Evaluation of the Accuracy of 3D Scan Data of Complete Dentures Obtained with Intraoral Scanners

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Evaluation of the Accuracy of 3D Scan Data of Complete Dentures Obtained with Intraoral Scanners

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감사의 글

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2024 년 12 월

전 소 영

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ABSTRACT

Evaluation of the Accuracy of 3D Scan Data of Complete Dentures Obtained with Intraoral Scanners

This study compared the accuracy of 3D scan data of various complete dentures obtained with different intraoral scanners. Three types of dentures—a resin-based maxillary denture, a resin-based mandibular denture, and a metal-based maxillary denture—were fabricated using heat-cure denture base resin. Three markers were attached to each denture to serve as reference points for scan data alignment. Reference 3D scan data of each denture was obtained with an industrial scanner without scanning spray. Each denture was scanned 10 times with three intraoral scanners (TRIOS 5, Group T; i900, Group I; Primescan, Group P). For the metal-based complete denture, scanning spray was applied to minimize reflectivity.

The scan data were aligned with the reference data using three-point and best-fit alignment methods. Accuracy was evaluated per ISO 5725-1:2023 guidelines, with trueness assessed by mean absolute deviation (mAD) and root mean square (RMS) and precision by the standard deviation of mAD (SDmAD) and the standard deviation of the original deviation (SDmOD). Statistical analyses included Kruskal-Wallis tests for trueness and Levene's test for precision, with significance set at $\alpha = 0.05$.

For the resin-based maxillary denture, Group T showed significantly superior trueness compared to others. For the metal-based maxillary denture, the mAD analysis showed no significant differences ($p = 0.532$), but RMS analysis found Group I significantly better than Group P ($p = 0.002$). For the resin-based mandibular denture, no significant mAD differences were found ($p = 0.289$), but RMS analysis showed Group T outperformed Group P ($p < 0.001$). For precision, Group T showed significantly lower SDmAD for the resin-based maxillary denture than Group I ($p < 0.001$), with no differences in SDmOD ($p = 0.055$). For the metal-based maxillary denture, precision showed no significant differences in SDmAD ($p = 0.496$) or SDmOD ($p = 0.239$). For the resin-based mandibular denture, SDmAD showed no significant differences ($p = 0.094$), but SDmOD indicated Group T was significantly better ($p = 0.007$ vs. Group I; $p = 0.005$ vs. Group P). These findings indicate the choice of intraoral scanner and denture material may impact the 3D scan data accuracy of complete dentures. The TRIOS 5 scanner consistently demonstrated superior or equivalent accuracy across all conditions, including resin-based and metal-based dentures. All scanners delivered results within clinically acceptable limits, making them viable for clinical use.

Key words: complete denture, intraoral scanner, best-fit alignment, 3D scan data, accuracy, trueness, precision

1. INTRODUCTION

1.1. Digital Diffusion in the Field of Dentistry and Healthcare

Interest in digital dentistry is rapidly growing within dental medicine. This transformation involves more than merely adopting new technologies; it signifies a profound evolution in dental treatment and care. Digital dentistry encompasses a wide array of technologies, including computer-aided design/ computer-aided manufacturing (CAD/CAM) systems, electronic health records, and digital radiography. These tools are increasingly integrated across dental fields, enabling more precise and efficient treatment options. Furthermore, as life expectancy increases and living standards rise, the demand for aesthetic and functional prosthetic solutions to restore oral health has expanded significantly.

The accuracy and efficiency of the impression-taking process, which is the initial and most crucial step in successful prosthodontic restoration, play a pivotal role in determining treatment quality. In contemporary clinical practice, advanced digital systems, such as 3D scanners, allow for the precise capture and replication of tooth structures, soft tissues, and mucosal forms. These advancements have not only replaced traditional impression-taking methods with streamlined digital workflows but also accelerated prosthesis fabrication while ensuring high accuracy (D'Ambrosio et al., 2023).

The widespread adoption of intraoral scanners has solidified their role as cornerstones of digital dentistry. These scanners facilitate digital workflows, enabling the fabrication of definitive prostheses without the need for traditional working cast models, offering unique and innovative dental treatment experiences.

1.2. Advancements in Intraoral Scanners

Intraoral scanners utilize optical principles to capture digital impressions. They project lasers or structured light onto tooth surfaces to generate precise three-dimensional images. During this process, reflected light from the tooth surfaces is detected, and shape and position data are collected to produce a point cloud using specialized software. This point cloud is converted into a triangular mesh format and exported as a standard tessellation language (STL) file. The STL file, which provides concise data on geometry, position, color, and orientation, seamlessly integrates with CAD/CAM systems to enable accurate and efficient prosthesis fabrication. This integration has significantly improved the planning and efficiency of clinical procedures (D'Ambrosio et al., 2023; Imburgia et al., 2017).

The introduction of intraoral scanners has revolutionized traditional impression-taking methods. Evaluation criteria for intraoral scanners include accuracy, speed, software utility, and ergonomic design. With advancements in CAD software and digital workflows, intraoral scanner accuracy continues to improve. These developments reduce impression-taking time, minimize distortion risks associated with traditional methods, and enhance overall efficiency (Fang et al., 2018; Gjelvold et al., 2016; Goodacre et al., 2012).

Before the advent of digital systems in the 1980s, irreversible hydrocolloid materials were widely used for impression-taking, followed by model fabrication and prosthesis design. While these materials are easy to use and set quickly, they present challenges like shrinkage during setting and deformation due to environmental factors, which negatively affect dimensional stability and accuracy (Gjelvold et al., 2016). Clinical studies indicate that traditional impression methods are time-dependent on the clinician expertise and often exhibit lower accuracy for single or fixed prostheses compared to digital methods (Güth et al., 2013). Moreover, patients frequently find traditional impression materials unpleasant due to their taste and texture, leading to discomfort.

To overcome these limitations, intraoral scanners have been introduced, enabling a more efficient and patient-friendly impression-taking process. Clinical studies by Ender et al. demonstrate that intraoral scanners provide the accuracy necessary for fabricating various prostheses, particularly excelling in single-unit restorations and short dental arches (Ender & Mehl, 2013; Ender[a] & Mehl[b], 2013). Additionally, intraoral scanners allow rapid acquisition of intraoral data, reduce chair time, and mitigate errors associated with the physical properties of conventional materials. Patient satisfaction has become a crucial factor in adopting intraoral scanners, with studies showing that their use enhances patient satisfaction in terms of treatment time and prosthesis fit (Al-Kaff & Al Hamad, 2024; Fang et al., 2018).

1.3. Accuracy of Intraoral Scanners

Intraoral scanners consistently demonstrate reliability across diverse clinical settings, offering high precision for single, complex, and implant-supported restorations, as well as edentulous arches. Research on single-arch accuracy has shown that intraoral scanners effectively capture fine surface details of teeth, facilitating more efficient and accurate prosthesis fabrication compared to traditional methods (Abduo & Elseyoufi, 2018). These advancements highlight their clinical utility by ensuring reproducibility and precision.

Studies have confirmed that intraoral scanners reliably record intricate shapes and depths between teeth in complex dental arches, achieving accuracy comparable to or better than traditional methods (Kong et al., 2022; Le Texier et al., 2024). For implant-supported restorations, intraoral scanners excel in capturing detailed information on implant positions, angles, and depths, contributing to improved prosthesis fit and clinical outcomes (Kong et al., 2022). This level of precision is critical to the success of implant-supported prostheses.

Edentulous arches present a more challenging environment for impression-taking. Currently, digital scanning has overcome many limitations of traditional methods. Lione et al. (2024) demonstrated that intraoral scanners maintain high precision for edentulous arches, reduce deformation risks associated with conventional impression materials, and enhance patient comfort (Lione et al., 2024). Collectively, these findings validate the consistent accuracy of intraoral scanners across various clinical scenarios. This consistency supports their ability to replace traditional impression methods, significantly improving clinical efficiency and patient experience.

1.4. Intraoral Scanning of Complete Dentures

Advancements in digital approaches have significantly improved the accuracy of edentulous arch scanning. Recent studies suggest that scanner type and scanning strategy significantly play a crucial role in the accuracy of edentulous arch data acquisition (Jamjoom et al., 2024). Earlier intraoral scanners faced challenges such as high costs, low user convenience, slow data processing, and limited accuracy. However, technological advancements have addressed these issues. Modern intraoral scanners now offer high-resolution scans, improved software capabilities, and broader fields of view, enabling faster and more precise scanning. These improvements have expanded their applications to include attempts at replicating complete dentures (Le Texier et al., 2024).

With the integration of artificial intelligence-based algorithms and advanced data-processing technologies, intraoral scanners now effectively minimize data loss and noise during scanning. This progress has enhanced the fit and patient satisfaction of complete dentures, increasing the reliability of digital workflows. Advanced software further facilitates precise data capture and error correction, ensuring accurate reproduction of complex anatomical structures necessary for denture fabrication.

The expanded clinical use of intraoral scanners has made direct scanning at clinical sites feasible, surpassing the previous reliance on laboratory-based scanning. For example, intraoral scanners can scan existing dentures to create surgical guides for implant placement or fabricate new dentures and prostheses. This digital workflow allows clinicians to deliver customized results efficiently, reducing patient visits and eliminating the need for laboratory scanning, thereby enhancing convenience and efficiency. However, challenges persist. Limitations in scan accuracy for extensive denture surfaces and complex structures remain (Giachetti et al., 2020). Issues such as scan distortion on polished surfaces and overlapping images due to prolonged scanning times also require further resolution (Le Texier et al., 2024).

This study aimed to compare and analyze the accuracy of 3D scan data for complete dentures using different types of intraoral scanners and denture base materials. The null hypothesis was that there would be no differences in the accuracy of 3D scan data among intraoral scanners used for various types of complete dentures.

2. MATERIALS AND METHODS

2.1. Complete Denture Fabrication Process

Maxillary and mandibular edentulous dentiforms (B-3 NHJWUK; Frasaco GmbH, Tettnang, Germany) were impressed using a rubber impression material (Aquasil Ultra XLV; Dentsply Sirona, Charlotte, NC). Subsequently, definitive casts were fabricated from type IV dental stone (Snow Rock; DK Mungyo, Gyeongnam, Korea). The definitive casts were mounted on an articulator (PROTARevo 7; KaVo, Biberach, Germany) with bite blocks (B-3 NHB; Frasaco) (Figure 1). Two types of denture bases were fabricated for the maxilla, while one type was fabricated for the mandible.

Artificial teeth (Orthosit; Ivoclar Vivadent AG, Schaan, Liechtenstein) were arranged, and gingival festooning was performed on the trial denture bases to create resin-based maxillary and mandibular complete dentures. To ensure maximum similarity in the artificial tooth arrangement patterns and sizes between the two types of maxillary complete dentures, multiple indentations were made on the edge of the maxillary definitive cast. Subsequently, a silicone putty (CharmFlex Putty bulk; Dentkist, Gyeonggi-do, Korea) impression was stabilized at the edge of the maxillary definitive cast. When arranging artificial teeth for the metal-based maxillary complete denture, the negative impressions left in the putty served as guides for tooth positioning, ensuring maximum similarity between resin-based and metal-based maxillary complete dentures (Figure 2). After establishing appropriate occlusal relationships between the resin-based maxillary and mandibular wax trial dentures, as well as between metal-based maxillary and resin-based mandibular wax trial dentures, heat-cure denture base resin (SR Triplex Hot; Ivoclar Vivadent AG) was used to finalize the complete dentures.

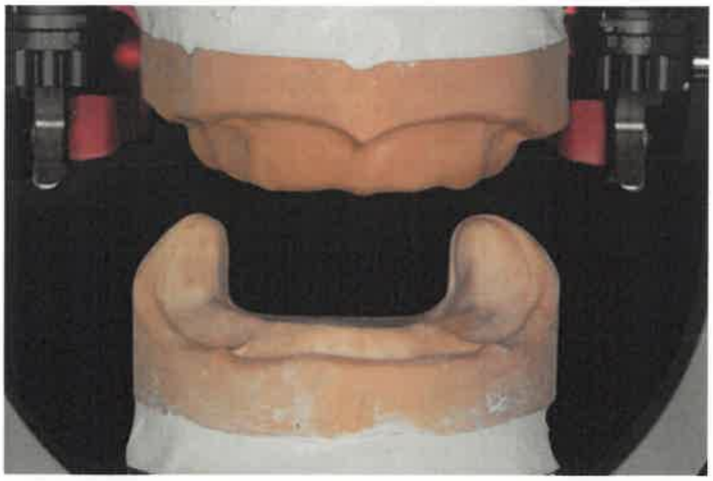

Figure 1. Maxillary and mandibular definitive casts mounted on an articulator.

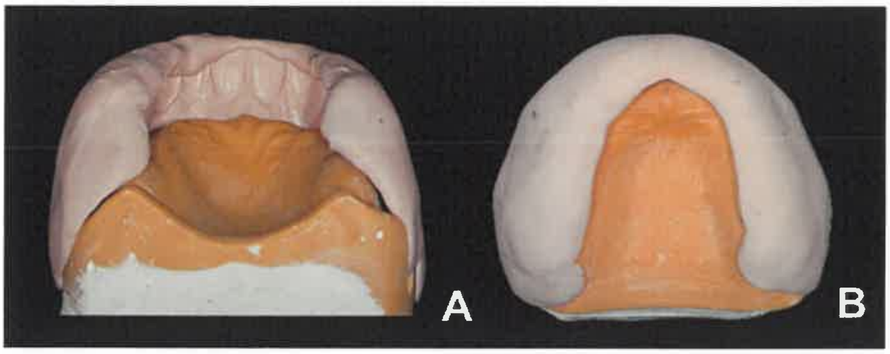

Figure 2. Multiple indentations and putty impressions ensuring consistent artificial tooth arrangement on two types of maxillary complete dentures. A, Rear view. B, Occlusal view.

For each maxillary complete denture type, three markers (CT-23; Suremark, Mesa, AZ) were placed 8 mm above the buccal midpoints of the left and right first and second molars and the midpoint of the central incisor. For the mandibular complete denture, markers were positioned 5 mm below these corresponding points (Figure 3).

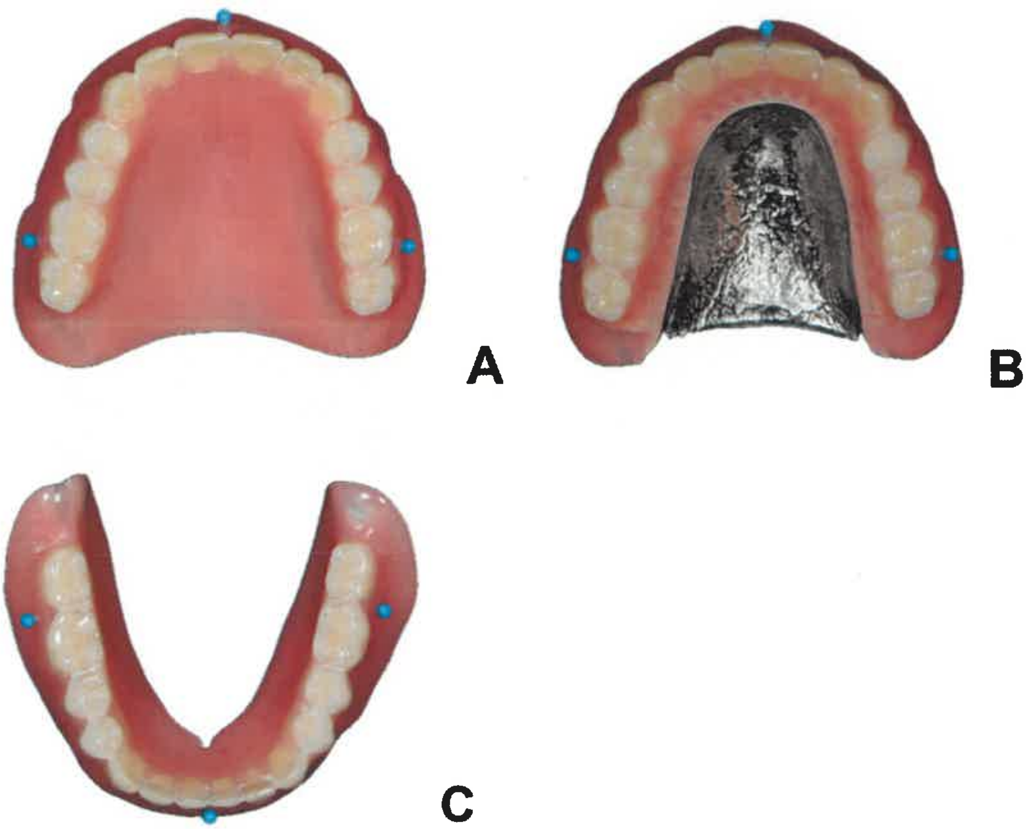

Figure 3. Maxillary and mandibular complete dentures. A. Resin-based maxillary complete denture. B, Metal-based maxillary complete denture; C, Resin-based mandibular complete denture.

2.2. Acquisition of 3D Scan Data

Each complete denture was scanned using an industrial scanner (SIMSCAN 3D Scanner; YOUNG IN AT Co., Ltd., Anyang-si, Korea) without application of the scanning spray to obtain reference 3D scan data. Three state-of-the-art intraoral scanners—TRIOS 5 (3Shape A/S, Copenhagen, Denmark), i900 (Medit, Seoul, Korea), and Primescan (Dentsply Sirona, Charlotte, NC)—referred to as Group T, Group I, and Group P, respectively, were used to scan the entire surfaces of the three types of complete dentures. Each scanner performed 10 scans for each denture type, resulting in 90 STL files.

For the metal-based complete denture, scanning spray (EASY SCAN; PD Dental, Seoul, Korea) was applied to ensure accurate scanning of both tissue and polished surfaces of the denture. The scanning protocol for polished surfaces adhered to the manufacturer's instructions. For maxillary complete dentures, scanning began at the occlusal surface of the left posterior teeth, continued along the buccal surface, crossed the anterior teeth in a zigzag pattern, and concluded at the palatal surface of the right posterior teeth, maintaining horizontal alignment throughout. Subsequently, the palate area was scanned from the anterior to the posterior region. The protocol for the mandibular complete denture, scanning at the occlusal surface of the left posterior teeth and progressing sequentially to the right posterior teeth. Subsequently, the lingual surfaces were scanned, starting from the left posterior to the right posterior teeth. Finally, the buccal surfaces were scanned, beginning at the left posterior teeth and progressing toward the right posterior teeth, completing the scanning procedure (Figure 4).

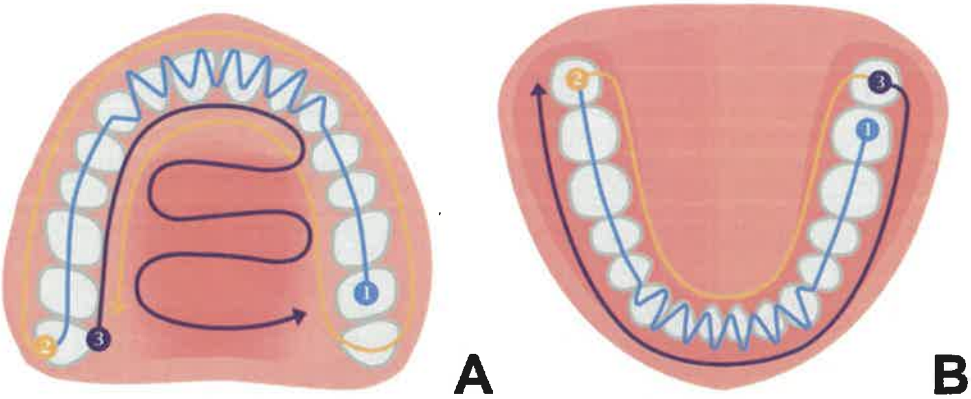

Figure 4. Scanning protocol for polished surfaces of complete dentures. A, Maxillary complete denture. B, Mandibular complete denture.

After completing the scans of the polished surfaces, the tissue surface was scanned, ensuring alignment with the polished surface scan data, maintaining smooth transition from the polished surface to the border and the tissue surface, and minimizing data loss at denture boundaries. For the maxillary complete dentures, the wide palatal tissue surface was scanned continuously from the anterior to the posterior teeth to ensure comprehensive coverage. For the mandibular complete denture, the narrow tissue surface was scanned along the buccal border to ensure uniform coverage of the entire tissue surface (Figure 5).

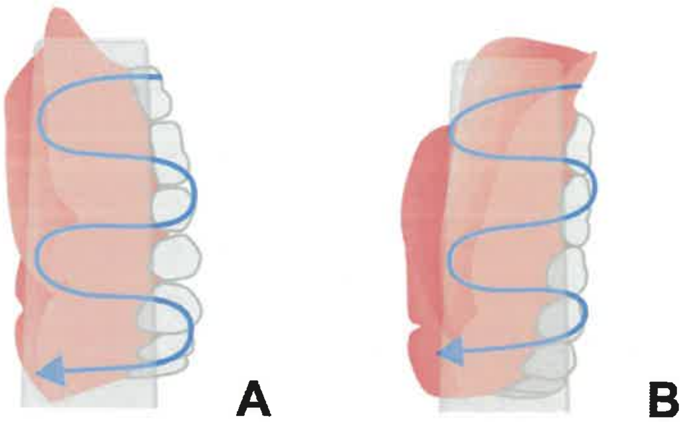

Figure 5. Scanning process demonstrating transition protocol between polished and tissue surfaces of complete dentures. The transparent bar-shaped object represents the scanner tip. A, Maxillary complete denture. B, Mandibular complete denture.

Each intraoral scanner followed the same protocol, producing 90 3D scan data files in STL format (10 files per denture type per intraoral scanner). Precision measurement software (Geomagic Control X, version 2024.2.0; 3D Systems, USA) was used to align and superimpose the scan data (Group T, Group I and Group P) with the reference 3D scan data through a best-fit alignment based on the markers attached to each denture (Figure 6). The aligned 3D coordinate data for each complete denture and intraoral scanner were exported as comma-separated values (CSV) files. In the raw data, intraoral scan points within the reference data were assigned negative distance values, while points outside were assigned positive values.

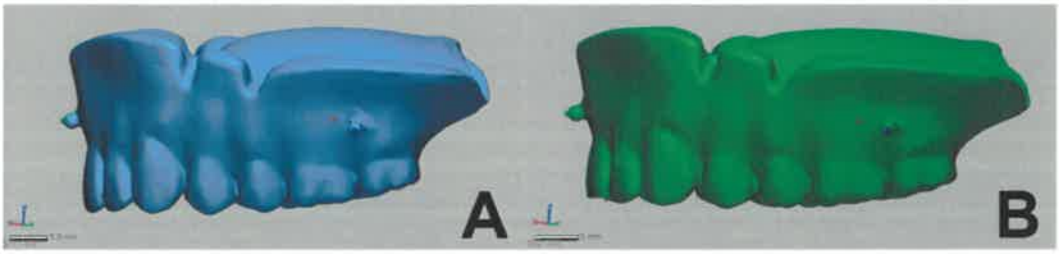

Figure 6. Superimposition of 3D scan data for complete dentures. A. Reference 3D scan data. B, Measurement 3D scan data.

2.3. Accuracy Measurement and Representation

According to ISO 5725-1:2023, accuracy is categorized into trueness and precision (International Organization for Standardization. (2023) Accuracy (trueness and precision) of measurement methods and result Part 1: General principles and definitions (ISO 5725-1:2023). Trueness refers to the closeness of a measured value to the true value, while precision reflects the consistency of repeated measurements, indicating the reliability of the measurement system. These parameters enable the identification of error factors and provide a quantitative assessment of accuracy. The following indicators were used to analyze accuracy in this study:

Trueness.

- Mean absolute deviation (mAD)
- Root mean square (RMS)

Precision.

- Standard deviation of the mean absolute deviation (SDmAD)
- Standard deviation of the mean of original deviations (SDmOD)

Trueness was evaluated using the mean absolute deviation (mAD), representing the average of absolute deviations from the true value, and the root mean square (RMS), calculated as the square root of the mean of the squared deviations. Precision was assessed using the standard deviation of the mean absolute deviation (SDmAD), calculated as the standard deviation of the mean of absolute deviations converted to positive values, and the standard deviation of the mean of original deviations (SDmOD), calculated as the standard deviation of the mean of the original deviations while retaining their signs. By definition, higher mAD and RMS values indicate lower trueness, while higher SDmAD and SDmOD values indicate lower precision.

The trueness and precision of each complete denture type were compared across different intraoral scanners using statistical software (IBM SPSS Statistics for Windows, v23.0; IBM Corp). Trueness was analyzed using mAD and RMS values with the Kruskal–Wallis nonparametric test. When significant differences were observed, the Mann–Whitney U test was applied for post-hoc analysis. Precision was evaluated using SDmAD and SDmOD values. Levene's test for homogeneity of variance was used to evaluate statistically significant differences among the groups. The significance level (α) was set at 0.05, with a post-hoc significance level of 0.0167.

3. RESULTS

For the resin-based maxillary complete denture, both mAD and RMS analyses revealed significant differences among the groups. Group T demonstrated significantly superior results compared to the other two groups (mAD: 66.5 ㎛, RMS: 93.3 ㎛). The mAD analysis indicated that Group P exhibited significantly higher trueness than Group I ($p < 0.001$). However, no significant difference between Groups P and I was observed in the RMS analysis ($p = 0.684$; Figure 7). For the metal-based maxillary complete denture, the mAD analysis showed no significant differences among the groups ($p = 0.532$). However, the RMS analysis revealed that Group I exhibited significantly higher trueness than Group P ($p = 0.002$; Figure 8). For the resin-based mandibular complete denture, no significant differences were noted among the groups in the mAD analysis ($p = 0.289$). In contrast, the RMS analysis indicated that Group T demonstrated significantly better trueness than Group P ($p < 0.001$; Figure 9).

Regarding the precision of the resin-based maxillary complete denture, the SDmAD analysis revealed that Group T was significantly superior to Group I ($p < 0.001$). However, no significant differences among the groups were observed in the SDmOD analysis ($p = 0.055$; Figure 10). For the metal-based maxillary complete denture, neither SDmAD nor SDmOD analyses showed significant differences among the groups ($p = 0.496$ for SDmAD; $p = 0.239$ for SDmOD; Figure 11). For the resin-based mandibular complete denture, no significant differences were observed in the SDmAD analysis ($p = 0.094$). However, the SDmOD analysis indicated that Group T exhibited significantly superior precision compared to the other groups ($p = 0.007$ for Groups T and I; $p = 0.005$ for Groups T and P; Figure 12).

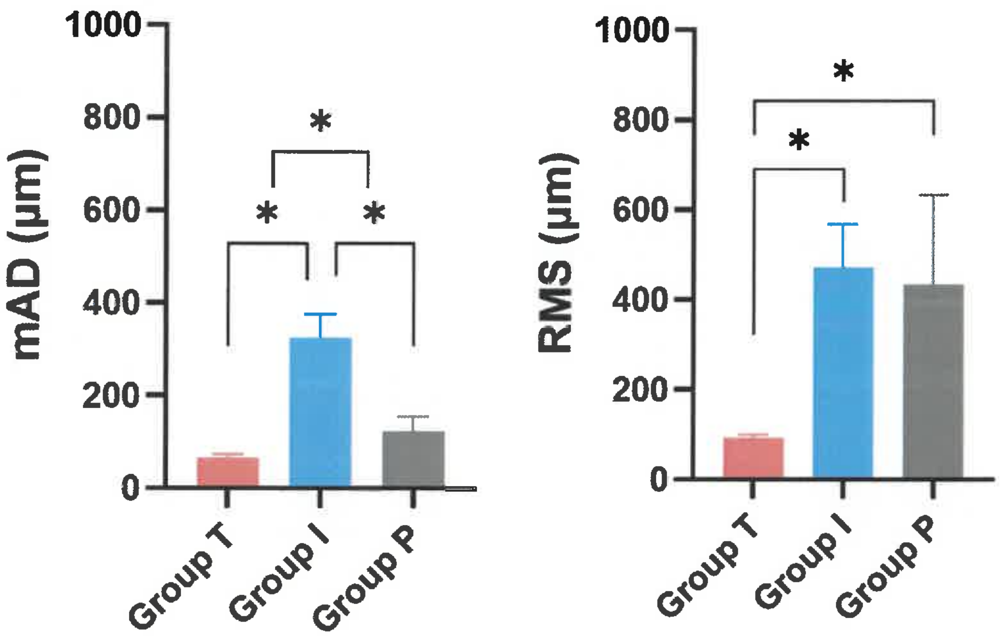

Figure 7. Trueness of resin-based maxillary complete denture assessed using mAD and RMS. Asterisks indicate statistically significant differences among the groups ($p < 0.05$). mAD, mean absolute deviation. RMS, root mean square.

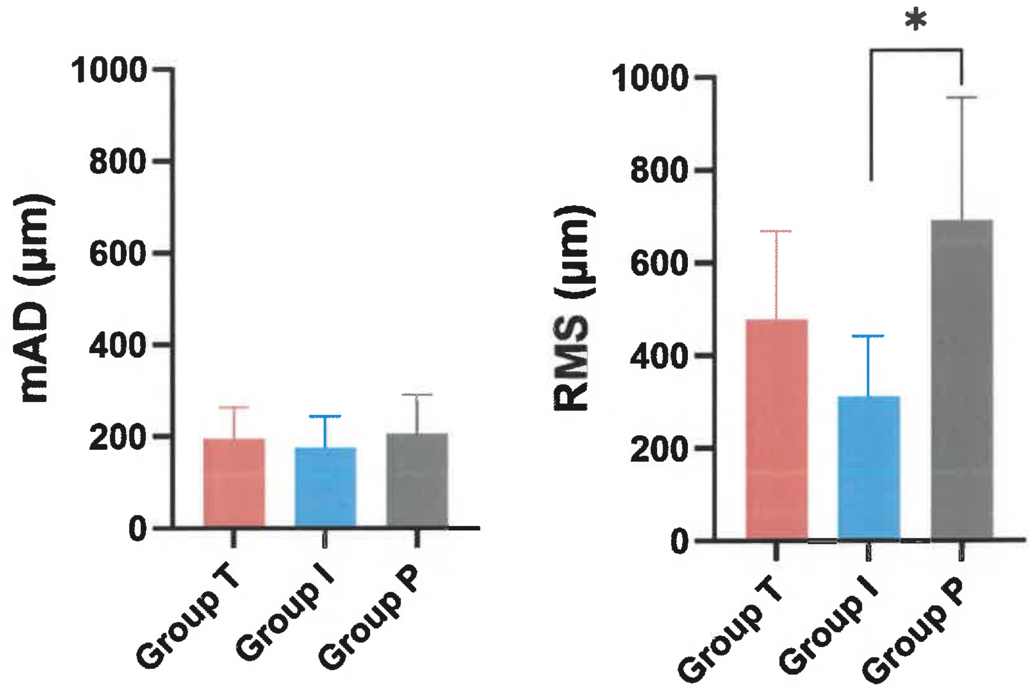

Figure 8. Trueness of metal-based maxillary complete denture assessed using mAD and RMS. Asterisks indicate statistically significant differences among the groups ($p < 0.05$). mAD, mean absolute deviation. RMS, root mean square.

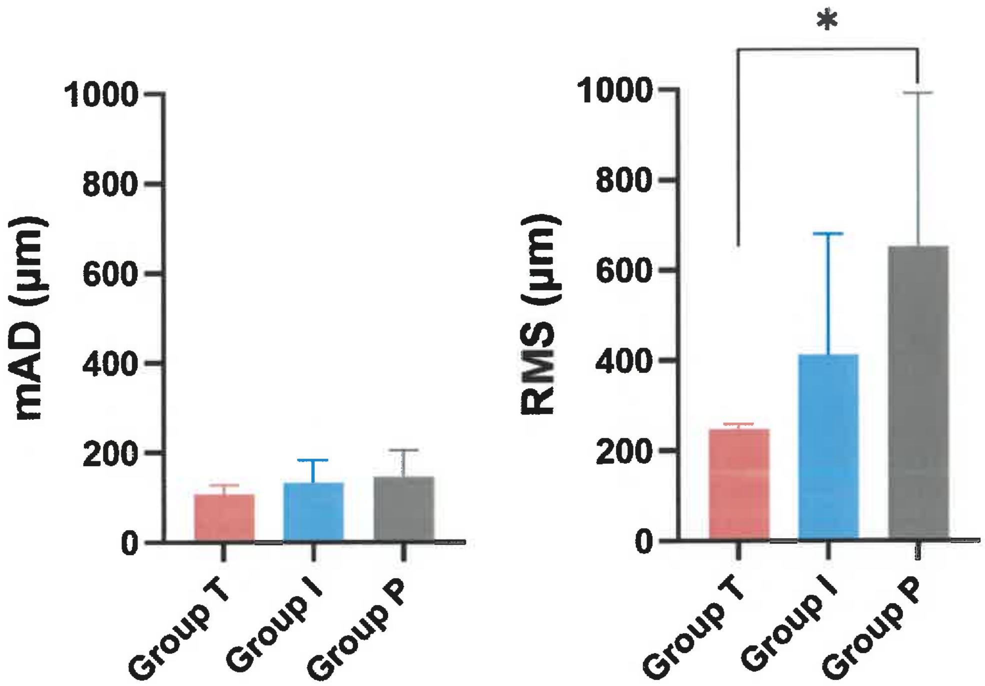

Figure 9. Trueness of resin-based mandibular complete denture assessed using mAD and RMS. Asterisks indicate statistically significant differences among the groups ($p < 0.05$). mAD, mean absolute deviation. RMS, root mean square.

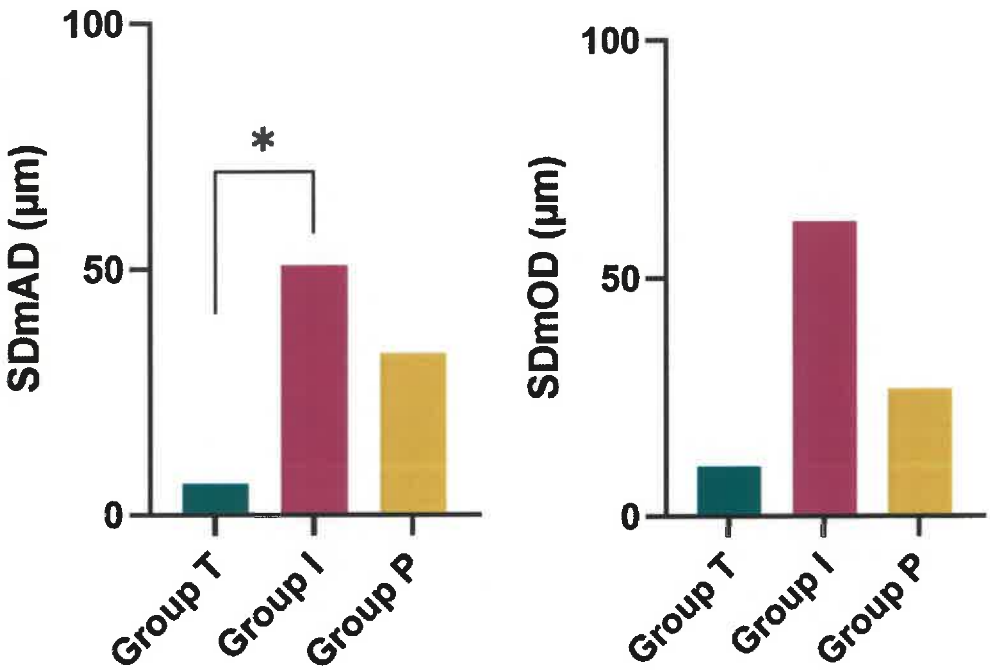

Figure 10. Precision of resin-based maxillary complete denture assessed using SDmAD and SDmOD. Asterisks indicate statistically significant differences among the groups ($p < 0.05$). SDmAD, standard deviation of the mean absolute deviation. SDmOD, standard deviation of the mean of original deviations.

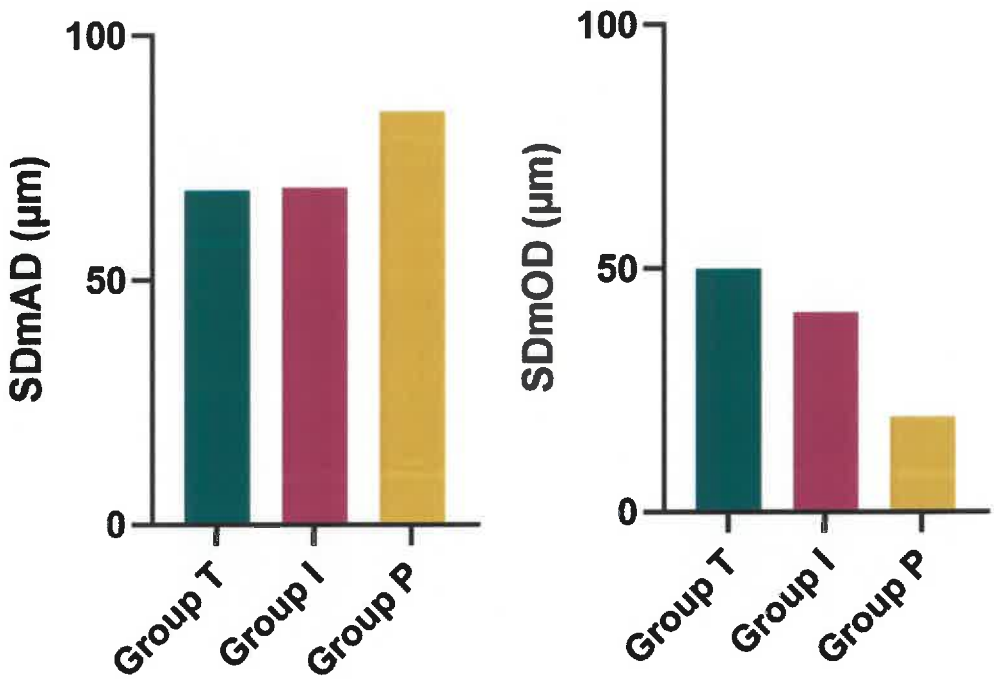

Figure 11. Precision of metal-based maxillary complete denture assessed using SDmAD and SDmOD. SDmAD, standard deviation of the mean absolute deviation. SDmOD, standard deviation of the mean of original deviations.

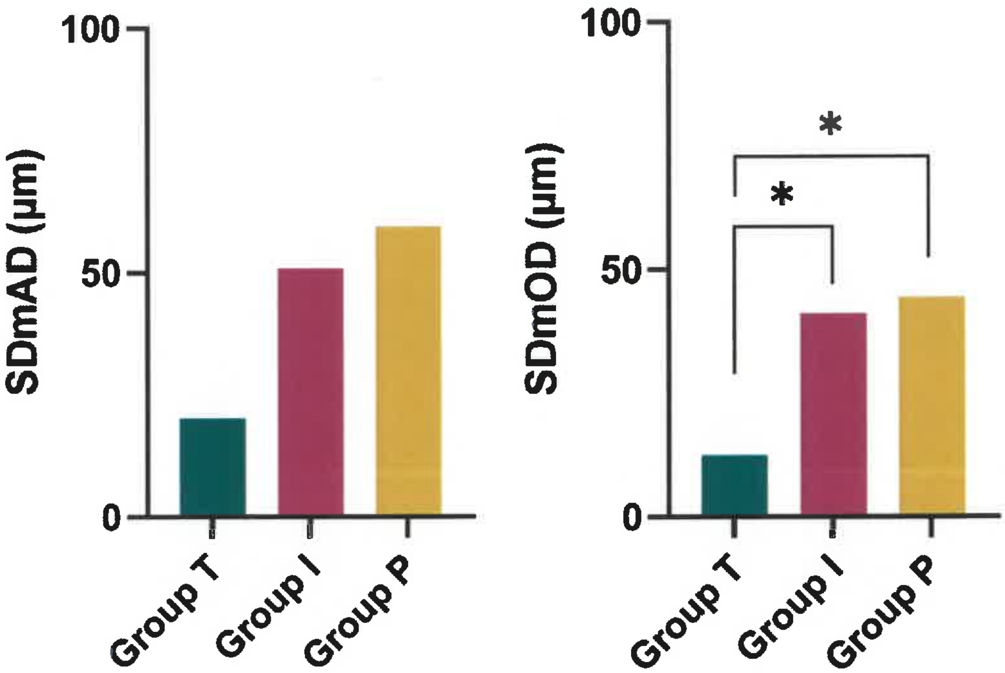

Figure 12. Precision of resin-based mandibular complete denture assessed using SDmAD and SDmOD. Asterisks indicate statistically significant differences among the groups ($p < 0.05$). SDmAD, standard deviation of the mean absolute deviation. SDmOD, standard deviation of the mean of original deviations.

4. DISCUSSION

The results of this study revealed significant differences in the accuracy of 3D scan data depending on the type of intraoral scanner and denture base material, leading to the rejection of the null hypothesis. These findings emphasize that the choice of the intraoral scanner can substantially impact the accuracy and fit of complete dentures under specific conditions.

For the resin-based maxillary complete denture, Group T demonstrated significantly superior accuracy compared to the other two groups. This can likely be attributed to the advanced optical sensors and data processing algorithms employed by the Group T scanner, which enhanced its ability to capture complex anatomical structures and the extensive palatal surface area (D'Ambrosio et al., 2023; Le Texier et al., 2024). Conversely, for the metal-based maxillary complete denture, the mAD analysis revealed no significant differences among the groups, while the RMS-based analysis showed minor differences. The use of a scanning spray may have mitigated variations in optical sensor performance by addressing the challenges of reflectivity on metal surfaces. However, in the RMS analysis, Group P showing significantly lower trueness than Group I in the RMS analysis might be due to the tendency of RMS calculations to accentuate deviations as a result of the squaring process. For the resin-based mandibular complete denture, no significant differences were found among the groups in the mAD analysis. However, the RMS analysis indicated that Group T outperformed Group P in terms of trueness. This might be attributed to the smaller and less complex anatomy of the mandibular arch, which reduces distortion and variance in the scan data.

Overall, the Group T scanner consistently demonstrated the highest or equivalent trueness across all conditions, irrespective of arch type or denture base material, underscoring its reliable performance in diverse clinical settings. In contrast, the Group I scanner faced challenges in achieving high trueness for the resin-based maxillary complete denture, while the Group P scanner showed limitations in handling both metal-based maxillary and resin-based mandibular complete dentures.

Precision evaluations using SDmAD and SDmOD revealed similar patterns. The Group T scanner consistently demonstrated superior or equivalent precision under all tested conditions. In contrast, the Group I scanner showed reduced precision for the resin-based maxillary complete denture, while the Group P scanner exhibited lower precision for the resin-based mandibular complete denture. For the metal-based maxillary complete denture, no significant differences in precision were observed among the groups, likely due to the use of a scanning spray that minimized performance disparities.

The dual application of mAD and RMS for assessing trueness and precision was intended to provide a comprehensive evaluation of intraoral scanner performance. While both mAD and RMS are widely recognized metrics for trueness, methods for evaluating precision vary across studies (CA et al., 2019; Ender & Mehl, 2013). Notably, trueness assessment commonly involves the superimposition of 3D scan data from intraoral scanners onto reference scan data to calculate mAD or RMS—a method extensively adopted in existing literature However, precision assessment presents a distinct challenge: the exclusion of reference scan data necessitates a significantly larger number of superimpositions, resulting in a more complex and time-intensive process. To address these limitations and align with ISO 5725-1:2023 definitions, recent studies have proposed using standard deviation as a metric for precision, offering a streamlined and standardized approach.

Oh et al. (2020) introduced a method for expressing precision by calculating the standard deviation of mean values derived from repeated intraoral scans while retaining the signs of the deviations (Li et al., 2022; Oh et al., 2020). For instance, in 10 intraoral scans, 10 mean values with their respective signs are generated, and the standard deviation of these serves as a precision metric. Conversely, other studies have assessed precision using the standard deviation of mean values obtained after converting deviations into absolute values, disregarding the sign, following repeated scans (Revilla-León et al., 2023; Revilla-León et al., 2020). This study employed both signed and absolute deviation-based standard deviation methods to provide a multidimensional perspective. Adopting standard deviations as representative values precludes the use of error bars in graphical representations (Revilla-León et al., 2020).

An industrial scanner was employed as a reference to enhance data accuracy. This scanner provides high-precision data without requiring scanning spray, minimizes errors due to surface reflectivity, and ensures consistency in experimental conditions. Additionally, a three-point alignment using triangular markers was utilized to improve data registration accuracy. According to Revilla-León et al. (2023), such optimized alignment methods achieve higher precision compared to landmark-based alignments, which informed the alignment process in this study (Revilla-León et al., 2023).

From a clinical perspective, errors occurring during the scanning phase have been reported to fall within acceptable ranges according to previous studies, with trueness errors reported up to 433 μm and precision errors up to 299 μm (Braian & Wennerberg, 2019; Kernen et al., 2022; Revilla-León et al., 2020). In this study, Groups T and I consistently achieved trueness values below 200 μm in most cases, aligning with the acceptable ranges established by prior research and demonstrating clinically reliable scan data. In contrast, Group P exhibited deviations exceeding 400 μm in some instances. While higher, such deviations are common in complete denture scans and may remain clinically acceptable (Kernen et al., 2022; Revilla-León et al., 2020).

From the perspective of precision, Group T demonstrated exceptional consistency, with deviations below 50 μm, indicating high clinical reliability. Groups I and P, while exhibiting slightly greater variability in certain cases, remained mostly within 100 μm, which is still considered clinically acceptable. These findings confirm that Groups T, I, and P are all suitable for clinical applications in terms of trueness and precision. However, Group T consistently showed the lowest deviations, making it the most reliable choice. Groups I and P also performed acceptably, particularly under specific clinical conditions and requirements.

One limitation of this study was the inability to compare scans of the metal-based complete denture with and without the application of scanning spray. Moreover, the study did not account for a diverse range of arch sizes and shapes, limiting direct comparisons for complete denture replications. Although the experimental environment was controlled and ideal, real-world variables such as scan speed, angulation, computer specifications, patient movement, and saliva may limit the generalizability of the findings to clinical settings. Nevertheless, this study successfully compared state-of-the-art intraoral scanners and evaluated differences in trueness and precision based on denture base materials, emphasizing the importance of scanner selection in clinical practice.

This study highlights the importance of selecting an appropriate scanner in the digital workflow to optimize the trueness and precision of 3D scan data. The results provide valuable insights for enhancing clinical decision-making and operational efficiency in dental practice. Future studies should focus on broader arch sizes, more complex clinical scenarios, and a wider range of intraoral scanners to further validate and expand these findings.

5. CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1. The TRIOS 5 scanner demonstrated superior or equivalent trueness and precision compared to the i900 and Primescan scanners, regardless of arch type or denture base material, including resin-based maxillary and mandibular dentures as well as the maxillary metal-based denture.

2. The i900 and Primescan scanners exhibited varying performance under specific conditions but consistently provided clinically acceptable levels of trueness and precision.

3. While the three intraoral scanners showed significant differences in trueness and precision depending on the analysis method and conditions, all scanners delivered results within clinically acceptable limits.

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Abstract in Korean

구강 스캐너를 이용하여 획득한

총의치 내외면 3D 스캔데이터의 정확도 분석

구강 스캐너의 성능이 크게 향상되었음에도 불구하고, 이를 이용하여 총의치 내외면의 3D 스캔 데이터의 정확도를 분석한 연구는 드물다. 이에 본 연구는 다양한 구강 스캐너를 이용하여 획득한 총의치 3D 스캔 데이터의 정확도를 비교 분석하는 것을 목적으로 하였다. 연구는 세 가지 유형의 총의치(상악 레진상 총의치, 상악 금속상 총의치, 하악 레진상 총의치)를 대상으로 수행되었으며, 열중합형 의치상용 레진을 사용하여 총의치를 제작하였다. 각 총의치에는 3D 스캔 데이터 정렬을 위한 기준점으로 3 개의 마커를 부착하였다. 참조 3D 스캔 데이터는 산업용 스캐너를 사용하여 총의치 내외면을 스캐닝 스프레이(scanning spray) 없이 획득하였다. 이후, 각 총의치의 내외면을 TRIOS 5 (T 군), i900 (I 군), Primescan (P 군)의 세 가지 최신 구강 스캐너를 이용하여 스캐너당 10 회씩 스캔하여 데이터를 획득하였다. 단, 상악 금속상 총의치의 경우 금속 반사를 최소화하기 위해 스캐닝 스프레이를 적용하였다.

구강 스캐너로 획득한 3D 스캔 데이터를 세 점을 이용한 최적화 정렬(best-fit alignment)법을 사용을 사용하여 참조 데이터와 정렬하였다. 정확도(accuracy) 평가는 ISO 5725-1:2023 가이드라인에 따라 수행되었다. 진실도(trueness)는 평균 절대 편차(mean absolute deviation, mAD)와 제곱근 평균 편차(root mean square, RMS)로,

정밀도(precision)는 평균 절대 편차(mAD)의 표준 편차(SDmAD)와 원 편차(original deviation)의 표준 편차(SDmOD)로 평가하였다. 진실도를 평가하기 위하여 Kruskal-Wallis 검정을, 정밀도를 평가하기 위하여 Levene's 검정을 이용하였으며, 유의 수준(α)은 0.05 로 설정하였다.

상악 레진상 총의치에서는 T 군이 다른 군보다 유의미하게 높은 진실도를 나타냈다. 상악 금속상 총의치의 경우, mAD 분석에서는 유의한 차이가 없었으나 (p = 0.532), RMS 분석에서는 I 군이 P 군보다 유의미하게 높은 진실도를 보였다 (p = 0.002). 하악 레진상 총의치에서는 mAD 분석에서 유의한 차이가 없었으나 (p = 0.289), RMS 분석 결과에서는 T 군의 진실도가 P 군보다 유의미하게 우수했다 (p < 0.001). 정밀도 평가에서는 상악 레진상 총의치에서 T 군이 I 군보다 유의미하게 더 낮은 SDmAD 값을 나타냈다 (p < 0.001). 그러나 SDmOD 에서는 군 간 유의한 차이가 없었다 (p = 0.055). 상악 금속상 총의치에서는 SDmAD (p = 0.496)와 SDmOD (p = 0.239) 모두에서 유의차가 관찰되지 않았다. 하악 레진상 총의치에서는 SDmAD 분석에서는 유의차가 없었으나 (p = 0.094), SDmOD 분석에서는 T 군이 다른 군들에 비해 유의미하게 우수한 정밀도를 보였다 (p = 0.007 vs. I 군; p = 0.005 vs. P 군).

본 연구를 통해 구강 스캐너와 총의치 종류가 총의치 3D 스캔 데이터의 정확도에 영향을 미칠 수 있음을 확인하였다. TRIOS 5 는 모든 조건에서 다른 구강 스캐너에 비해 일관되게 우수하거나 동등한 수준의 진실도와 정밀도를 보여주며, 다양한 조건에서도 뛰어난 성능을 발휘하였다. 그러나, 평가된 모든 구강 스캐너가 임상적으로 허용 가능한 정확도 범위 내의 결과를 제공하였으므로, 세 가지 구강

스캐너 모두 총의치 3D 스캔 데이터를 획득하는 데 실질적으로 활용 가능할 것으로 판단된다.

핵심되는 말: 총의치, 구강 스캐너, 최적합 정렬, 3D 스캔 데이터, 정확도, 진실도, 정밀도