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Accuracy of Three Intraoral Scanners in Digital Impressions: An In Vitro Study

3종 구강스캐너의 정확도 비교 평가를 위한 비임상 연구

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치의과학과 치과생체재료과학 전공

박 정 원

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지도교수 임 범 순

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Abstract

Accuracy of Three Intraoral Scanners in Digital Impressions: An In Vitro Study

Jung-Won Park, *BS*

Department of Dental Biomaterials Science

Graduate School, Seoul National University

(Directed by Professor Bum-Soon Lim, *Ph.D.*)

As a result of the technological advances, digitalization is being applied in various areas of dentistry. As intraoral scanners are widely used for digital impression with the advantage of being easy to use and comfortable for patients, many studies are being conducted. However, new intraoral scanners with various mechanisms and characteristics are constantly pouring out, and comparative evaluation for clinical application is continuously needed. The purpose of this study is to evaluate and verify the

performance of the intraoral scanner through trueness and precision comparison.

In this study, trueness and precision are evaluated for the accuracy comparison of intraoral scanners (ISO 5725). The object was designed with the CAD software (Solidworks^{TM} 2016, 3D Systems SolidWorks Corp., Waltham, MA, USA) and the model was fabricated from the NextDent C&B MFH (3D Systems, Rockhill, USA) using the 3D printer (NextDent 5100, 3D Systems, Rockhill, SC, USA). Inlay, Onlay and three-unit Bridge were produced by representing deep and narrow forms frequently used in clinical practice, and the same resin model was used in all experimental groups. Three types of intraoral scanners were evaluated: TRIOS 4® (3 Shape, Copenhagen, Denmark), I500 (Medit Co, Seoul, South Korea), COMFORT+ (DDS, Seoul, South Korea), and five scan data were obtained by the same trained researcher for consistency. The acquired data was superimposed with the reference data by the 'best-fit alignment' of the Geomagic Control X^{TM} (3D Systems, Rock Hill, SC, USA) software, and the tolerance range was set to ±30㎛ for 3D comparison to calculate RMS (Root Mean Square). For comparison, the one-way ANOVA and Bonferroni t-test were performed with a significance level of 0.05.

For trueness, the RMS values in the Inlay (36.32㎛~37.22㎛) model increased in the order of TRIOS4, COMFORT+, and I500, but

the trueness tended to decrease. In Onlay (35.98μm~37.22μm) and three-unit Bridge (52.24μm~ 56.64μm) models, RMS values increased in order of I500, TRIOS4, and COMFORT+, but the trueness tended to decrease. But no significance was found between each scanner group on the All pairwise multi-analysis Bonferroni t-test ($p>0.05$). For precision, there was a significant difference between TRIOS4 and I500, I500 and COMFORT+ in the Inlay model (respectively $p=0.027$, $p<0.001$). In the Onlay and three-unit Bridge models, a significant difference was found between COMFORT+ and the remaining two intraoral scanners (TRIOS4, I500).

Trueness and precision are lowered if the optimal distance between the scanner and the model is not maintained due to the narrow and deep part such as a three-unit bridge or the insufficient space between the units. Thus, errors tend to accumulate when the scan range increases. This study provides accuracy information on intraoral scanners, contributing to decision making it offer a view on which intraoral scanners is appropriate for use.

Keyword : digital impression, intraoral scanner, trueness, precision, best fit alignment
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Contents

Ⅰ. INTRODUCTION

Nowadays, as a result of technological advances, digitalization exists around us in various areas. Dentistry is no exception. The application of digitalization spans a wide range of areas of dentistry. Digital dentistry is a corresponding meaning to analog, and includes not only a series of diagnostics, treatment, and evaluation in the clinical dentistry, but also electronic charts for recording. Specifically, patient-related informations including medical history, systemic diseases, use of drugs, allergy, oral conditions identified through clinical examination information, materials used for treatment, as well as visits, receipt, and reservation status can be recorded and checked in an electronic chart in the hospital, and it is used for all digital activities. In addition, it can be used in many fields of dental areas, such as digital radiographs, impression taking, production of restorations, and replacement of defective structures. In the case of radiographs, it is possible to easily manage data through actions such as acquisition and storage as well as transmission using PACS (Picture Archiving and Communication System) based on digitalization of images, thereby facilitating communication and reducing cost and time. Thus, in the process of producing customized prothetics, immediate feedback is possible through the network between the dentist and the dental technician, and the need for it is further increased in areas that require aesthetics by predicting the appearance after prosthetics. The aforementioned prosthesis means artificial alternatives, including simple forms such as inlay, crown, provisionals to complex forms like a mouth guard for bruxism, surgical guides, and dentures. In summary, the digital workflows is as follow: digital planning, design, and fabricating. Planning, which is the first step as one of the important stages, makes the results predictable. Thus, CAD/CAM simplify the process because they do not require a replication[1,2]. That is to say, it can be involved in all stages related to design and production, and there are additional functions such as the digital shade matching process of the final prosthesis. The function of digital shade selection can be used as digital equipment such as T3 (TRIOS3 intraoral scanner) or SS (SpectroShade spectrophotometer). However, the colors obtained by each equipment (T3, SS) may be different, in some cases, additional instrument may be needed to determine the color[3]. Materials are also developing over a wide range of areas, including composite resin, ceramics, zirconia, and titanium. In particular, most of the materials currently used, such as PMMAs, composite resin, and ceramics, have a high success rate from a long-term perspective[4]. Based on the advantages of user-friendly and patient-friendly, the digital dentistry is gradually expanding in terms of biocompatibility, aesthetics, and functionality. Accordingly, it is continuous efforts to change into a paradigm toward digital dentistry, and computer-aided technology has been continuously evolving to meet demands.[5]

Although digital impression taking using intraoral scanners has been widely used with a lot of advantages such as decreased storage space, brief chair time, better hygienic and economic reasons, it is questionable whether it is reliable technology for use in clinical dentistry.[5,6] Controversy still exists, various efforts are being made to evaluate and prove the accuracy and clinical applicability of intraoral scanners.[5] Wahle and Ahlholm noted that the maximum clinical acceptable range for marginal opening is 80 to 120 μm. [7,8]

It is no exaggeration to say that intraoral scanners have developed with Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technology. The technology was first introduced to the dental field in 1970s by Dr.Duret[9]. In 1980s, the first intraoral scanner using CAD/CAM was announced by Dr.Mőrmann and Brandestini, and commercially available in 1987 under the name of CEREC® (Sirona Dental systems LLC, Charlotte, USA)[10]. As mentioned above, the introduction of intraoral scanners compensated for the weakness of conventional impressions. In a study written by Mörmann et al.[11], CEREC is an abbreviation for CERamic REConstruction, as the name suggests, it uses ceramic materials. In the aforementioned study, the subsequent development process was also mentioned, and intraoral scanners can be largely considered as hardware and software in the process. In terms of hardware, starting with a CEREC1 called 'lemon' because of its color, the CEREC operating system has been evolved into CEREC2 with upgraded 3D camera. Subsequently, it has developed into CEREC3, which has become more sophisticated in image acquisition, design, and machining stages. In respect of software capability, it was improved from 2D to 3D, and prosthetics were diversified from initial single tooth restoration such as inlay, onlay, and veneers to multi-unit bridges. Also, automatic virtual occlusion adjustment was possible. Since then, various studies on the high trueness and precision of intraoral scanners have been actively conducted in areas such as orthodontics and implants[12,13]. To date, CAD is able to reproduce aesthetically and functionally superior prosthetics, but its usage is gradually becoming simple. In the same vein, the CAM is becoming more accurate and sophisticated, while its size is decreasing[4]. Digital impression has been continuously developed because it is very important for dental digitalization as the first step in the entire digital workflow. Currently, intraoral scanners using various mechanisms and light sources have been advanced, expanding the range of choices[14].

Most intraoral scanners used in clinical dentistry have LED as a light source, and images are acquired to create 3D images through video methods. There are some differences in data capturing principles, field of view (FOV), and depth of field (DOF) by manufacturer, so caution is required in clinical applications. Many experimental studies using various types of intraoral scanners have been reported, but new types of intraoral scanners are also constantly being introduced. Therefore, it is necessary to compare and evaluate the accuracy of newly introduced intraoral scanners with existing intraoral scanners for clinical application. In many studies, trueness and precision was assessed in accordance with ISO 5725 to compare the accuracy of intraoral scanners, and a discrepancy was shown in three-dimensional using root mean square (RMS) values as indicators of error. Specifically, precision is measured repeatedly using each intraoral scanner, trueness is measured using intraoral scanners with a model scanner as reference.[15]

In order to make an accurate prosthesis, various aspects such as the starting point of the scan, the direction of progress, and the location·angle·range of the scanners should be considered. Nagy et al.[16], measured the accuracy at various points of the teeth with seven types of intraoral scanners, which most scanners indicated that the error increased as it moved away from the location where the scan started. In addition, Park et al.[17], also noted that errors tend to accumulate from the starting point in the entire scan process. Therefore, if treatment is required, the scanning strategy is recommended to obtain the teeth that need restoration first[18]. As previously described, it is necessary to pay attention to the starting point when designing the experiment and applying clinical dentistry. Müller et al.[19], obtained different scan images according to the scan order and evaluated the trueness and precision. If the scan was obtained in the order of occlusal-palatal and buccal, the trueness was higher than that of scanning by conversely acquiring or drawing the 'S' shape, but it was not a significant level. On the other hand, in terms of precision, when proceeding in the order of buccal and occlusal-palatal, the error was the highest compared to the other two groups, which was statistically significant. Considering this, it can be seen that the method with the highest trueness and precision of occlusal−palatal and buccal surface. In addition, it can be considered that the intraoral scanner should be placed horizontally in a state perpendicular to the focal plane to get a relatively accurate scan image, and given an angle of 60 degrees or more, considering that a smaller angle makes the larger error[5,20,21].

As such, there are several factors related to the intraoral scanner itself, but it may also be affected by external factors such as a operator's ability using the scanner or the environment in which an image is obtained. So it should be examined. Giménez et al.[14], noted that the presence of experience can affect the results because the scan images obtained by experienced operator exhibit higher accuracy than that obtained by the inexperienced. Similarly, in an experiment involving three operators with different degrees of experience (high; more than 2 years, medium; more than 1 years, low experience; only the training), the operator with the least experience only going through the training for the study showed the lowest precision value with a significant level[22]. Also, there were significant differences in all experimental groups regardless of the number of implants in three clinical scenarios[23]. However, experience is a very subjective part. Even if you have experience of the same number or period, the degree of adaptation varies depending on your ability[18]. So caution is required when interpreting the results. Next, sometimes software becomes unstable by losting tracking during digital impression acquisition. This phenomenon can happen when the distance between the intraoral scanner and the object or scan path is not sufficiently retained, because the movement is too fast or twitchy[24]. Therefore, it is recommended that the re-scan starts from an easy region such as occlusal surfaces of posterior teeth. In the aforementioned way, even if tracking is missed, the software can obtain sufficient infromation[25]. In order to continue scanning, rescanning should be started from the meaningful area to make it easy for the camera and the software to recognize.

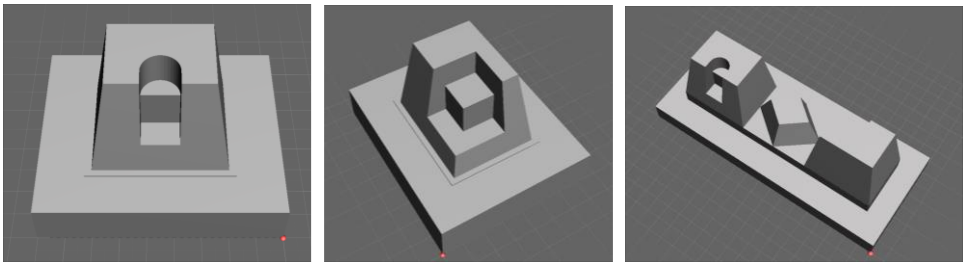
In other aspect, reflection of light may be considered. That is, periodontal tissue with a reflective surface, such as enamel, can interfere with POI (Points Of Interest) maching by software due to excessive exposure[24]. For the aforementioned reasons, polarizing filters or powder application of uniform thickness may be required to adjust the reflection of light depending on the type of intraoral scanner[26,27]. Specifically, the powder needs to be applied uniformly to the thickness of 20-40μm, and there is a risk of powder inhalation or possibility of additional application if contaminated by saliva, which can lead to a longer time[6,24]. As another light-related consideration, Revilla-León et al.[28], stated that it is better to obtain a digital impression in a specific lighting condition on the types of intraoral scanner to acquire high accuracy scan images. In the previous study, iTero Element Scanner showed high trueness and precision in chair (10,000 lux) and room light (1,003 lux). On the other hand, for CEREC Omnicam, zero light (0 lux) improved the values, and the TRIOS3, room light provided better values.

Last, as interesting studies related to the acuuracy of the intraoral scanners, there were various experiments on the scanbody used for digital impression. First of all, the more exposed parts of the scanbody, the more accurate digital impression can be obtained. So it is recommended to use a longer type of scanbody if the implant is deeply planted[18]. In addition, it was said that the quality of digial impression obtained by intraoral scanners may vary depending on the geometry of the scanbody[29,30]. Furthermore, when acquiring a full-arch digital implant impression, it was found that the accuracy differs according to the material of the scanbody, and peek(Polyetheretherketone) showed the best results in linear and angular measurements, followd by titanium and peek-titanium[31]. In terms of surface roughness, it also affects the scan accuracy, because the smoother surface makes less noise, so a better scan image could be acquired[32,33]. Splinting the scanbody by assembling the modular chains can increase the accuracy of the intraoral scanner at a low cost[34]. As such, there are diverse studies connected the accuracy of intraoral scanners, but this study attempted to construct comparative experimental datasets by evaluating and verifying the performance of the intraoral scanner itself first.

Therefore, in this study, it will be basis for implementing and developing excellent prosthetics with stable and high suitability by comparing and evaluating the accuracy according to the types of intraoral scanners. The purpose of this study is to compare three different intraoral scanners through objective RMS values, recognizing that it is necessary to evaluate trueness and precision of intraoral scanners in the current situation, where new intraoral scanners are pouring out.

Ⅱ. MATERIALS AND METHODS

The study utilized reference models (Figure 1) using a Computer Aided Design (CAD) software (Solidworks 2016^{TM}, Dassault Systèmes SolidWorks Corp., Waltham, MA, USA), and the object was produced by a 3D printer based on DLP (Digital Light Processing) technology (Figure 2). The materials for 3D printing was NextDent C&B MFH (3D Systems, RockHill, SC, USA).



(A) (B) (C)

Figure 1. STL file of reference models used in this study: (**A**) Inlay, (**B**) Onlay, (**C**) Three-unit Bridge model.

(A) (B) (C)

Figure 2. Reference models were printed by 3D printer: (**A**) Inlay, (**B**) Onlay, (**C**) Three-unit Bridge model.

Before pouring in the resin tray of the printer, stirring device (LC-3DMixer, 3D Systems, RockHill, SC, USA) was used for mixing 3D printing materials (Figure 3). Because only handshaking is insufficient for optimum consistency, the device should be used to completely mix the materials. After printing is completely finished, a platform is removed from the 3D printer (NextDent 5100, 3D Systems, RockHill, SC, USA) and washed in a pre-prepared IPA solution. Then, the model is removed with an instrument. Next, moving the model to the newly prepared IPA solution, put it in an ultrasonic cleaner (Saehan ultrasonic, Seoul, South Korea) and wash it for 5 minutes. Afterward, dried model is put into a post-curing machine to conduct post-curing (LC-3D Print Box, 3D Systems, RockHill, SC, USA) for 30 minutes. Finally, take out the model and use the remover to get rid of unnecessary parts such as supports and complete it.

Reference models consist of Inlay, Onlay, and three-unit Bridge models, reproducing the shape of representative prosthetics commonly used in clinical dentistry (Figure 2). The International Standard Model (ISO 20896-1) was difficult to reproduce various type of deep and narrow forms used in clinical dentistry, so the model was designed in consideration of various forms that could be produced in chairside position to meet the purpose of the study. In other words, models were designed to evaluate accuracy by acquiring digital impressions with intraoral scanners, and just one model was fabricated and used for each group. Since data were acquired using the same resin model in all experimental groups, it was easy to conduct a comparative evaluation.

(A) (B) (C)

Figure 3. Reference models fabricated by (**A**) 3D Printer (NextDent 5100, 3D Systems, RockHill, SC, USA), (**B**) Post-curing (LC-3DPrint Box, 3D Systems, RockHill, SC, USA), (**C**) LC-3DMixer (3D Systems, RockHill, SC, USA).

Three types of intraoral scanners were tested for this study: TRIOS4® (3 Shape, Copenhagen, Denmark), I500 (Medit Co, Seoul, South Korea) and COMFORT+ (DDS, Seoul, South Korea) (Table 1, Figure 4). Five scan data were obtained according to the type of intraoral scanners. And Identica Hybrid® (Medit Co, Seoul, South Korea) was used to create digital reference data of 3 models. All datasets were measured by the same investigator for consistency. In addition, the scan image was acquired with the same starting point and path, considering that it could affect the result. Trueness was measured as an overlapping value of experimental data compared with reference data, and precision was measured as a value obtained by overlapping experimental data in each group.

Table 1. Characteristics of three intraoral scanners used in this study

Intraoral scanners	TRIOS4	I500	COMFORT+
Manufacturer	3Shape (Denmark)	Medit (Korea)	DDS (Korea)
Existence of wire	Wireless	Wired	Wired
Source of light	Blue LED	Blue or White LED	R/G/B LED
Data capturing principle	Confocal	Triangulation	Triangulation
Acquisition	Video technology	Video technology	Video technology
Weight	375g	280g	350g
Dimension	274x42mm	264x44x54.5mm	263x43x49mm
FOV (Scan area)	17x20	14x13	14x14.5
DOF	16~17	Default: 18.5 Range: 12~21	16

(A) (B) (C)

Figure 4. Intraoral scanners used in this study (**A**) TRIOS4® (3 Shape, Copenhagen, Denmark), (**B**) I500 (Medit Co, Seoul, South Korea), (**C**) COMFORT+ (DDS, Seoul, South Korea).

Scan files of the three experimental scanners were exported to Geomagic Control X™ (3D Systems, RockHill, SC, USA) as STL (stereolithography) files, which is superimposed on reference data using the geomagic software 'best-fit alignment'. Because that alignment is a method of measuring deviation by randomly averaging over the entire surface, we can obtain an accurate value by selecting actual information that we need. Therefore, reference data was edited using the CAD software (Meshmixer v3.5, Autodesk, California, USA). Finally, the tolerance range for 3D comparison was set to $\pm 30\mu m$ to get an RMS value representing a discrepancy in the 3 dimensions. The difference is presumed through the mean and standard deviation of the RMS values to evaluate accuracy of individual scanners. The software used provides a visualization of grade or distribution of the deviations between the model scanner and intraoral scanners at a glance (Figure 5).

Statistical Analysis

Datasets were analysed with SigmaPlot™ (Systat Software Inc., San Jose, CA, USA) for one-way ANOVA to compare the trueness and precision values. All data passed the nomality test. Multiple comparisons were carried out among the three intraoral scanners. Then, Bonferroni test was used for post-hoc test to compare three groups in pairs. The level of significance was set at $p < 0.05$.

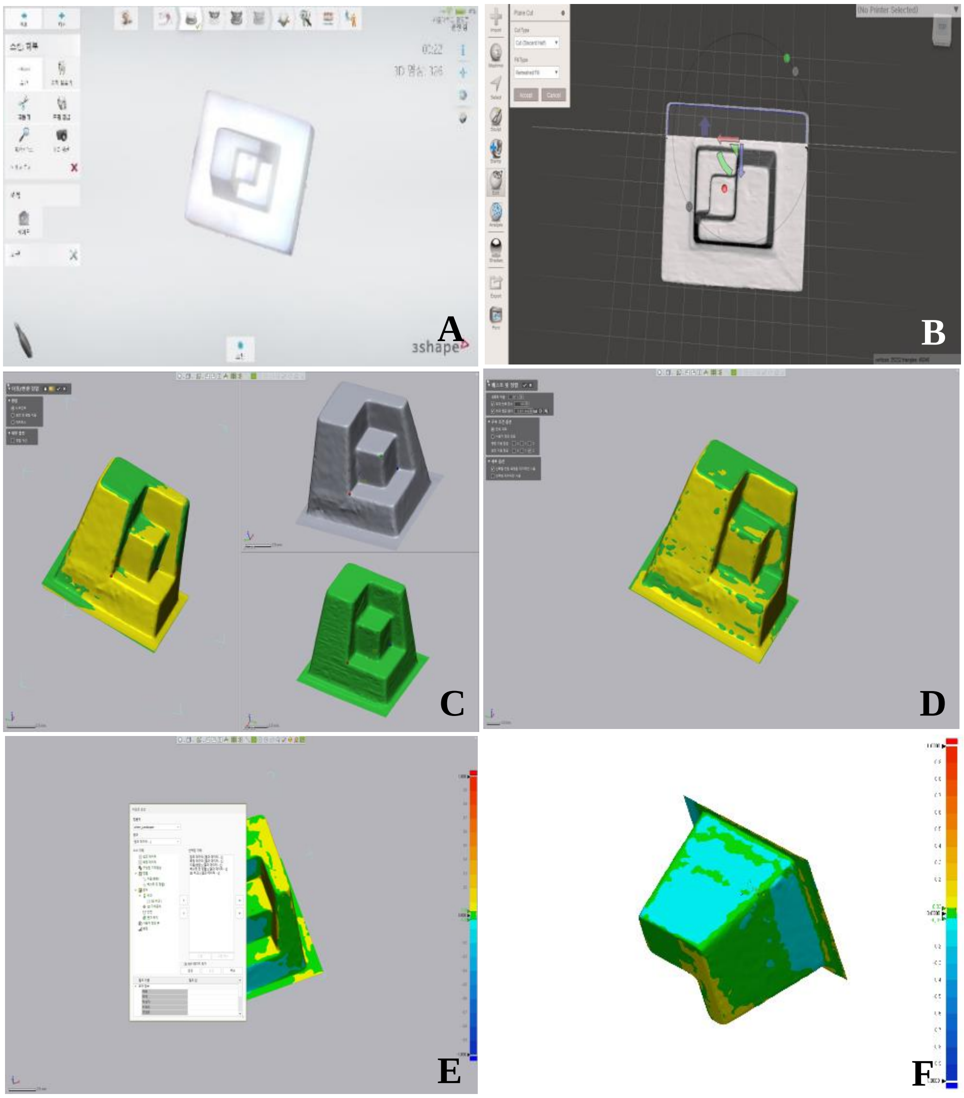


Figure 5. 3D Comparison procedure (tolerance range ±30μm respectively) (**A**) 3D image acquired with intraoral scanners (**B**) Editing using the CAD software (Meshmixer v3.5, Autodesk. California, USA), (**C**) Superimposing data through Point to Point alignment on Geomagic Control X^{TM} (3D Systems, RockHill, SC, USA), (**D**) Best-fit alignment, (**E**) Measuring overlapping value of experimental data, (**F**) Deviations expressed in a color-coded image.

Ⅲ. RESULTS

3.1. Trueness

Scan datasets (STL) of the model scanner (Identica) and intraoral scanners (TRIOS4, I500, and COMFORT+) for three reference models were obtained. One experimental data of the model scanner for each model and five data of intraoral scanners were obtained, and the trueness of the intraoral scanner was calculated by superimposing two objects on 3D. The means of the trueness RMS value are shown in Table 2. The trueness RMS value for three experimental groups with reference data is summarized in Figure 6.

First, looking at error value in the Inlay model, the RMS value for TRIOS4 was the lowest on mean at 36.32μm, followed by 36.90μm and 37.22μm, respectively, in the order of COMFORT+ and I500. But trueness tended to decrease. On the other hand, in the Onlay and three−unit Bridge models, the RMS values in the I500 experimental group were the lowest at 35.98μm and 52.24μm, respectively. The value gradually increased in order of TRIOS4 and COMFORT+, but the trueness tended to decrease. In the three−unit Bridge model, when statistically analysed with one−way ANOVA, there was a significant difference between intraoral scanners. Although COMFORT+ showed relatively high RMS values for trueness in all three types of models, no statistically significant differences were found between each intraoral scanner on the All pairwise multi−analysis Bonferroni t−test ($p>0.05$).

In three−unit Bridge models, regardless of scanner type, it was confirmed that the means and deviations of trueness RMS value were higher than other models (Inlay, Onlay), which could be considered as having a lower ability to represent the experimental data in a state close to reference data. In other words, as the RMS value between the model scanner and the intraoral scanner image rise, the deviation also increases and the trueness decreases.

Table 2. The mean and standard deviation of trueness (mean ± SD of RMS)

Trueness	n	TRIOS4 (μm)	I500 (μm)	COMFORT+ (μm)
Inlay	5	36.32 ± 1.602	37.22 ± 3.112	36.90 ± 1.812
Onlay	5	36.30 ± 1.935	35.98 ± 0.698	37.22 ± 0.998
Three-unit Bridge	5	52.62 ± 1.773	52.24 ± 1.798	56.64 ± 3.564

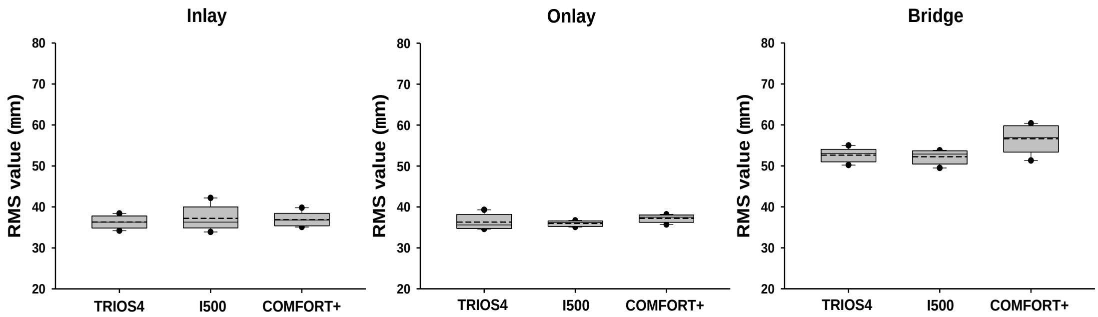


Figure 6. Box plots of the trueness RMS value for three experimental groups with reference data. (**A**) Inlay model, (**B**) Onlay model, (**C**) Three-unit Bridge medel.

Finally, when the tolerance range of the error was set to 30μm, the distribution of the deviation for the superimposed mesh file was shown (Figure 7). As mentioned above, for three-unit Bridge model, a relatively large RMS value could be found. Especially errors in the superimposed area were distributed in narrow, deep parts. In addition, it can be seen that the error increases as the range of the scan widens.

3.2. Precision

The RMS value for precision was obtained by overlapping the data acquired by three types of intraoral scanners. The measured RMS values have 10 values for each experimental group, and the mean of the precision RMS value is calculated and presented in Table 3. The error values for three experimental groups are summarized in Figure 8.

According to the results of precision deviation analysis for the three types of intraoral scanners used in this study, the RMS value of I500 was the lowest in all reference models. Specifically, in the Inlay model, the I500 was statistically significant lower than TRIOS4 and COMFORT+ (p = 0.027 and p <0.001, Figure 8A). Notable, there was no statistically significant difference between TRIOS4 and COMFORT+ (Figure 8A). However, on the Onlay model, TRIOS4 and I500 showed significantly lower RMS values compared to COMFORT+ (p <0.001, Figure 8B). Last, in the three-unit Bridge model, like the Onlay model, COMFORT+ showed significantly higher RMS values in both TRIOS4 and I500 (p =

0.002, $p<0.001$, Figure 8C).

In the case of I500 and COMFORT+, it was assessed that the standard deviation of the Onlay group for the precision RMS value was lower than that of the other two groups. In Onlay model, it could be interpreted that even if the scan image is acquired several times, the error between the obtained scan data appears relatively small.

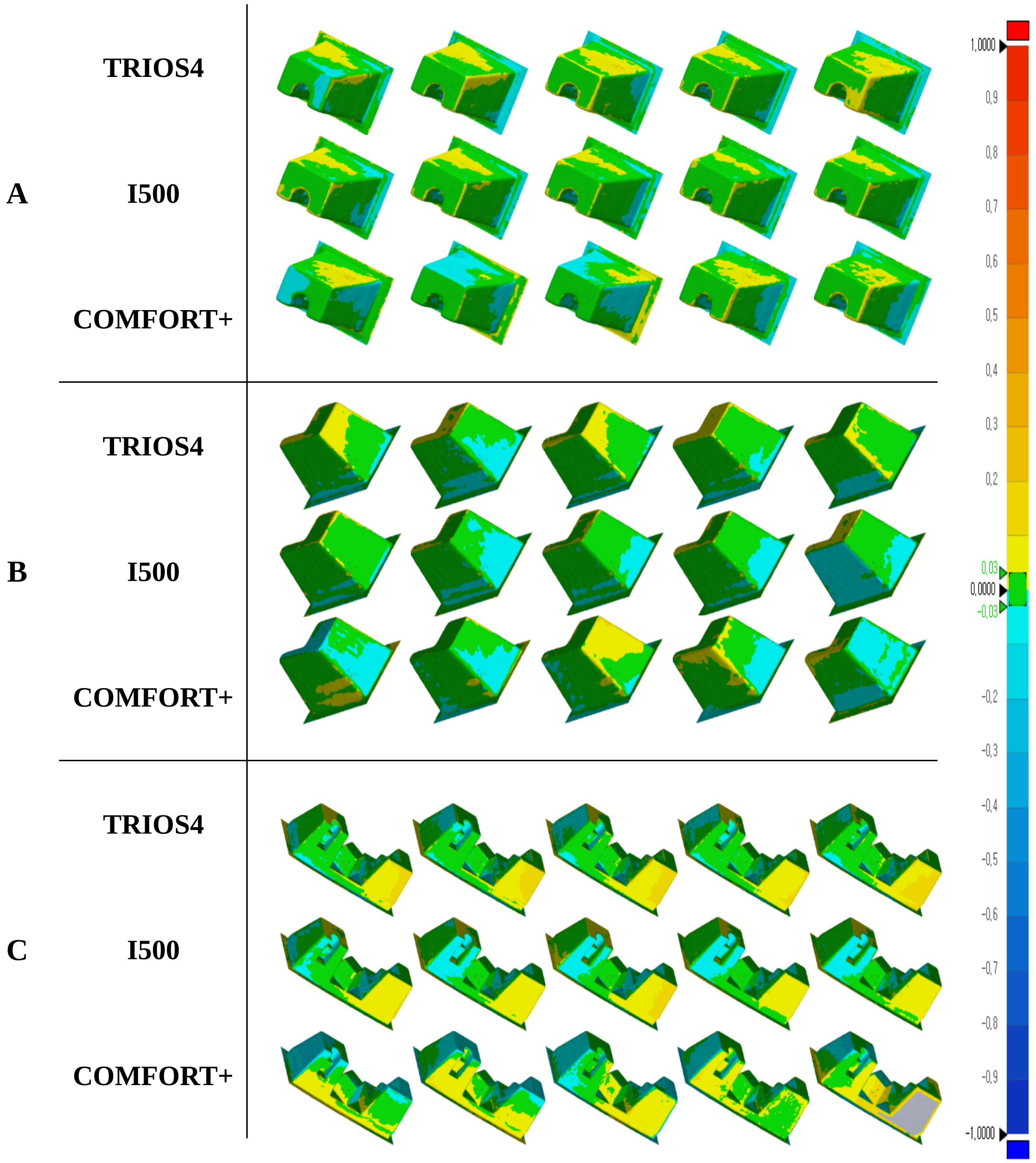


Figure 7. Color-coded image of error distribution according to three experimental groups with the reference models. (**A**) Inlay model, (**B**) Onlay model, (**C**) Three-unit Bridge model.

Table 3. The mean and standard deviation of precision (mean ± SD of RMS)

Precision	n	TRIOS4 (μm)	I500 (μm)	COMFORT+ (μm)
Inlay	10	29.55 ± 5.658	22.64 ± 1.825	36.52 ± 8.739
Onlay	10	31.26 ± 4.677	26.55 ± 0.787	44.71 ± 6.473
Three-unit Bridge	10	27.04 ± 1.906	25.22 ± 3.471	60.39 ± 10.796

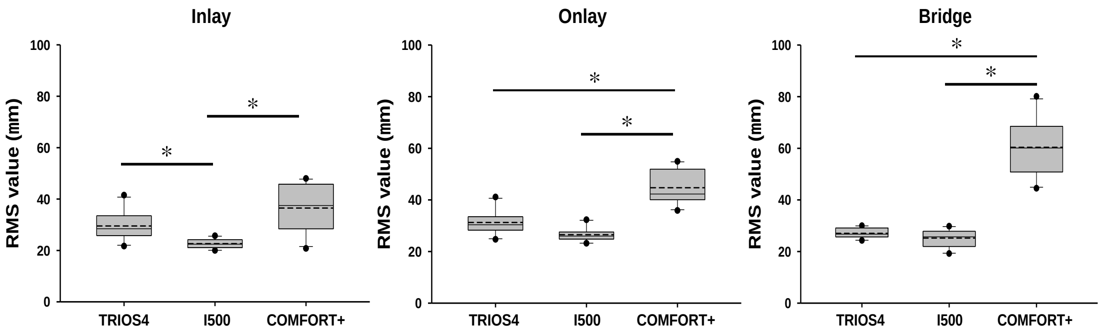


Figure 8. Box plots of the precision RMS value for three experimental groups, *p <0.05 by Bonferroni test: (**A**) Inlay model, (**B**) Onlay model, (**C**) Three-unit Bridge model.

Ⅳ. DISCUSSION

The aim of this study is to compare the accuracy (trueness, precision) of three different intraoral scanners on the market in the situation where many new scanners are pouring out. TRIOS4 and COMFORT+ are recently released products, and research on the accuracy of the two scanners is insufficient. So, research on newly introduced intraoral scanners is continuously needed. Based on the evaluation, it can be used as basic data for the development of devices that can reproduce more precise oral conditions. Furthermore, the final purpose is to understand the mechanisms and characteristics of intraoral scanners and to recognize that there is an optimal approach when using the scanner, so that they can find the ways to use them appropriately in clinical dentistry to obtain high accuracy scan images.

The specifications of the intraoral scanners used in this study are summarized in Table 1. All of intraoral scanners (TRIOS4, I500, and COMFORT+) are based on the principle that light source is reflected from objects and then recognized through sensors to acquire images, and the obtained images are made in 3D. The image acquisition is performed in a video method, which has the advantage of being able to immediately check the image taken by the real-time rendering method. Since an LED light source is used, scanning may be performed without using a scanning-aid material such as powder.

The three intraoral scanners use dissimilar data capturing principles: TRIOS4 uses confocal technology, so the distance is automatically measured by detecting only light matching the focus. By using that, more accurate image can be acquired. In addition, the distance to the focus is fixed. So, there is no need to make efforts to focus and no special scan strategy is required for full arch[24]. But I500 and COMFORT+ acquire images by recognizing the distance by applying trigonometry as the mechanism of triangulation using structured light. Therefore, the angle between the projector (light source) and the sensor is set in advance, and it is calculated by Pythagoras theorem to obtain 3 dimensional information. In the process, structured light with a pattern such as a stripe is projected onto the object and then the object is obtained, enabling fast and precise scanning[35].

The unique feature of COMFORT+ is that it applies a pattern compression method by using R/G/B LED light sources at the same time. Through this, natural colors can be obtained by uniformly matching the color density of the projected area, thereby enabling rich color expression on 3D. It is possible to clearly distinguish teeth, prostheses, and gums, so that the reproducibility is good. Also, images in a state similar to that of the oral condition can be acquired. Another prominent point is that a scanner, CAD/CAM software, and a milling machine are provided by one manufacturer as an integrated software (D+ Suite Full SW Package, DDS, Seoul, Korea), so that it is possible to produce a simple fixed prosthesis in chairside position. The point is that the attachment of indirect restorations is completed with only one visit. That is to say, it is possible to directly link with CAD software after acquiring a scan data image. When designing is completed, it leads to the CAM prosthesis manufacturing process. So, there is no need to consider compatibility in the process. After manufacturing, it can finish patient treatment immediately (Figure 9).

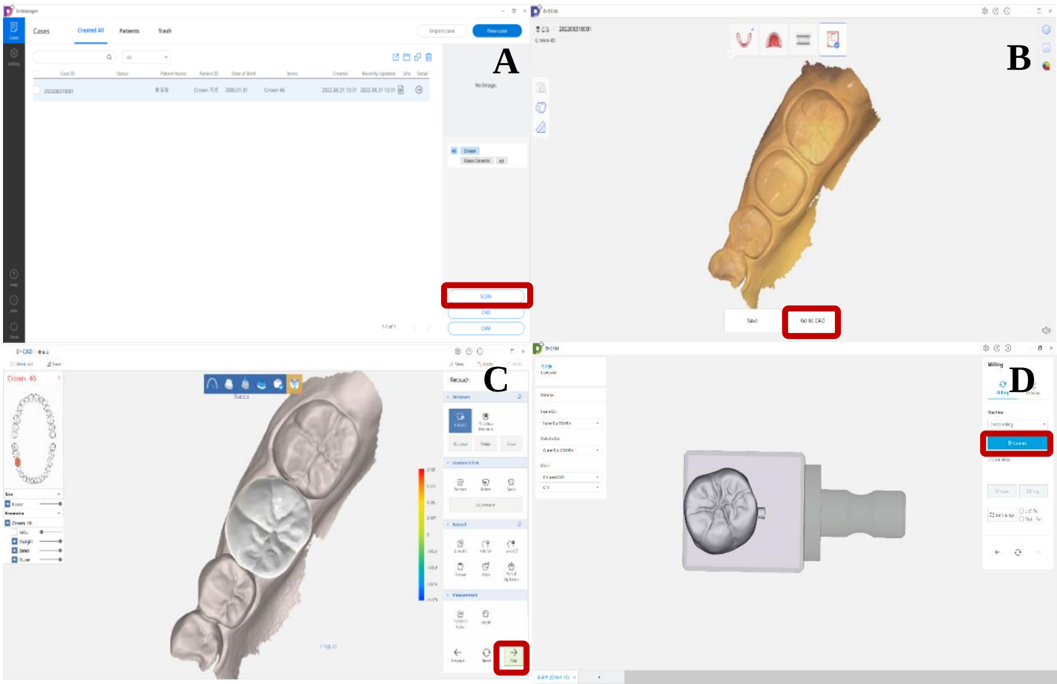


Figure 9. D+Suite Full SW Package (A) D+Manager, Managing created SCAN, CAD, CAM database (B) D+SCAN, Obtaining 3D data of tooth to be treated (C) D+CAD, Supporting functions such as location of prosthesis, margin adjusting etc (D) D+CAM, preparing for milling such as block selection, sprue position etc

Next, looking at the appearance of intraoral scanners, all three types of scanners had similar handpiece sizes, so there was no significant difference in a feeling of grip during use, but the biggest difference was the presence of lines. The TRIOS4 was released as a wireless device, while the I500 and COMFORT+ were launched as a wired device. In particular, in the case of TRIOS4, since it is a wireless product, it was convenient to hold the center of gravity regardless of movement when acquiring a scan image. And it was more comfortable to use because it can be placed at a desired location without considering the position of the PC. In addition, although it is wireless, there was no inconvenience in the resolution or speed that can be felt. Morever, the FOV, which means scan area, was larger than other intraoral scanners, so the scan image was seen at a glance, making it easy to proceed with the scan. Thus, fast scan was possible. Also, there was no need to set up a tooth number or prosthetic form selection because of the "Scan only" mode. Lastly, when the focus was on during the scan, it could be recognized with a click sound rather than a music sound, making it convenient to distinguish it clearly without looking at the screen.

The accuracy of the IOS (intraoral scanner) international standard is described in two terms, the first being trueness and the second being precision[36]. Specifically, the trueness expresses how close the experimental data is to the reference data, and the precision is an indicator of reproducibility of how similar the data separately scanned between experimental groups are.[37,38]

Graffin et al.[39] compared the trueness of five types of intraoral scanners (Element2, I500, Primescan, TRIOS3, and TRIOS4). It showed a high error at I500 than others after scanbody alignment in experienced operators. However, the results of this study suggest that TRIOS4 showed the lowest RMS value in the

Inlay model, the I500 RMS values were the lowest in the Onlay and three−unit Bridge models, but there was no significant difference in the three experimental groups.

Oh at al.[6] noted that in a study analysed trueness and precision using scanning−aid materials the three−unit Bridge model showed low trueness in all groups (Scancure, IP, VITA, No treatment) compared to Inlay and Onlay models. Likewise, in a study evaluating the trueness of 10 intraoral scanners for one−unit crown and three−unit fixed denture preparation models, Zhang at al.[40] stated that there was statistically significant difference between the two preparations for several scanners (TRIOS2, True Definition, CEREC AC Omnicam, DWIOP, Xianlin, DL−100, and I500). In this study, three−unit Bridge showed high RMS values in all experimental groups using all types of intraoral scanners, so it was found that it had low trueness and precision. The reason for the same results in the previous three studies is that the longer the model is, the more the scope of scanning increases, also the error of stitching one image continuously becomes accumulated, as well as the proper distance between the intraoral scanner and the model cannot be maintained[5,41]. Particularly, the tendency to accumulate errors according to the scan range was confirmed in several studies of partial and full−arch. For instance, the study conducted by Imburgia et al.[42] in two situations: partially (PEM) and fully edentulous model (FEM) showed that accuracy and precision values were low in FEM regardless of the type of intraoral scanners (CS 3600, TRIOS3, CEREC Omnicam, True Definition). In addition, based on the above−mentioned correlation, there was a study that limited scan range should be used in clinical practice, such as a 3−unit prosthesis supported by two implants when using intraoral scanners[43]. In this process of using the intraoral scanner, a simple way to overcome space constraints can be compensated by acquiring a scan image from various angles[5].

However, this study has several limitations. First, due to the small number of samples, it is necessary to pay attention to data interpretation to generalize based on the results of this study. Second, because the Inlay, Onlay, and three−unit Bridge models are made of resin using the 3D printer, the insufficient light reflection such as metal light scattering was not fully considered. Especially, it should be noted that the accuracy may vary depending on the material due to the characteristic of the intraoral scanner. That is, scanners detects reflected light from the surface and recognizes the appearance of the model. For example, metal may be less accurate because it reflects more light than the teeth surface. Third, a relatively small model was used, additional studies using the full−arch should be conducted, considering that the deviation may increase as the scan range is wider[17]. Last, since the study was conducted as a laboratory investigation, adjacent anatomical structures were not considered. That is, scanner's movement was not disturbed by the tongue and reflection by saliva. If the study conducts in vivo, the experiment could be carried out in consideration of various obstacles in actual oral conditions.

All types of scanners currently available on the market have various scanning strategies like alignment optimization. It includes precautions for data acquisition, such as scan direction, optimal angle, and appropriate depth recommended by manufacturers. When the scanner and teeth are located at an proper distance, the location and direction of the scanners should be considered. In order to get appropriate data, the roughness or shape of the surface should be pondered in combination. Although active research was conducted on scanning methods that can achieve high accuracy for full arch, there is no established scanning strategy yet[44]. In this study, we tried to evaluate the simple form of prosthetics that are often used on the chairside, such as Inlay and Onlay, by understanding the mechanism, optical properties, and characteristics of intraoral scanners.

From a long-term perspective, whether prosthetics are successful or not depends on the exact marginal fit and internal suitability to the structure of the teeth. Therefore, acquiring an accurate impression is a very important first step in the fabrication of dental prosthetics[45]. From the perspective of acquiring digital image, it means obtaining an accurate scan image. Continuous scanner development is essential in the proper selection and use of scanners in clinical dentistry, which is necessary to obtain high-accuracy scan data. Therefore, this study contributed to quality improvement by verifying and evaluating the performance for clinical use through trueness and precision comparison of images scanned with various resin models. In addition, quantitative evaluation was performed by constructing comparison data.

Furthermore, based on the results of this study, it is intended to contribute to the development of dentistry moving forward to the digitalization by increasing the satisfaction both technicians and patients with an efficient approach to obtain accurate digital impressions.

V. CONCLUSIONS

Despite some limitations given in this study, the following conclusions are drawn:

1. For trueness, the RMS values in the Inlay (36.32 μm~37.22 μm) model increased in the order of TRIOS4, COMFORT+, and I500, but trueness tended to decrease. In Onlay (35.98 μm~37.22 μm) and three-unit Bridge (52.24 μm~ 56.64 μm) models, RMS values increased in order of I500, TRIOS4, and COMFORT+. That is, the trueness tended to decrease. But no significant difference was found between each scanner group on the All pairwise multi-analysis Bonferroni t-test (p>0.05).
2. For precision, there was a significant difference between TRIOS4 and I500, I500 and COMFORT+ in the Inlay model (respectively p=0.027, p<0.001). In the Onlay and three-unit Bridge models, a significant difference was found between COMFORT+ and the remaining two intraoral scanners (TRIOS4, I500).
3. Given that the reported clinical acceptable range (80 ~ 120 μm), all scanners used in this study seem to have no clinical use problem. However, caution is required when interpreting because the cement space and errors in the manufacturing process must be considered.
4. Trueness and precision are lowered if the optimal distance between the scanner and the model is not maintained due to the narrow and deep part or the insufficient space between the units. In addition, errors tend to accumulate when the scan range

increases such as a three−unit bridge.

5. This study provides accuracy information on intraoral scanners, contributing to decision making: it offer a view on which intraoral scanner is appropriate for use.

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국문 초록

3종 구강스캐너의 정확도 비교 평가를 위한 비임상 연구

치과생체재료과학 전공
(지도교수: 임 범 순)
박 정 원

본 연구에서는 최근 소개된 구강스캐너의 진실도 (trueness) 및 정밀도 (precision) 비교를 통해 스캐너 자체 정확도 (accuracy) 등의 성능에 대하여 평가하고 검증하고자 하였다.

ISO 5725를 참고하여 구강스캐너의 정확도 비교를 위해 진실도 및 정밀도를 평가하였다. 진실도는 모델스캐너로 측정한 참조 데이터에 대하여 구강스캐너로 측정한 비교 데이터 간의 차이를 나타내는 값이며, 정밀도는 3 종류의 구강스캐너를 이용해 반복하여 얻은 데이터를 서로 중첩하여 얻은 오차 값이다. CAD 소프트웨어인 Solidworks 2016™ (Dassault Systèmes SolidWorks Corp., Waltham, MA, USA) 으로 모델을 설계하였고, NextDent C&B MFH (3D Systems, RockHill, SC, USA) 3D 프린팅 레진으로 NextDent 5100 (3D Systems, RockHill, SC, USA) 3D 프린터를 이용하여 모델로 제작하였다. 임상에서 자주 쓰이는 깊고 좁은 형태 등을 재현하여 인레이, 온레이 및 3본-브릿지 모델을 제작하였으며, 모든 실험군에서 동일한 레진 모델을 사용하여 제품 비교 평가에 용이하였다. 또한, 본 논문에서는 TRIOS4 (3 Shape, Copenhagen, Denmark), I500 (Medit Co, Seoul, South Korea),

COMFORT+ (DDS, Seoul, South Korea) 3가지 종류의 구강스캐너를 평가하였는데, 일관성을 위해 숙련된 동일한 연구자에 의해 각각 5개의 스캔 데이터를 채득하였다. 채득된 데이터는 Geomagic Control X^{TM} (3D Systems, RockHill, SC, USA) 소프트웨어의 '최적 적합 중첩법(베스트-핏 정렬)'을 통해 참조 데이터와 중첩하였고, 3D 비교 시 허용범위는 ±30㎛으로 설정하여 RMS (Root Mean Square) 를 산출하였다. 진실도와 정밀도 비교를 위해 유의수준 0.05를 기준으로 일원분산분석, Bonferroni test로 통계 분석하였다.

진실도의 경우, 인레이 모델에서 RMS 값은 36.32㎛~37.22㎛에 걸쳐 TRIOS4, COMFORT+, I500 순으로 커지며 진실도가 낮아지는 경향을 보였다. 온레이와 3본-브릿지 모델에서 RMS 값은 각각 35.98㎛~37.22㎛와 52.24㎛~56.64㎛를 보였으나, 일원분산분석 후 다중비교분석 Bonferroni t-test에서 모든 모델에 있어 구강스캐너 종류에 따른 진실도 값의 유의한 차이는 발견되지 않았다.

정밀도의 경우, 인레이 모델에서 TRIOS4와 I500, I500과 COMFORT+간 유의한 차이가 있었으며 (각각 p=0.027, p<0.001), 온레이와 3본-브릿지 모델에서는 COMFORT+와 나머지 두 종류의 구강스캐너 (TRIOS4, I500) 사이에서 유의한 차이를 발견하였다. 결론적으로, 3본-브릿지와 같이 폭이 좁고 깊은 부분을 포함하고, 구성 단위(unit) 사이 간격이 좁아 스캐너와 모델 간의 최적의 거리가 확보되지 않을 경우 진실도와 정밀도는 낮아진다. 더하여, 스캔의 범위가 넓어질수록 오차는 축적되어 정확도는 감소하게 된다. 본 연구를 통해 구축된 실험 데이터를 기반으로 임상에서 적절한 구강스캐너의 선택 및 스캔 전략에 도움되고자 하였다.

주요어 : 디지털 인상, 구강스캐너, 정확도, 진실도, 정밀도, 최적 적합 중첩법

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