The accuracy of the CAD system using intraoral and extraoral scanners for designing of fixed dental prostheses

Sakura SHIMIZU, Akikazu SHINYA, Soichi KURODA and Harunori GOMI

Department of Crown and Bridge, School of Life Dentistry at Tokyo, The Nippon Dental University 1-9-20 Fujimi, Chiyoda-ku, Tokyo 102-8159, Japan

Corresponding author, Akikazu SHINYA; E-mail: akikazu_dds@msn.com

The accuracy of prostheses affects clinical success and is, in turn, affected by the accuracy of the scanner and CAD programs. Thus, their accuracy is important. The first aim of this study was to evaluate the accuracy of an intraoral scanner with active triangulation (Cerec Omnicam), an intraoral scanner with a confocal laser (3Shape Trios), and an extraoral scanner with active triangulation (D810). The second aim of this study was to compare the accuracy of the digital crowns designed with two different scanner/CAD combinations. The accuracy of the intraoral scanners and extraoral scanner was clinically acceptable. Marginal and internal fit of the digital crowns fabricated using the intraoral scanner and CAD programs were inferior to those fabricated using the extraoral scanner and CAD programs.

Keywords: Accuracy, CAD/CAM, Intraoral scanner, Extraoral scanner, CAD software

INTRODUCTION

In the fabrication of prostheses using a CAD/CAM workflow, long-term clinical success^{1,2)} depends on the systems involved in scanning the tooth surface and in prosthesis design, which determine the marginal and internal fit of the restorations to the abutment tooth³⁻⁸⁾.

Dental impressions are the most important step in the fabrication of prostheses in restorative dentistry. Numerous CAD/CAM systems enable the design and fabrication of prostheses using stone casts made from conventional impressions and scanned by extraoral scanners. Restorations made in this way show excellent long-term results⁹⁾. Nonetheless, in fabrications involving a stone cast, a risk of technical errors exists because of the physical steps; such errors reduce the quality of the final prosthesis¹⁰⁾. Recently, digital impressions used in conjunction with intraoral scanners have become widely used in clinical dentistry to construct digital models of oral structures; such digital impressions are used in the fabrication of CAD/CAM prostheses, simplifying the fabrication procedure. For clinical success, the accuracy of the digital impression using an intraoral scanner must be similar to that of a conventional impression using an extraoral scanner. The literature contains few studies⁹⁾ comparing the digital data accuracy of impressions constructed using intraoral and extraoral scanners.

The process of fabricating a crown using CAD/CAM workflow comprises the scanning of the abutment tooth, the design of the prosthesis, and the physical manufacture of the crown. Measurements of the marginal and internal fit of the final restoration evaluate this process as a whole structure; however, assessing the three steps individually is important. The present study focuses on the first step: the taking of a digital impression. In this step, two factors are potentially

important: the precision of the scanners in collecting three-dimensional (3D) coordinate points and the quality of the software re-construction of the 3D structure. Several studies have compared the fitting of crowns fabricated with different scanners^{11,12)} and milling machines¹³⁾. However, very few studies evaluating the effect of different scanning systems and CAD software on the construction of the 3D digital structure have been reported¹⁴⁾.

The first aim of the present study was to compare the accuracy of the digital abutments created using two different intraoral scanners, one with active triangulation and one with a confocal laser, and an extraoral scanner with active triangulation. The null hypothesis was that no difference exists between the scanners.

The second aim was to compare the accuracy of construction of the digital crown between two systems of scanners and a CAD program. The null hypothesis in this study was that no difference exists between the two systems with respect to the marginal and internal discrepancies of the digital crown.

MATERIALS AND METHODS

Master model

To assess the scanners and software, a single master model (18-8 stainless steel, SUS304), which is shown in Fig. 1A, was used. The use of a single model ensures that the object being scanned undergoes no changes between experiments. The base diameter of the stainless master model was 9.0 mm, the upper surface was 6.0 mm in diameter, and the height was 6.0 mm.

This master model resembles a first molar prepared for a full-coverage crown restoration. Reference data for the master model were obtained using a coordinate measuring machine (E-DC-M400, Tokyo Seimitsu,

Fig. 1 Dimensions of the master model.
A: Stainless steel master model. B: Schematic of the die model and their dimensions. C: Image reconstructed from STL data.

Tokyo, Japan; CMM). Measurements were taken with a horizontal probe measurement load of 15 gf, and a vertical probe measuring load of 25 gf at an ambient operating temperature of $21.0 \pm 2.0^\circ\text{C}^{15}$.

Accuracy of scanning systems

An extraoral scanner with active triangulation (D810, 3Shape, Copenhagen, Denmark; EAT) was used to acquire comparative data from conventional scanning. A modulated blue light was projected onto the master model surface, and the reflected light was captured with an objective with a small depth of objected field. The system is capable of measuring surfaces within a field of $10 \times 10 \times 10 \text{ mm}^3$ with a single scanning shot. As the experimental groups, two types of intraoral scanner were used: an intraoral scanner with active triangulation (Cerec Omnicam, Sirona Dental Systems, Bensheim, Germany; IAT) and an intraoral scanner with confocal laser (3Shape Trios, 3Shape; ICL).

Active triangulation devices operate by emitting light of different wavelengths in strip patterns, which are reflected by the structural surfaces and then recorded by a charge-coupled device chip. Confocal laser devices use ultrafast optical sectioning that combines confocal microscopy with the projection of structured light. A time-and-location-dependent illumination pattern is projected onto the structure while the lens system is moved from one focal plane to another¹⁶.

Before the scans, the surface of the master model was treated with a matting powder (Sirona OptiSpray, Sirona Dental Systems). All scanners were used in accordance with the manufacturer's instructions at an ambient temperature of $23 \pm 2^\circ\text{C}$. Scans using the two intraoral scanners were started scanning from an axial wall to the occlusal surface and were completed at the opposite axial wall. An extraoral scanner was used to scan automatically after the model was positioned in the scanning die holder. The master model was scanned 10 times with each scanner, and the scan data were directly acquired and exported as a stereolithography (STL) file. All data from the scanners were imported into 3D diagnostic software (GOM Inspect V8.0, GOM, Braunschweig, Germany) for comparison. The measurement points were the distances from the axis to

the wall, the margin, and the height from the margin to the occlusal surface (Fig. 1B). The diameter of the axis wall was measured at distances 2.0 mm (a), 3.0 mm (b), 4.0 mm (c), and 5.0 mm (d) from the plane of the occlusal surface, the diameter of the margin (e) and the height of the abutment (f) were also measured. The mean and the standard deviation of the discrepancy from the master model were calculated for each scanner. An example of image reconstructed from STL data is shown in Fig. 1C. The influence of independent variables, including the type of scanner and the measurement points, was analyzed using a two-way ANOVA. A *post hoc* analysis was performed using Tukey's test ($p < 0.05$).

Accuracy of digital crown

Ten scans were acquired by both EAT and IAT. The scanning conditions for each method were the same as those used in the comparison of the scanners. Each scanner was used with its associated CAD software: Cerec in Lab15 (Sirona Dental Systems) was used with IAT (Group 1), and Dental designer Ver. 2014 (Dental Design, 3Shape) was used with EAT (Group 2).

In the design of the digital crown, the thickness of the cement space was set to $120 \mu\text{m}$ except at the margin, where it was set to $0 \mu\text{m}$, and the thickness of the crown was set to 1.0 mm in all groups; the thickness of the cement was referred to a preliminary experiment.

To compare the marginal and internal fit within each group, the data for the digital crown were analyzed using 3D diagnostic software (GOM Inspect V8.0, GOM). The measurement points were the margin and the radii of the axis wall. The diameter of the axis wall was measured at distances 2.0 mm (a), 3.0 mm (b), 4.0 mm (c) and 5.0 mm (d) from the occlusal surface; the diameter of the margin (e) was also measured. The means and the standard deviations of the internal and marginal discrepancies of the digital crown were calculated. The accuracy of each scanner was measured on the basis of two terms: the trueness (the extent to which the scan data differ from the reference data) and the precision (the differences between the results of repeated scans). The measure of precision is usually expressed in terms of imprecision and computed as a standard deviation (S.D.) of the test results¹⁷. The trueness was calculated

by subtracting the reference data from the mean of the scanner results, whereas the precision was measured as the S.D. of the scanner results. The influence of the independent variables, the system type, and the measurement points was analyzed using a two-way ANOVA. A *post hoc* analysis was performed using Tukey's test ($p < 0.05$).

RESULTS

Accuracy of scanning systems

A comparison of the trueness and precision of each scanner is shown in Table 1 and Fig. 2. The two-way ANOVA showed that measurement points and scanner significantly affected the accuracy of the scanners ($p < 0.05$) (Table 1). With regard to trueness, the IAT and ICL results were significantly different from almost all the EAT results, although the margin values were not significantly different between EAT and ICL. Statistically significant differences were also observed between the IAT and ICL at each measurement point. All scanners showed smaller values than the reference data at the axis wall, with the exception of the value of the EAT results at measurement point d, which

showed no difference; the EAT results were closest to the reference data. At the margin (e), the IAT results showed no difference from the reference value, whereas the values measured by the other scanners became larger than the reference values. Regarding the height (f), IAT showed a height lower than the reference value, whereas both ICL and EAT showed higher heights. The largest differences were concentrated in the IAT results. EAT showed the highest accuracy across all measured points of the master model and the highest accuracy at each measurement point except the margin.

Accuracy of digital crown

Table 2 and Fig. 3 show the results of the digital crown tests. Group 1 showed a mean gap between the crown and the axial wall of $80 \pm 3 \mu\text{m}$ and a gap of $6 \pm 3 \mu\text{m}$ on the margin. Group 2 showed a mean gap between the crown and the axial wall of $100 \pm 3 \mu\text{m}$ on the axial wall and a gap of $9 \pm 5 \mu\text{m}$ on the margin. The gaps at the axial wall (a, b, c, d) were smaller than the setting for cement thickness ($120 \mu\text{m}$) in both groups, and Group 1 showed a significantly smaller gap than Group 2. The two-way ANOVA with Tukey's test showed that the system significantly affected the fit of crowns ($p < 0.05$), as did

Table 1 The results of two-way ANOVA of the accuracy

Independent variable	<i>f</i>	<i>p</i>
Measurement points	1208.190	<0.001
Scanner	599.597	<0.001
Measurement points×Scanner	57.350	<0.001

Fig. 2 The accuracy of each scanner used in this study. The precision is given in SD. The same superscript indicates values with no statistically significant difference ($p > 0.05$). IAT: an intraoral scanner with active triangulation; ICL: an intraoral scanner with confocal laser; EAT: an extraoral scanner with active triangulation.

Table 2 The results of two-way ANOVA of the accuracy

Independent variable	<i>f</i>	<i>p</i>
Measurement points	2721.549	<0.001
Machine (scanner and CAD software)	366.620	<0.001
Measurement points×Group	39.154	<0.001

Fig. 3 The internal and marginal discrepancy of virtual crowns. The precision is given in SD. The same superscript indicates values with no statistically significant difference ($p>0.05$). Group 1: Cerec in Lab15 was used with IAT. Group 2: Dental designer Ver. 2014 was used with EAT.

the measurement points. The accuracy of the fit at the margin (e) showed no statistically significant difference between Group 1 and Group 2.

DISCUSSION

Study design

In this study, the first aim was to evaluate the accuracy of the three scanners. The IAT scanner has long-term clinical experience, and the Cerec system is one of the most common intraoral scanners that operates on an IAT method. The 3Shape Trios, which operates on the basis of the ICL method, is commonly used in clinical environments because the 3Shape Trios is licensed by another manufacture that does not develop original technology. The D810, an EAT scanner from 3Shape, is also one of the most popular scanners for the same reasons. These methods of scanning systems have been used to fabricate prostheses in clinics, and earlier studies have shown that their accuracy is acceptable for long-term clinical success¹⁸⁻²⁰. These scanners were selected for this study as representative systems.

The second aim was to compare the accuracy of construction of a digital crown fabricated using

two different scanners and CAD programs. The combinations used in this study are recommended by the manufacturers and are popular in clinical use in digital dentistry, which is again why they were chosen.

An ideal cement thickness of 40 μm is normally recommended; however, in this study, a thickness of 120 μm was used on the basis of a preliminary experiment, which indicated that a maximum discrepancy of 80 μm was expected by extrapolation at the occlusal surface of the model. To obtain a cement thickness of 40 μm , the maximum discrepancy of 80 μm was added in the design of the cement thickness, resulting in a total thickness of 120 μm for all systems investigated in this study.

A powder consisting mostly of titanium dioxide was sprayed onto the master model prior to scanning for consistency with clinical practice. The materials scanned in clinics have variable translucencies, which may affect the results of the scan; they are therefore coated with powder to standardize the translucency. The use of the powder in our experiments ensures that the optical properties of the experimental model are as close as possible to the materials scanned in the clinic.

Accuracy of scanning systems

Recently, the accuracy (the trueness and precision) of digital impressions and that of conventional ones has been compared using 3-dimensional data through a “best-fit alignment” comparison. This method enables an easy comparison of the discrepancy between two or more different digital data sets. However, the only information obtained from best-fit alignment is the greatest discrepancy between the digital data; the information concerning discrepancies in direction is not provided. Consequently, the best-fit alignment does not consider differences in the size of the digital data sets. In the current study, a CMM, as used in the quality control of industrial components, was used to obtain reference data. This device uses a 1.0-mm-diameter touch probe to record the surface of an object. As reported elsewhere^{21,22}, CMMs are considered the most accurate tools for measuring the dimensions of objects, although they are slower than other methods^{23–25}. Determining the difference in values of data transformations is useful information for data adaptation. From the results of the present study, all scanned data were smaller than the master model, and the maximum discrepancy was $-62\text{ }\mu\text{m}$.

In this study, the intraoral scanners were used in an extraoral environment. This approach permits a comparison of the intrinsic accuracy of the two types of scanner. Nevertheless, experiments comparing the scanners in their normal modes of operation would be valuable, although practical difficulties can be anticipated.

The null hypothesis that an intraoral scanner with a master model would show the same accuracy as the extraoral scanner was rejected ($p<0.05$) because the extraoral scanning system shows higher trueness. The discrepancy values of IAT and ICL were larger than those of EAT; thus, the accuracy differs among the three systems. However, the difference in the precision between the intraoral scanners and the extraoral scanner was not statistically significant, which means that although the values of discrepancy differ from each other, the values are very consistent.

Accuracy of digital crown

The aim of this part of the study was to evaluate the effect of data processing on the adaptation of crown restorations. Two different CAD programs were used, and the fit of the digital crown was measured using 3D diagnostic software. As the results show, the crowns designed using the CAD program with an extraoral scanner produced a better fit than those designed using the CAD program with an intraoral scanner, particularly in the axial wall.

Although significant differences were found in the internal fit between the two compared groups of scanner and CAD software combinations, the digital crowns showed good fitting in both groups. The maximum discrepancy of $62\text{ }\mu\text{m}$, which was less than the cement thickness of $120\text{ }\mu\text{m}$, was observed at point a of Group 1. This value was the same as the result from the scanned

data of IAT at measurement point a (Table 1); thus, the discrepancy of the digital crown is directly affected by the discrepancy of the scanning data of the master die, and this value represents the data adaptation value.

The recommended marginal gap for the clinical longevity of crown restorations is less than $120\text{ }\mu\text{m}$ ^{2,26}; the results obtained in this study showed marginal gaps much smaller than $120\text{ }\mu\text{m}$: $6\text{ }\mu\text{m}$ for the extraoral scanner and $9\text{ }\mu\text{m}$ for the intraoral scanner.

A comparison of the accuracies of the crowns generated from the scan requires the use of both the scanner and the CAD software. However, whereas the EAT and IAT systems are supplied with software installed and are widely used with that software, the ICL scanner has no recommended software. Thus, in clinical practice, it is used with many different software packages, which makes a general comparison of the clinical usefulness of the ICL system to that of other scanners difficult. No criteria have been established for choosing a particular set of software. Therefore, in the present work, this comparison was limited to the IAT and EAT systems, which are the most widely used triangulation-based systems.

Crowns fabricated using a CAD/CAM system showed marginal gaps of less than $120\text{ }\mu\text{m}$ in earlier studies²⁷. The gaps observed in the present study are much smaller than those reported in many previous studies, and this difference may arise from the transition from a digital model to a physical crown. Further studies comparing the fit of a digital model to the fit of a physical crown manufactured using the model would be valuable. Clinically, knowledge of how well a crown fits the tooth at the margin is important; however, the thickness of the cement is equally important. Nevertheless, internal fit has been largely neglected in earlier research, despite extensive studies of marginal fit. Thus, the present study clarified both the marginal and internal fit accuracy of digital crowns.

Clinical significance

The accuracy of a digital crown was related to the trueness of the scanning data; in addition, all scanning data at the axial wall were smaller than the master die, except at the margin, where the scanning data were larger. The present study shows that the measurement point and machine significantly affect the accuracy of the scanners; thus, the design value as a data adaptation also differs among scanning systems and is related to each system. For clinical use, the discrepancy between abutment teeth and scanned data in each scanner should be known as a design value before designing a digital crown. In the design of a digital crown, the design value may require fulfillment of a target cement thickness and this adjustment will contribute to the accuracy of the digital crown.

CONCLUSIONS

The results of this study led to the following conclusions:

1. With regard to trueness of scanning, the intraoral

scanners were significantly different from the extraoral scanner for all values, with the exception of the margin value, where ICL was not different from EAT.

2. The accuracy of digital crowns made with different sets of scanners and CAD programs showed significant differences at the axial wall.
3. The accuracy of the digital crown margin showed a larger value than the designed value in both groups, and the two groups exhibited no significant difference. The axial wall of the digital crown showed a smaller value than the designed value in both groups, and their difference was statistically significant.

REFERENCES

- 1) Molin MK, Karlsson SL. A randomized 5-year clinical evaluation of 3 ceramic inlay systems. *Int J Prosthodont* 2000; 13: 194-200.
- 2) Sailer I, Fehér A, Filser F, Gauckler LJ, Lüthy H, Hammerle CH. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. *Int J Prosthodont* 2007; 20: 383-388.
- 3) Jacobs MS, Winder AS. An investigation of dental luting cement solubility as a function of the marginal gap. *J Prosthet Dent* 1991; 65: 436-442.
- 4) Sachs C, Groesser J, Stadelmann M, Schweiger J, Erdelt K, Beuer F. Full-arch prosthesis from translucent zirconia: accuracy of fit. *Dent Mater* 2014; 30: 817-823.
- 5) Keul C, Stawarczyk B, Erdelt KJ, Beuer F, Edelhoff D, Güth JF. Fit of 4-unit FDPs made of zirconia and CoCr-alloy after chairside and labside digitalization —a laboratory study. *Dent Mater* 2014; 30: 400-407.
- 6) Katsoulis J, Mericske-Stern R, Rotkina L, Zbären C, Enkling N, Blatz MB. Precision of fit of implant-supported screw-retained 10-unit computer-aided-designed and computer-aided-manufactured frameworks made from zirconium dioxide and titanium: an in vitro study. *Clin Oral Implants Res* 2014; 25: 165-174.
- 7) Mously HA, Finkelman M, Zandparsa R, Hirayama H. Marginal and internal adaptation of ceramic crown restorations fabricated with CAD/CAM technology and the heat-press technique. *J Prosthet Dent* 2014; 112: 249-256.
- 8) Keshvad A, Hooshmand T, Asefzadeh F, Khalilnejad F, Alihemmati M, Van Noort R. Marginal gap, internal fit, and fracture load of leucite-reinforced ceramic inlays fabricated by CEREC inLab and hot-pressed techniques. *J Prosthodont* 2011; 20: 535-540.
- 9) Seelbach P, Brueckel C, Wostmann B. Accuracy of digital and conventional impression techniques and workflow. *Clin Oral Investig* 2013; 17: 1759-1764.
- 10) Ziegler M. Digital impression taking with reproducibly high precision. *Int J Comput Dent* 2009; 12: 159-163.
- 11) Nedelcu RG, Persson AS. Scanning accuracy and precision in 4 intraoral scanners: an in vitro comparison based on 3-dimensional analysis. *J Prosthet Dent* 2014; 112: 1461-1471.
- 12) Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. *Clin Oral Investig* 2014; 18: 1687-1694.
- 13) Patzelt SB, Bishti S, Stampf S, Att W. Accuracy of computer-aided design/computer-aided manufacturing-generated dental casts based on intraoral scanner data. *J Am Dent Assoc* 2014; 145: 1133-1140.
- 14) Shim J, Lee J, Lee J, Choi Y, Shin S, Ryu J. Effect of software version and parameter settings on the marginal and internal adaptation of crowns fabricated with the CAD/CAM system. *J Appl Oral Sci* 2015; 23: 515-522.
- 15) Tomita S, Shinya A, Gomi H, Shinya A, Yokoyama D. Machining accuracy of crowns by CAD/CAM system using TCP/IP: influence of restorative material and scanning condition. *Dent Mater J* 2007; 26: 549-560.
- 16) Logozzo S, Zanetti EM, Franceschini G. Recent advances in dental optics. Part I: 3D intraoral scanners for restorative dentistry. *Opt Lasers Eng* 2014; 54: 203-221.
- 17) DIN Deutsches Institut für Normung. Accuracy (trueness and precision) of measurement methods and results —Part 1: General principles and definitions (ISO 5725-1:1994), Beuth Verlag, Berlin; 1997.
- 18) Rekow ED, Erdman AG, Riley DR, Klamecki B. CAD/CAM for dental restorations —Some of the curious challenges. *IEEE Trans Biomed Eng* 1991; 38: 314-318.
- 19) Chan DC, Chung AK, Haines J, Yau EH, Kuo CC. The accuracy of optical scanning: influence of convergence and die preparation. *Oper Dent* 2011; 36: 486-491.
- 20) Brawek PK, Wolfart S, Endres L, Kirsten A, Reich S. The clinical accuracy of single crowns exclusively fabricated by digital workflow—the comparison of two systems. *Clin Oral Investig* 2013; 17: 2119-2125.
- 21) Persson M, Andersson M, Bergman B. The accuracy of a high-precision digitizer for CAD/CAM of crowns. *J Prosthet Dent* 1995; 74: 223-229.
- 22) DeLong R, Heinzen M, Hodges JS, Ko CC, Douglas WH. Accuracy of a system for creating 3D computer models of dental arches. *J Dent Res* 2003; 82: 438-442.
- 23) Jemt T, Hjalmarsson L. In vitro measurements of precision of fit of implant-supported frameworks. A comparison between “virtual” and “physical” assessments of fit using two different techniques of measurements. *Clin Implant Dent Relat Res* 2012; 14: 175-182.
- 24) Arnetzl G, Pongratz D. Milling precision and fitting accuracy of Cerec Scan milled restorations. *Int J Comput Dent* 2005; 8: 273-281.
- 25) Al-Fadda SA, Zarb GA, Finer YA. comparison of the accuracy of fit of 2 methods for fabricating implant-prosthetic frameworks. *Int J Prosthodont* 2007; 20: 125-131.
- 26) Stappert CF, Chitmongkolsuk S, Silva NR, Att W, Strub JR. Effect of mouth-motion fatigue and thermal cycling on the marginal accuracy of partial coverage restorations made of various dental materials. *Dent Mater* 2008; 24: 1248-1257.
- 27) Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. *J Clin Periodont* 1983; 10: 563-578.