Assessment of Internal Fitness on Resin Crown Fabricated by Digital Light Processing 3D Printer

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Background: Recently, three-dimensional (3D) printing has been hailed as a disruptive technology in dentistry. Among 3D printers, a digital light processing (DLP) 3D printer has certain advantages, such as high precision and relatively low cost. Therefore, the latest trend in resin crown manufacturing is the use of DLP 3D printers. However, studies on the internal fitness of such resin crowns are insufficient. The recently introduced 3D evaluation method makes it possible to visually evaluate the error of the desired area. The purpose of this study is to evaluate the internal fitness of resin crowns fabricated by a DLP 3D printer using the 3D evaluation method.

Methods: The working model was chosen as the maxillary molar implant model. A total of 20 resin crowns were manufactured by dividing these into two groups. One group was manufactured by subtractive manufacturing system (PMMA), while the other group was manufactured by additive manufacturing system, which uses a DLP 3D printer. Resin crowns data were measured using a 3D evaluation program. Internal fitness was calculated by root mean square (RMS). The RMS was calculated using the Geomagic Verify software, and the mean and standard deviation (SD) were measured. For statistical analysis, IBM SPSS Statistics for Windows ver. 22.0 (IBM Corp., USA) was used. Then, independent t-test was performed between the two groups.

Results: The mean $\pm$ SD of the RMS were 41.51 ± 1.51 and 43.09 ± 2.32 for PMMA and DLP, respectively. There was no statistically significant difference between PMMA and DLP.

Conclusion: Evaluation of internal fitness of the resin crown made using a DLP 3D printer and subtractive manufacturing system showed no statistically significant differences, and clinically acceptable results were obtained.

Key Words: Crowns, Printing, Three-dimensional image

Introduction

Dental computer-aided design/computer-aided manufacturing (CAD/CAM) systems used in the field of digital dentistry can be divided into systems for the three-dimensional (3D) design and manufacturing of prostheses¹⁾. 3D design refers to the process of obtaining scanned data from intraoral and model scanners, while prosthesis design refers to the process of using a CAD program to design a prosthesis suited for the patient. Manufacturing refers to the process of using design data to fabricate the prosthesis with various materials, such as ceramic, metal, and

resin²⁻⁵⁾.

Such CAD/CAM systems can be further divided into those for subtractive and additive manufacturing. Subtractive manufacturing is a process by which prostheses are fabricated by using a milling bur to cut disc or cube-shaped dental materials along the x, y, and z axes. Additive manufacturing is a process of repeatedly adding and curing layers of liquid or powder material⁶⁾.

CAD/CAM based on subtractive manufacturing offers the advantage of fabricating useful restorations using various materials, such as zirconia, resin, wax, and metal⁷⁾. However, this method also has the disadvantages of high

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equipment maintenance costs, and the need to discard raw materials left over from fabricating the restoration. The manufacturing process is also time-consuming⁸⁾.

3D printing based on additive manufacturing can overcome the disadvantages mentioned above. The fabrication process involves creating 3D shape data (stereolithography [STL] file) using intraoral or model scanner, designing using a proprietary CAD program, and printing the file with a dental 3D printer^{9,10)}.

Depending on the printing method, 3D printers can generally be divided into stereolithography apparatus (SLA), digital light processing (DLP), and fused deposition modeling (FDM)¹¹⁾.

The DLP method shares the same principle as a beam projector. With this method, a digital light projector irradiates the cross-sectional layer of the liquid photocurable resin and repeatedly laminates successive layers to print the output. Unlike SLA which uses point curing, this method cures an entire cross-sectional layer for faster printing speed¹²⁾; it also has higher precision than the FDM method¹³⁾.

To date, studies that used DLP printers include those that analyzed model shrinkage rate¹⁴⁾, model fitness^{12,15,16)}, and molar fitness of resin crowns¹⁷⁾. There are few studies on the fitness of resin crowns fabricated using a DLP printer in the current field of dental implants. In particular, internal fitness is very important inside the oral cavity. Poor internal fitness could have a detrimental effect on the lifespan of the prosthesis and remaining tooth owing to

poor esthetics and gingival recession caused by inflammation of the alveolar bone and gingival tissue around the prosthesis that has been installed¹⁸⁾.

Existing methods for assessing internal fitness include the silicon replica method. This is an analog method in which the inside of the prosthesis is filled with a low-viscosity silicon impression material, and then placed on a model. After curing, the silicon impression of regular body is cured laterally^{19,20)}. However, this method has limitations in assessing irregular and geometric shapes. Recently, 3D assessment was introduced to overcome such shortcomings. The 3D assessment method enables the visual assessment of errors in the desired area and modification of the final prosthesis before clinical application^{1,21)}.

Accordingly, the objective of this study is to conduct 3D analysis and assessment of the internal fitness of the abutment of resin crowns fabricated by DLP printing and conventional subtractive manufacturing using dental CAD/CAM systems.

Materials and Methods

1. Selection of working model

The working model used in this study was a model with a dental implant placed on the maxillary first molar (Fig. 1). As a type with the implant superstructure (US cement

Fig. 1. Working model. This is a working model for research.

Fig. 2. Resin crowns. There are resin crowns divided into two groups. PMMA: poly methyl methacrylate, DLP: digital light processing.

abutment; OSSTEM IMPLANT Co., Ltd., Seoul, Korea) and the lab analog (US fixture lab analog; OSSTEM IMPLANT Co., Ltd.) fastened, the ready-made abutment is a hex type with diameter of 5.0 mm, gingiva height of 1.0 mm, and height of 7.0 mm. Since this model had a standardized implant shape, it was selected as the working model.

2. Sample fabrication

A total of 20 resin crown samples were fabricated: 10

Fig. 3. Subtractive process computer-aided design/computer-aided manufacturing (CAD/CAM). This is a CAD/CAM machine for making poly methyl methacrylate resin crowns.

Fig. 4. Digital light processing (DLP) three-dimensional (3D) printer. This is a DLP 3D printer for making DLP resin crowns.

poly methyl methacrylate (PMMA) resin crowns fabricated by conventional subtractive manufacturing (control group) and 10 DLP resin crowns fabricated by additive manufacturing (experimental group; Fig. 2).

The working model was scanned using a blue light scanner (T500; MEDIT, Seoul, Korea) to create STL files. A dental design program (EXOCAD 2.2; exocad GmbH, Darmstadt, Germany) was used to design 10 resin crowns with 30 micron of cement space.

To fabricate the PMMA resin crowns, design data in 10 STL files were applied to subtractive CAM equipment (Milling Unit M3; Zirkonzahn, Neuler, Germany) (Fig. 3). Subsequently, resin blocks (Vipi block PMMA; Vipi, São Paulo, Brazil) were loaded and 10 PMMA resin crowns were fabricated by subtractive manufacturing. The crowns were machined to remove the support.

To fabricate the DLP resin crowns, design data was loaded in the 3D printer (ZD200; DENTIS Co., Ltd., La Palma, CA, USA), which is an additive manufacturing method (Fig. 4). A resin solution (ZMD-1000B TEMPORARY; DENTIS Co., Ltd.) was used to fabricate 10 DLP resin crowns. An ultra violet (UV) lamp (MP100; Meong Moon Dental Co., Ltd., Daegu, Korea) was used for final curing and the crowns were machined to remove the support.

Fig. 5. Intraoral scanner. TRIOS 3 basic scanner for obtaining three-dimensional data.

3. 3D data construction

For 3D data construction, the implant abutment surface was evenly coated with scanning powder (ERUM Scan spray; YOONWON BIO, Gwangju, Korea) and 3D data were constructed from scanning 20 samples with an intraoral scanner (TRIOS 3 Basic; 3Shape A/S, Copenhagen, Denmark) (Fig. 5).

The TRIOS 3 intraoral scanner scan and acquire 3,000 2D images per second and then combine the images. To make it easier to combine the acquired images, scanning was started from the center of the implant surface and the inside of the resin crown and moved in clockwise direction. To scan deep areas inside the resin crown, the angle of the scanner was controlled at $< 45^\circ$ when acquiring the images. For accuracy and uniformity, 100~200 cuts were imaged for over 10~20 seconds, while the rest were scanned according to the manufacturer's protocol.

4. Analysis using software

To examine the internal fitness between the resin crown and implant abutment surface obtained from 3D data, 3D assessment was performed by the following method. First, a 3D assessment program (Geomagic Verify; Geomagic GmbH, Stuttgart, Germany) was used to delete unnecessary parts from the implant abutment (reference

die) and 20 digital resin crown data. Upon completion of data revision, the implant abutment surface and inner surface of the resin crown were aligned by best fit alignment. After 3D comparison of different images, differences between the implant abutment and 20 digital resin crown data were calculated by the root mean square (RMS) value. The equation for RMS value is as follows:

$$-U \rightarrow \kappa \int \frac{\sum_{j=1}^n \sqrt{\frac{1}{n} \sum_{i=1}^n \frac{X_{1i}^2}{X_{2i}^2}}}{B}$$

Where X1 is the measurement point of the implant abutment (reference die), X2 denotes the digital resin crown, and n is the total number of points measured.

5. Statistical analysis

The collected data were analyzed using the IBM SPSS Statistics Windows ver. 22.0 (IBM Corp., Armonk, NY, USA). The statistical analysis methods used for data processing were as follows. Normality test was performed by Kolmogorov-Smirnov and Shapiro-Wilk tests, while significant differences between the PMMA and DLP resin crowns were tested by independent t-test. For statistical determination, the level of type 1 error was set to 0.05.

Fig. 6. Three-dimensional analysis process. This is the process of overlapping between resin crown and reference die.

Table 1. Comparison of Resin Crown (Unit: μm)

Group	PMMA	DLP
RMS		
1	44.00	43.60
2	42.40	43.30
3	40.90	42.00
4	39.90	44.50
5	40.20	44.50
6	41.70	45.60
7	40.90	38.00
8	40.58	45.70
9	40.50	41.20
10	44.10	42.20
Mean $\pm$ SD	41.51 $\pm$ 1.51	43.09 $\pm$ 2.32
p-value	0.09	

Values are presented as number only or mean $\pm$ standard deviation. PMMA: poly methyl methacrylate, DLP: digital light processing, RMS: root mean square, SD: standard deviation.

Results

For quantitative analysis, RMS values were calculated using the 3D assessment program to assess the internal fitness of the resin crowns fabricated with the DLP printer (Fig. 6). The mean and standard deviation (SD) of the experimental group are listed in Table 1. The RMS value represents the 3D deviation between the outer surface of the implant and inner surface of the resin crown, with RMS value closer to 0 indicating higher 3D consistency. For qualitative analysis, a color-difference map is presented in Fig. 7. The threshold deviation was set to $\pm 100 \mu\text{m}$, and tolerance range (green) was set to $\pm 50 \mu\text{m}$. Values closer to red indicated positive difference relative to the reference, while values closer to blue indicated negative difference relative to the reference.

In the normality test, PMMA and DLP showed significance probability of 0.057 and 0.200, respectively, indicating normal distribution. In the equality of variance test, the F value was 0.959 and significance probability was greater than 0.05; thus, equality of variance was assumed. Under the assumption of equality of variance, the significance probability was 0.09, which is greater than significance level of 0.05; thus, there was no

significant difference between PMMA and DLP resin crowns ($p > 0.05$).

Discussion

A resin crown, a temporary crown of implant, is usually fabricated by subtractive manufacturing or by mixing and building up using self-curing resin²²⁻²⁴. Recently, resin fabrication by DLP method using 3D printing has been developed for resin crown fabrication to meet the growing demand for implants. The DLP method involves fabrication using photopolymerization reaction by projecting high-resolution UV light throughout the digital mask region, on photocurable resin (photopolymer resin) by reflecting a large number of digital micromirror device chips. It has excellent speed and precision, and since each irradiation round irradiates a single layer by laser, it has lower error rate. Accordingly, the DLP method is preferred in dentistry¹³. However, there are few studies on the fitness of resin crowns fabricated by the DLP method on an implant model. Therefore, this study aims to assess the fitness between resin crowns and the model on which the implant is placed.

To collect 3D data, model or intraoral scanner is typically used²⁵. Such 3D data has often been used in studies on the accuracy of models or impressions^{7,26}. Moreover, 3D data of implant models with narrow and long holes have shown lower accuracy compared with the traditional impression-taking method²⁷. Therefore, to increase the reliability of measurements, this study used TRIOS 3 intraoral scanner, which shows no differences in accuracy of impressions when compared with the traditional impression-taking method²⁸.

The reference value usually considered as the clinically acceptable level of internal fitness is $< 100 \mu\text{m}$. This is because discoloration, cement leakage, plaque build-up, or gingival inflammation may occur when the internal gap is $\geq 100 \mu\text{m}$ ²⁹. Accordingly, $100 \mu\text{m}$ was set as the criterion for internal fitness in this study. The fitness of resin crowns measured was $< 100 \mu\text{m}$ for both PMMA and DLP, indicating that both show clinically-acceptable internal fitness. However, the mean and SD values of the resin crowns fabricated by the DLP method were larger

Fig. 7. Color-difference-map of poly methyl methacrylate (PMMA) and digital light processing (DLP). Color-difference-maps showing superimposition of three-dimensional data comparisons among material types. Green represents good fit, yellow or red represents positive error, and turquoise or blue represents negative error.

than those of the PMMA method. This difference may be attributed to the difference in fabrication method. Compared with the PMMA method, which is made by processing resin that has already been polymerized, DLP uses a method of polymerizing resin after processing. As a result, the mean and SD values may appear higher owing to polymerization shrinkage. A previous study on the accuracy of the dental model using the DLP method reported an error of $\geq 100 \mu\text{m}$ in certain areas due to shrinkage¹⁴⁾.

The significance of this study is that 3D measurements were obtained on the internal fitness of implant models based on subtractive and additive manufacturing methods. The findings showed that resin crowns fabricated using a DLP printer could replace resin crowns fabricated by conventional subtractive manufacturing method.

Among the limitations of this study is the fact that DLP 3D printing systems require secondary curing. Moreover, because differences in strength and physical properties occur according to changes in the amount of light and time during post-curing time, there were limitations in controlling errors is difficult.

Notes

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Ethical approval

This project does not require IRB review because it is an experimental paper using commercially available resins.

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