEK-K scans were superimposed with the Ref PEEK data. The deviation between the experimental scan and its corresponding reference data was analyzed following best-fit alignment using Geomagic Control X.

Statistical methods

All statistical analyses, interpretations, and inferential conclusions in this study were reviewed and validated by an independent statistician who was not involved in the experimental procedures.

Power analysis was conducted using a significance level of 0.05, a 95% confidence level, and an assumed effect size of 1.0. The results showed that a minimum of 10 scans per group was required (n = 10).

The data were analyzed using statistical analysis software (IBM SPSS Statistics, Version 25.0, IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was applied to assess the normality of deviation data obtained from the aligned scan reference models and the data did not follow a normal distribution ($P < .05$). Therefore, data were analyzed using the Kruskal-Wallis and post hoc pairwise comparison Mann-Whitney *U* tests were selected. ($P = .05$).

Results

All statistical analyses were performed and verified by an independent statistician. A total of 4 subgroups were evaluated: Ti-D, Ti-K, PEEK-D, and PEEK-K. The mean deviation values ($\pm$ standard deviation) for the scan body groups scanned with the Dentium scanner were 65 $\pm$ 4.5 μm for Ti-D and 24 $\pm$ 5.4 μm for PEEK-D.

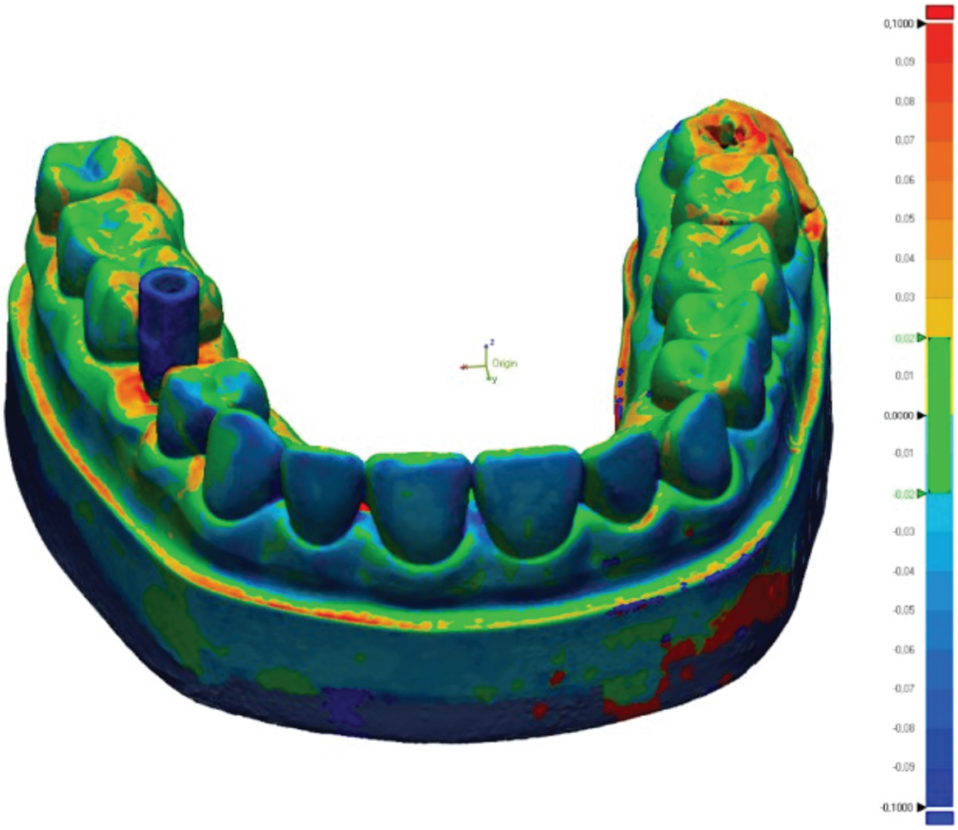

Figure 2. The deviation color map was generated in the Geomagic Control X software.

Corresponding values for the Kivi scanner were 81 ± 3.1 μm for Ti-K and 47 ± 9.1 μm for PEEK-K.

It was determined that both the scanner and the scan body material affected impression accuracy. The lowest deviation value was observed in Group PEEK-D; in contrast, the highest deviation value was recorded in Group Ti-K. These findings underscore the differences in impression accuracy between the materials tested. Median, quartiles (Q1, Q3), minimum, and maximum values of deviation were calculated by best-fit matching with reference STL data (Figure 3).

Regarding accuracy, the Mann-Whitney *U* revealed significant differences between the different subgroups. Statistically significant differences were observed between Ti-D and Ti-K ($P < .001$, effect size = 0.84), as well as between PEEK-D and PEEK-K ($P < .001$, effect size = 0.73). Both scanner and scan bodies' materials had a significant effect on trueness ($P < .001$). (Table).

The results align with the research aim of evaluating the influence of scan body material and scanner type on deviation values under standardized in vitro conditions. Among all tested groups, the PEEK scan bodies combined with the white-light Dentium scanner yielded the lowest deviation values, indicating the highest scanning accuracy. However, the titanium scan bodies used with the blue-light Kivi scanner exhibited the highest deviations. These findings emphasize the significant interaction between scan body material and scanning technology in determining digital impression accuracy.

Discussion

According to the results of this study, the first hypothesis—that scan bodies manufactured from different materials would not significantly affect scanning—was rejected. The second hypothesis that DS with different scanning technologies would not affect scanning accuracy was rejected.

There are numerous studies examining the effect of scan body material on impression accuracy. In studies examining the impact of scan body material on measurement accuracy with IOS, studies show that Ti scan bodies are more accurate,[25] as well as studies showing that PEEK scan bodies are more accurate.[26–28] In studies examining measurement accuracy on DS, studies show that Ti scan bodies[27] are more accurate, as well as studies showing that PEEK scan bodies are more accurate[28] as in this study. It is thought that parameters, such as the geometry and height of the scan bodies used in the studies, as well as the operating principles of the scanners, may be effective in shaping these differences. To minimize potential interferences from scan body shape, PEEK, and titanium scan bodies from the same manufacturer were chosen for this study. This approach aimed to evaluate the independent effect of scan body materials on the accuracy of scan data. According to the results obtained from the study, choosing PEEK scan body instead of titanium scan body may contribute to reduced deviations in digital impressions under controlled in vitro conditions, potentially enhancing restoration accuracy in similar scenarios.

The Dentium desktop scanner uses white-light scanning, whereas the Kivi DS uses blue-light scanning. Although no

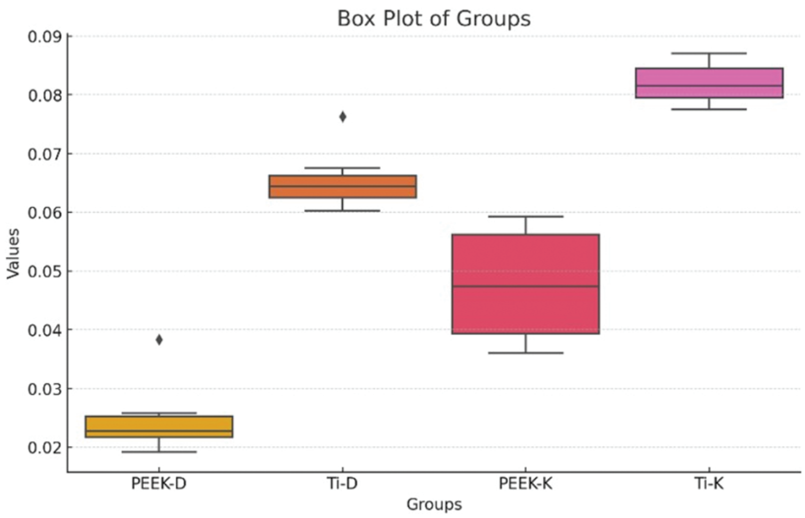

FIGURE 3. Box plot displaying deviation values (in μm) for each test group (Ti-D, Ti-K, PEEK-D, PEEK-K). The median, quartiles (Q1, Q3), minimum, and maximum values are shown.

statistical difference was observed in the full-arch scanning study conducted by Natsubori et al.,[22] the deviation value for the DS using blue-light scanning technology was higher, like the findings in this study.

Deviation values of test groups could be influenced not only by the materials of the scan bodies and the type of DS used but also by differences in the scanning process between the industrial scanner and the desktop scanners. To eliminate this issue, Hauschild et al. used a coordinate measuring machine to obtain reference data on the model in their study on digital measurement accuracy.[29] In this study, an industrial scanner with high accuracy was used for scanner accuracy evaluation.

For impression accuracy, 1,[30–32] 2,[23,25,33] 4,[15,34,35] 6,[17,19,26,35] and 10[3] implants or artificial jaw models with teeth[4,7,37,38] were used in previous studies. However, because the error was lower in scans with a single implant,[39] we used a single implant in our study.

Although some studies have used titanium oxide powder,[22,37,40] no powder was applied in this study according to the manufacturer's instructions. Due to the light-reflective surface of the titanium scan bodies, the deviation value was higher, consistent with findings from similar studies.[24,28]

For impression accuracy, 3-dimensional analysis software such as PolyWorks,[34] Geomagic,[25,30,41–43] and GOM[9,36,37] has been used. This study according to ISO 12836:2012[44] is used Geomagic.

TABLE

Groups' average deviation values and Mann-Whitney *U* test results

Groups	Deviation Value (μm) ± Standard Deviation: Dentium	Deviation Value (μm) ± Standard Deviation: Kivi	*P* Value	Effect Size*
Ti	65 ± 4.5	81 ± 3.1	<.001	.84
PEEK	24 ± 5.4	47 ± 9.1	<.001	.73

*Effect size values represent rank-biserial correlation (r) derived from Mann-Whitney *U* tests. Effect sizes are interpreted as follows: small (r ≈ 0.1), medium (r ≈ 0.3), and large (r ≥ 0.5).

After the superimposition process, deviation values were achieved from the aligned scan and reference datasets using the statistical analysis.[25,26,35] It is thought that the reason why the deviation values in DS are higher than in previous studies, may be the localized region-based analysis methodology following best-fit alignment.[27]

This study has some limitations. The study's limitations include the use of static resin models, and the absence of soft tissue simulation restrict, saliva, thermal changes, and oral humidity. Although material-related differences in deviation values may influence scanner performance under in vitro conditions, further in vivo studies are required to determine their clinical relevance. Another limitation is the use of a single implant. The effect of the scan body material on impression accuracy needs to be examined in models where implants with different angles, geometries and numbers are used. Studies examining the effects of scan bodies produced from different materials, in different numbers and angles, on the impression accuracy and precision of IOS and DS are among the future work targets.

This study demonstrates that both scan body material and scanner type significantly influence the accuracy of digital implant impressions. The results contribute to oral implantology in digital workflows to optimize implant restoration outcomes.

CONCLUSION

Within the limitations of this in vitro study, varying the scan body's material and the type of scanner influenced the accuracy of the digital implant.

The following conclusions could be drawn:

- The type of scanner and scan body material significantly affected impression accuracy ($P < .001$). Under the conditions of this in vitro study, PEEK scan bodies demonstrated higher accuracy compared to titanium scan bodies. The Dentium DS, which has white-light scanning technology, has more accuracy than Kivi, which is the blue light scanning technology. These findings may have clinical relevance in cases requiring high-precision impressions.

- The mean deviation values for the desktop scanners were under clinic-acceptable thresholds (<100 μm) for 2 types of scan bodies. However, the differences in accuracy between scan body materials and DS may be relevant in cases requiring high-precision digital impressions, such as full-arch implant restorations.
- These findings reinforce the importance of selecting appropriate scan body materials and scanning technologies to improve the reliability of digital implant workflows and ensure long-term clinical success. However, these results are limited to DS only; they may not be generalized to intraoral scanners. Similar studies need to be conducted with different implant systems and scanner technologies.

Acknowledgment

This study was conducted in accordance with the principles of the WMA Declaration of Helsinki. Ethical approval was not required for this study as it was conducted entirely in vitro without involving human or animal subjects.

Notes

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