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

Wol Kang1, Min-Su Kim2, and Won-Gi Kim1†

1Department of Dental Laboratory, Daegu Health College, Daegu 41453,
2Department of Dental Science, Graduate School, Kyungpook National University, Daegu 41566, Korea

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 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±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 prosthetic 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 resin3-5).

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
equipment maintenance costs, and the need to discard raw materials left over from fabricating the restoration. The manufacturing process is also time-consuming\(^8\).

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 speed\(^12\); it also has higher precision than the FDM method\(^13\).

To date, studies that used DLP printers include those that analyzed model shrinkage rate\(^14\), model fitness\(^12,15,16\), and molar fitness of resin crowns\(^17\). 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 installed\(^18\).

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.](image)

![Fig. 2. Resin crowns. There are resin crowns divided into two groups. PMMA: poly methyl methacrylate, DLP: digital light processing.](image)
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 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.
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 <45º 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:

$$\text{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2}$$

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.

| 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±SD| 41.51±1.51| 43.09±2.32|
| p-value| 0.09  |     |

Values are presented as number only or mean ± 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 ±100 μm, and tolerance range (green) was set to ±50 μm. 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 resin. 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 dentistry. 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 used. Such 3D data has often been used in studies on the accuracy of models or impressions. Moreover, 3D data of implant models with narrow and long holes have shown lower accuracy compared with the traditional impression-taking method. 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 method.

The reference value usually considered as the clinically acceptable level of internal fitness is <100 μm. This is because discoloration, cement leakage, plaque build-up, or gingival inflammation may occur when the internal gap is ≥100 μm. Accordingly, 100 μm was set as the criterion for internal fitness in this study. The fitness of resin crowns measured was <100 μm 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.
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 $\geq 100 \mu m$ in certain areas due to shrinkage.\(^{14}\)

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.

**ORCID**

Wol Kang, https://orcid.org/0000-0002-1175-8170

Min-Su Kim, https://orcid.org/0000-0002-5458-158X

Won-Gi Kim, https://orcid.org/0000-0001-8642-9542

**Acknowledgements**

This research was supported by the P0006692 grant funded by Ministry of Trade, Industry and Energy Promotion Agency SMEs.

**References**

1. Tinschert J, Natt G, Hassenpflug S, Spiekermann H: Status of current CAD/CAM technology in dental medicine. Int J Comput Dent 7: 25-45, 2004.
2. Rekow D: Computer-aided design and manufacturing in dentistry: a review of the state of the art. J Prosthet Dent 58: 512-516, 1987. https://doi.org/10.1016/0022-3913(87)90285-x
3. Samet N, Resheff B, Gelbard S, Stern N: A CAD/CAM system for the production of metal copings for porcelain-fused-to-metal restorations. J Prosthet Dent 73: 457-463, 1995. https://doi.org/10.1016/0022-3913(05)80075-7
4. Beuer F, Schweiger J, Edelhoff D: Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 204: 505-511, 2008. https://doi.org/10.1038/sj.bdj.2008.350
5. Vafiadis D, Goldstein G: Single visit fabrication of a porcelain laminate veneer with CAD/CAM technology: a clinical report. J Prosthet Dent 106: 71-73, 2011. https://doi.org/10.1016/S0022-3913(11)00100-4
6. Song JK, Park KS, Kim MS, Kwon TY, Hong MH: Accuracy comparison between subtractive and additive methods in fabricating working model. Korean J Dent Mater 45: 89-96, 2018. https://doi.org/10.14815/kjdm.2018.45.1.89
7. Ender A, Mehl A: Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent 109: 121-128, 2013. https://doi.org/10.1016/j.prostho.2010.12.008
8. Choi JW, Choi BC, Kim SC: Marginal fit of the prosthesis fabricated by dental oral scanner and model scanner. Korean J Dent Mater 44: 79-86, 2017. https://doi.org/10.14815/kjdm.2017.44.1.079
9. Martorelli M, Gerbino S, Giudice M, Ausiello P: A comparison between customized clear and removable orthodontic appliances manufactured using RP and CNC techniques. Dent Mater 29: e1-e10, 2013. https://doi.org/10.1016/j.dental.2012.10.011
10. van Noort R: The future of dental devices is digital. Dent Mater 28: 3-12, 2012. https://doi.org/10.1016/j.dental.2011.10.014
11. Stampfl J, Liska R: New materials for rapid prototyping applications. Macromol Chem Phys 206: 1253-1256, 2005.
1. Hazeveld A, Huddleston Slater JJ, Ren Y: Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. Am J Orthod Dentofacial Orthop 145: 108-115, 2014. https://doi.org/10.1016/j.ajodo.2013.05.011

2. Envision TEC: Advanced DLP for superior 3D printing. Envision TEC white papers, Dearborn, pp.1-8, 2017.

3. Kim SY, Shin YS, Jung HD, Hwang CJ, Baik HS, Cha JY: Precision and trueness of dental models manufactured with different 3-dimensional printing techniques. Am J Orthod Dentofacial Orthop 153: 144-153, 2018. https://doi.org/10.1016/j.ajodo.2017.11.004

4. Moon JM, Kim JM, Bae JM, Oh SH: Evaluation of acceleration aging effect on the deformity of dental 3D printer products. Korean J Dent Mater 44: 53-60, 2017. https://doi.org/10.14815/kjdm.2017.44.1.053

5. Jang Y, Sim JY, Park JK, Kim WC, Kim HY, Kim JH: Accuracy of 3-unit fixed dental prostheses fabricated on 3D-printed casts. J Prosthet Dent 2019. [Epub ahead of print] https://doi.org/10.1016/j.prosdent.2018.11.004.

6. Kim DY, Kim JH, Kim HY, Kim WC: Comparison and evaluation of marginal and internal gaps in cobalt-chromium alloy copings fabricated using subtractive and additive manufacturing. J Prosthodont Res 62: 56-64, 2018. https://doi.org/10.1016/j.jpor.2017.05.008

7. Jung JH, Lee KE, Kim YR: Marginal and internal fit of metallic and zirconia copings depending on manufacturing methods. Clin Oral Implants Res 29: 192, 2018. https://doi.org/10.1111/clr.13358

8. Han MS, Kim KB: Comparison of the marginal and internal fit on the cast and CAD-CAM cores. J Dent Hyg Sci 12: 368-374, 2012.

9. Pimenta MA, Frasca LC, Lopes R, Rivaldo E: Evaluation of marginal and internal fit of ceramic and metallic crown copings using x-ray microtomography (micro-CT) technology. J Prosthet Dent 114: 223-228, 2015. https://doi.org/10.1016/j.prosdent.2015.02.002

10. Hwang SH, Yu JS, Han YK: The effect of various coffees on the color stability of self-cured temporary crown resin. J Dent Hyg Sci 12: 342-347, 2012.

11. Park JW, Bae SS: Color stability of self-cured temporary crown resin according to different surface treatments. J Dent Hyg Sci 16: 150-156, 2016. https://doi.org/10.17135/jdhs.2016.16.2.150

12. González de Villaumbrosia P, Martínez-Rus F, García-Orejas A, Salido MP, Pradíes G: In vitro comparison of the accuracy (trueness and precision) of six extraoral dental scanners with different scanning technologies. J Prosthet Dent 116: 543-550,e1, 2016. https://doi.org/10.1016/j.prosdent.2016.01.025

13. Jørgensen KD, Esbensen AL: The relationship between the film thickness of zinc phosphate cement and the retention of veneer crowns. Acta Odontol Scand 26: 169-175, 1968. https://doi.org/10.3109/00016356809026130