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RESEARCH AND EDUCATION

Digital evaluation of absolute marginal discrepancy: A comparison of ceramic crowns fabricated with conventional and digital techniques

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ABSTRACT

Statement of problem. Marginal discrepancy is key to evaluating the accuracy of fixed dental prostheses. An improved method of evaluating marginal discrepancy is needed.

Purpose. The purpose of this in vitro study was to evaluate the absolute marginal discrepancy of ceramic crowns fabricated using conventional and digital methods with a digital method for the quantitative evaluation of absolute marginal discrepancy. The novel method was based on 3-dimensional scanning, iterative closest point registration techniques, and reverse engineering theory.

Material and methods. Six standard tooth preparations for the right maxillary central incisor, right maxillary second premolar, right maxillary second molar, left mandibular lateral incisor, left mandibular first premolar, and left mandibular first molar were selected. Ten conventional ceramic crowns and 10 CEREC crowns were fabricated for each tooth preparation. A dental cast scanner was used to obtain 3-dimensional data of the preparations and ceramic crowns, and the data were compared with the "virtual seating" iterative closest point technique. Reverse engineering software used edge sharpening and other functional modules to extract the margins of the preparations and crowns. Finally, quantitative evaluation of the absolute marginal discrepancy of the ceramic crowns was obtained from the 2-dimensional cross-sectional straight-line distance between points on the margin of the ceramic crowns and the standard preparations based on the circumferential function module along the long axis.

Results. The absolute marginal discrepancy of the ceramic crowns fabricated using conventional methods was 115 ±15.2 μm, and 110 ±14.3 μm for those fabricated using the digital technique was. ANOVA showed no statistical difference between the 2 methods or among ceramic crowns for different teeth (*P*>.05).

Conclusions. The digital quantitative evaluation method for the absolute marginal discrepancy of ceramic crowns was established. The evaluations determined that the absolute marginal discrepancies were within a clinically acceptable range. This method is acceptable for the digital evaluation of the accuracy of complete crowns. (J Prosthet Dent 2017;■:■-■)

The size of the marginal discrepancy between a restoration and tooth preparation is an important predictor of future ceramic fracture, periodontal health, plaque retention, caries, pulpal pathology, and bone resorption.[1-3] Precise marginal adaptation is essential to ensure long-term prosthetic success.

The quality of the prosthetic fit is usually evaluated in the marginal, axial, and occlusal regions of the prepared teeth.[4] However, no standard has been agreed for the measurement of marginal discrepancy. Holmes et al[5] divided the restoration marginal discrepancy into horizontal marginal discrepancy, vertical marginal discrepancy, and absolute marginal discrepancy. They consider absolute marginal discrepancy to be the most important, as it takes both the horizontal and vertical directions into consideration. It is defined as the linear distance from the finish line of the preparation to the margin of the restoration. This distance can be measured from a cross-sectional view, direct view of the crown on a die, impression replica technique, or clinical examination.[6,7]

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Clinical Implications

A digital method of evaluating marginal discrepancy improves evaluation accuracy and helps dentists evaluate the quality of fixed prostheses objectively and accurately. Digital evaluation methods can also improve communication between dentist and patient. However, the methods used to analyze the restorations are not universally applicable.

Current measurement methods include both in vivo and in vitro techniques. In vivo measurement methods include examination with a dental explorer; however, explorer examination is only qualitative, and examination of the subgingival margin is difficult.[8] Another in vivo method is to seat the crown with a silicone impression material to reproduce the marginal discrepancy and then measure from scanning electron micrographs; however, the silicone material may have defects in the observation area.[9] In vitro measurements may involve sectioning the crown on a die. However, with this method, some locations cannot be observed, and deformation can result during the sectioning process.[10] Another method is to measure images of the margin with a stereoscopic microscope using a computer for processing and measurement.[11]

Dental computer-aided design and computer-aided manufacturing (CAD-CAM) systems are now commonly used in dental offices and are highly sophisticated, allowing marginal discrepancy measurements. Yuan et al[12] used 3-dimensional (3D) scanning and reverse engineering software to digitally design a representation of a complete crown preparation. Lee[13] described a method of visualizing and quantifying the fit discrepancy of fixed dental prostheses by digitizing a misfit space replica and using computer-aided spatial analysis.

With CAD-CAM production of crowns, the cement space is typically set in the software to 50 μm, as 30 to 50 μm has been found to deliver the best marginal fit.[14] However, Beschnidt and Strub[15] demonstrated that the evaluation of the marginal adaptation of restorations depends on factors such as the type of die material used during marginal fit evaluations, whether the specimens were cemented, the effects of aging procedures, the type of microscope, and the location and quantity used for measurements. The factors that have been documented to influence the marginal fit of a dental restoration are the preparation design, location of the preparation finish line (subgingival or supragingival), restorative material, fabrication method, and impression material and technique.[16-20] McLean and von Fraunhofer[6] stated that a restoration is considered clinically successful when the marginal discrepancy and the luting space are less than 120 μm, a range that has been considered clinically acceptable.[20-23]

The purpose of this in vitro study was to use reverse engineering software to investigate a digital quantitative method for evaluating the absolute marginal discrepancy between a ceramic crown restoration and a master preparation, and to use this method to evaluate quantitatively the absolute marginal discrepancy of ceramic crowns fabricated using conventional or digital methods. The null hypotheses were that the absolute marginal discrepancies of ceramic crowns fabricated using conventional or digital methods would not differ and that the absolute marginal discrepancies of different tooth preparations would be similar.

MATERIAL AND METHODS

A typodont (Standard model A50 SET; Nissin) with tooth preparations for the right maxillary central incisor, right maxillary second premolar, right maxillary second molar, left mandibular lateral incisor, left mandibular first premolar, and left mandibular first molar was used for the study. The tooth preparation margins were clearly visible, smooth, and formed a continuous right-angled shoulder. The typodont was placed in a dental simulator (Type 1 Advance; Nissin) mounted on a dental chair. Ten conventional ceramic crowns and 10 CAD-CAM crowns were fabricated for each preparation. The sample size (n=10) was determined from pilot studies with a power analysis to provide statistical significance (α=.05) at 80% power. For the conventional crowns, an elastomeric impression (Impregum Penta Soft; 3M) was made and poured with Type 4 gypsum (Die Stone Peach; Heraeus Kulzer) to produce a cast. The crowns were fabricated by an experienced technician in a feldspathic porcelain (Vita In-Ceramic Alumina; Vita Zahnfabrik). The CAD-CAM crowns were fabricated with the CEREC chairside system. A digital impression (CEREC Omnicam; Dentsply Sirona), was made and the system used to fabricate 10 ceramic crown from feldspathic ceramic blocks (CEREC Blocs S3-O 14; Dentsply Sirona).

A calibrated dental cast scanner (Activity 880; Smartoptics) was used to scan the preparation and the ceramic crown after it has been seated on the preparation. The 3D point clouds of the standard preparation surface and the surface of the ceramic crown after it had been seated on the standard preparation were obtained in standard tessellation language (STL) format. The scan was made twice in the same coordinate system. Subsequently, the 3D scanner was used to scan the ceramic crown, and the 3D data of the intaglio and external surfaces of the ceramic crown were obtained in STL format (Fig. 1).

A registration module (Studio 2013; Geomagic) was used for manual registration. The initial position was

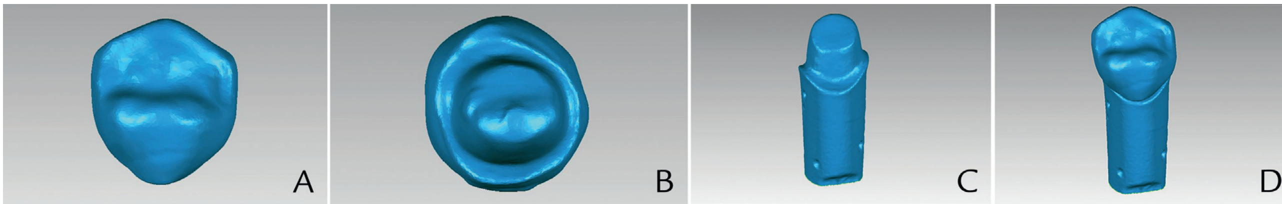

Figure 1. STL data of ceramic crowns, preparations, and seated crown. A, External surface data of crown. B, Intaglio of crown. C, Tooth preparation data. D, Tooth preparation and crown data. STL, standard tessellation language.

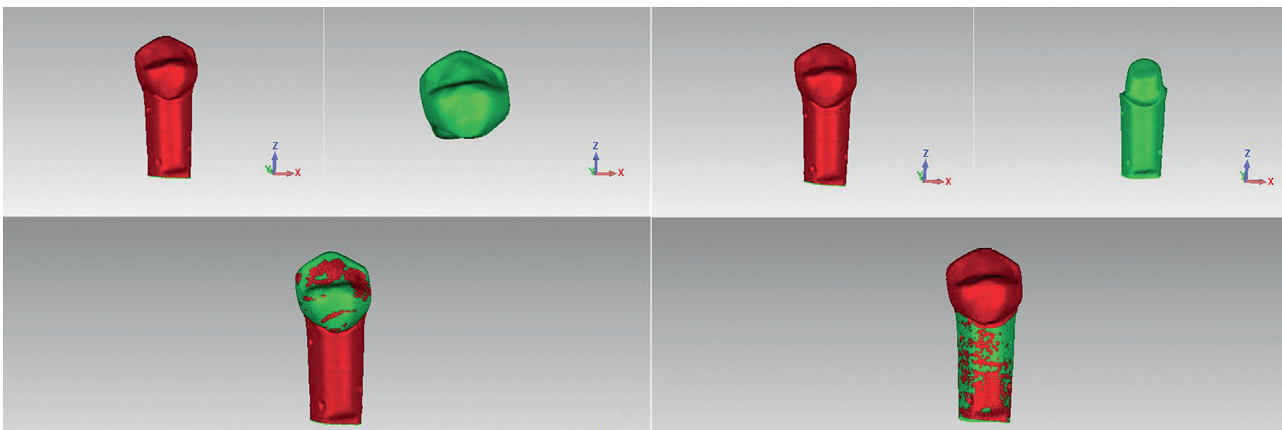

Figure 2. Virtual seating by double registration of complete preparation with ceramic crown.

interactively selected, and the 3D data of the ceramic crown were registered to the data obtained from the external surface of the ceramic crown. Global registration was performed again, and finally, the 3D data of the virtual seating of the intaglio and external crown surfaces on the preparations were obtained (Fig. 2).

Software (Imageware v13.0; Siemens Product Lifecycle Management [PLM] Software) with a line-sharp edges module was used to extract the margins of the ceramic crowns and preparations. After the interactive operation, the observed long axis of the ceramic crown was confirmed; this observed long axis was considered the central axis. The software's construct cross-sectional cloud circular command was used to divide the preparation evenly into 25 parts and 50 curves. Every curve intersected with the outer edge of the ceramic crown and the shoulder margin of the preparation at 2 points.[24,25] The distance between these 2 points, which represented the absolute marginal discrepancy, was measured (Fig. 3).

The data were analyzed by statistical software (IBM SPSS Statistics v19.0; IBM Corp). The mean values and standard deviations were calculated for each group. One-way ANOVA was used to analyze the difference between the absolute marginal discrepancies of ceramic crowns fabricated using the digital technique and conventional methods, and to analyze the difference in the absolute marginal discrepancy of ceramic crowns for different teeth.

RESULTS

The absolute marginal discrepancies are presented in Table 1. The 1-way ANOVA detected no statistically significant difference between the absolute marginal discrepancy of ceramic crowns fabricated using the digital technique and conventional methods ($F(1,118)=3.818$, $P=.053$). Also, no statistically significant difference was found in the absolute marginal discrepancy of ceramic crowns for different teeth as determined by 1-way ANOVA ($F(5,114)=1.658$, $P=.150$). The mean values of the absolute marginal discrepancy of ceramic crowns fabricated using 2 methods for different teeth were less than 120 μm (Table 2).

DISCUSSION

On the basis of the results of this study, both null hypotheses were accepted, as no significant differences were found as a result to fabrication method or tooth preparation. With the development and application of computer analysis such as the 3D image analysis systems, measurement methods have become increasingly high resolution, automated, and noninvasive. The present study used 3D scanning and digital iterative closest point registration measurement methods to measure absolute marginal discrepancy by changing coordinate systems. The technique is theoretically feasible and accurate.

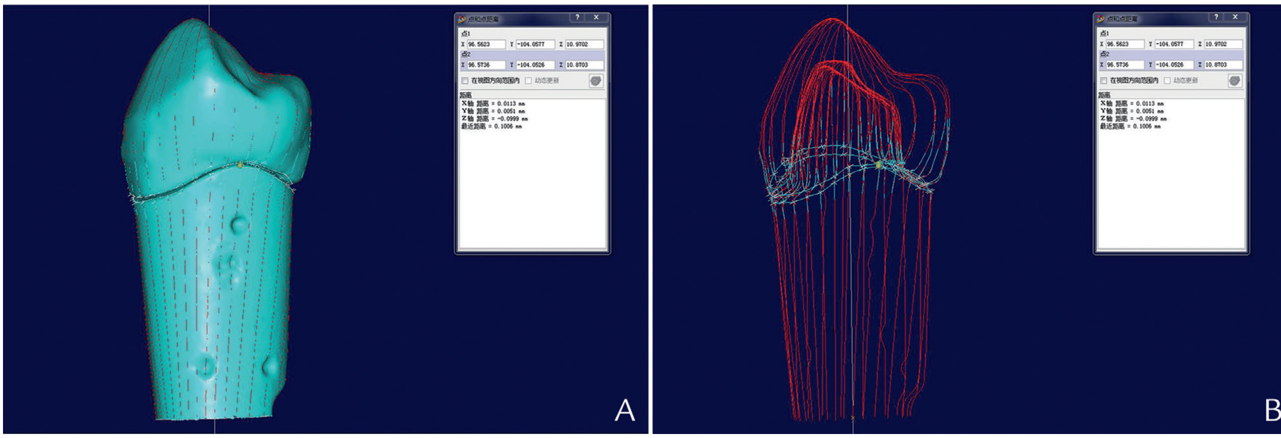

Figure 3. Measurement of absolute marginal discrepancy. A, the process of extracting the margins of the ceramic crowns and preparations; B, the process of measuring the absolute marginal discrepancy.

Table 1. Absolute marginal discrepancy (μm) of ceramic crowns with 2 fabrication methods

			95% Confidence Interval for Mean			
Method	N	Mean ±SD	Lower Bound	Upper Bound	Minimum	Maximum
Manual	60	115 ±15.2	111	119	92	162
Digital	60	110 ±14.4	106	113	82	161
Total	120	112 ±15.0	110	115	82	162

Table 2. Absolute marginal discrepancy ±SD (μm) of ceramic crowns fabricated for different teeth

			95% Confidence Interval for Mean			
Tooth	N	Mean ±SD	Lower Bound	Upper Bound	Minimum	Maximum
Right maxillary central incisor	20	112 ±10.9	106	117	90.8	131
Right maxillary second premolar	20	108 ±15.2	101	115	82.1	149
Right maxillary second molar	20	118 ±15.4	111	125	95.7	161
Left mandibular lateral incisor	20	111 ±18.0	103	120	87.4	162
Left mandibular first premolar	20	108 ±15.1	101	115	84.9	148
Left mandibular first molar	20	117 ±13.1	111	123	96.8	143
Total	120	112 ±15.0	110	115	82.1	162

However, the experimental process had some limitations. First, in the present study, the conventional impressions were made at room temperature. The thermal contraction of the impression material from mouth to room temperature was thus not modeled.[26] Second, powder (CEREC Optispray; Dentsply Sirona) was used with the dental cast scanner. Powder was used to prevent light reflection of the optical scanner and to acquire precise digital data. The thickness of powder certainly exists, which might introduce errors into the surface reproduction of the standard preparations and ceramic crowns.

The absolute marginal discrepancy of ceramic crowns fabricated by CAD-CAM and conventional techniques was measured, and the results indicated that the absolute marginal discrepancy of ceramic crowns fabricated with the 2 methods were within 120 μm, thus meeting clinical requirements.[22] To the authors' knowledge, no study has reported that the absolute marginal discrepancy of ceramic crowns from different tooth position was evaluated using this digital method. In the present study, different tooth positions did not influence the absolute marginal discrepancy of ceramic crowns.

Regardless of the method used to measure the discrepancy, the appropriate selection of points for measurement is important. In the present study, 50 measurement points selected from different regions were analyzed, similar to the points used in the study by Groten et al.[24]

Application of the prosthetic scan module of the 3D scanning instrument allows multiple scan data on the same coordinate system and automatic registration of the multiple scan data. The present study used the Smartoptics scanning instrument to implement 2 scans and to automatically match targets. Particularly important was the function for separately scanning the location of the ceramic crown seated on the preparation in the same coordinate system, in which the ceramic crown seated on the preparation is scanned first, followed by extraction of the ceramic crown without moving the preparation while continuing to scan in the same coordinate system. This step uses iterative closest point registration to virtually seat the ceramic crown. In addition, the 3D data of the interior and exterior surfaces of the ceramic crown could be obtained through the prosthetic scan module of the 3D scanning instrument.

During the dual scan of the ceramic crown, the 3D scanning instrument can only obtain partial point cloud data from the surface of the crown (>20 μm resolution). A certain level of error will exist during the iterative closest point registration virtual seating process and will have a certain effect on the experimental results. With improvements in instruments and equipment, scanning resolution will be increased, and results from this measurement method will improve.

In the present study, the right maxillary central incisor, right maxillary second premolar, right maxillary second molar, left mandibular lateral incisor, left mandibular first premolar, and left mandibular molar were selected for standard preparations. These teeth represent different maxillary, mandibular, and left and right tooth positions. The appropriateness of digital quantitative evaluation methods was validated; however, comparison with other measurement methods is still needed to increase the accuracy of experiments. In addition, the present study established a method based on Imageware reverse engineering software for measuring absolute marginal discrepancy between the ceramic crown restorations on the model. However, the measurement process involves many interactive and time-consuming operations and requires specialist personnel with high 3D skills, making it time-consuming and inappropriate for oral medicine technicians. Future studies should integrate various functional modules to establish an automated software platform to increase the automation of the measurement process.

On the basis of 3D scanning and Imageware and Geomagic reverse engineering software, the present study preliminarily established a 3D digital quantitative method for evaluating absolute marginal discrepancy between a ceramic crown and tooth preparation, and it establishes a foundation for the digital evaluation of the efficacy of ceramic crown restoration.

The digital method improves the quantitative evaluation accuracy for absolute marginal discrepancy and can evaluate the quality of the prosthesis objectively and accurately. However, the method involves many interactive operations, making it difficult for dentists. It may be not clinically feasible for each restoration. In the future, the process should be simplified and the evaluation function improved to establish an automatic evaluation method.

CONCLUSIONS

On the basis of the findings of this in vitro study, the following conclusions were drawn:

1. A digital quantitative method for evaluating the absolute marginal discrepancy of a ceramic crown was preliminarily established.
2. Through comparison and evaluation, the absolute marginal discrepancy of ceramic crowns fabricated using conventional methods and digital methods was shown to fall within clinically acceptable ranges.

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