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Comparison of Flexural Strength of Three-Dimensional Printed Three-Unit Provisional Fixed Dental Prostheses according to Build Directions

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Purpose: The aim of this study was to compare the flexural strength of provisional fixed dental prostheses which was three-dimensional (3D) printed by several build directions.
Materials and Methods: A metal jig with two abutment teeth and pontic space in the middle was fabricated. This jig was scanned with a desktop scanner and provisional restoration was designed on dental computer-aided design program. On the preprocessing software, the build angles of the restorations were arranged at 0°, 30°, 45°, 60°, and 90° and support was added and resultant structure was sliced to a thickness of 100 μm. Processed restorations were printed with digital light processing type 3D printer using poly methyl meta acrylate–based resin. After washing and post-curing, compressive loading was applied at a speed of 1 mm/min on a metal jig fixed to a universal testing machine. The maximum pressure at which fracture occurred was measured. For the statistical analysis, build direction was set as the independent variable and fracture strength as the dependent variable. One-way analysis of variance and Tukey's *post hoc* analysis was conducted to compare fracture strength among groups (α=0.05).
Result: The mean flexural strength of provisional restoration 3D printed with the build direction of 0° was 1,053±168 N; it was 1,183±188 N at 30°, 1,178±81 N at 45°, 1,166±133 N at 60°, and 949±170 N at 90°. The group with a build direction of 90° showed significantly lower flexural strength than other groups ($P<0.05$). The flexural strength was significantly higher when the build direction was 30° than when it was 90° ($P<0.01$).
Conclusion: Among the build directions 0°, 30°, 45°, 60°, and 90° set for 3D printing of fixed dental prosthesis, an orientation of 30° is recommended as an effective build direction for 3D printing.

Key Words: CAD/CAM; Fixed partial denture; Flexural strength; Printing, three-dimensional

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Introduction

Three-dimensional (3D) printing manufacture of dental prostheses has many advantages, when compared to the conventional method using impression materials and lost wax technique. The 3D printed restoration can be made from intraoral scan data and the impression procedure using silicone material is not needed in this case. Therefore, the dental application of 3D printing can prevent patients from experiencing nausea swallowing the impression materials. In addition, the unnecessary prosthesis manufacture process such as stone pouring, model trimming, wax up, investing, and casting can be omitted. Consequently, it helps saving materials and energy, and is more economical than the conventional method[1,2].

The 3D printing has considerable potential for application in the dentistry field. 3D printing or additive manufacturing (AM) device comes to be cheaper than before[3]. They can work with various materials such as metals, ceramics, and polymers. Recently, studies have shown that dental prostheses manufactured using the AM method have an acceptable degree of precision[4]. Furthermore, various studies on the clinical application of 3D printing technology have been reported[3-8].

With the AM technology, one can manufacture objects by stacking various materials such as polymer, metal, and ceramic. Ceramic printers are not yet widely used because of the complexity of the debinding and sintering process to remove the polymer binder material after ceramic build-up. Metal printers are also not popularized in the dental field because the equipment is still expensive as the high-power laser should be used, and the metal powder is not easy to manufacture. Although the entry barriers are high for metal 3D printers, the low-cost equipment is being introduced and can gradually be used in the dental field soon.

There are several principles for polymer 3D printers and are actively utilized in dentistry. Fused deposition modeling (FDM) is a method in which a filament type thermoplastic resin is ejected through the melting head. Stereolithography apparatus (SLA) and digital light processing (DLP) printers selectively polymerize light-cured liquid resins in a water bath called ‘vat’. DLP technology uses digital micromirror and the laser is controlled by this digital micromirror. Hence, the entire layer of liquid resin is polymerized at once, making DLP faster than SLA and more actively utilized in the dental field[9].

While the AM method comes to be actively utilized in everyday clinical practice, the physical properties of the prosthesis manufactured using this technology must be investigated. There is few researches on the physical properties of the fixed dental prostheses (FDPs) that can be used in clinical practices[10]. In this study, the flexural strength of the three-unit provisional FDP fabricated with the DLP technology was compared. The primary objective was to find the optimal direction for 3D printed provisional with flexural strength enough for clinical application. The null hypothesis was that the flexural strength of 3D printed provisional FDP was not different according to the various build directions.

Materials and Methods

A metal jig was made for the abutments of the three-unit implant prosthesis. The indenter was manufactured with spherical end with a diameter of 6 mm. The metal jig and the indenter were made of stainless steel my milling procedure. The measurements of the indenter were referenced from other studies that measured the flexural strength of three-unit resin prostheses, and the pressure was also applied according to previous reports[11,12].

For the flexural strength test of 3D-printed specimens that were fabricated with five different build directions, a poly methyl meta acrylate (PMMA)-based 3D printing resin (C&B; NextDent Co., Seosterberg, The Netherlands) was used to print the specimens using DLP (Table 1). Before scanning procedure by desktop scanner (Identica Hybrid; Medit Co., Seoul, Korea), the scan powder (IP-Scan-Spray; IP division Co., Hainhausen, Germany) was applied on the metal jig. After the virtual model of the metal jig were obtained, parameter for cement space was set so that the prosthesis could be appropriately seated on the abutment. Exocad (Exocad Co., Darmstadt, Germany) was used for designing the three-unit prosthesis. For the preprocessing for 3D printing, the completed design was placed in slicing software (VeltzBP; Veltz 3D Co., Incheon, Korea), and the supports required for successful 3D printing were added under the design (Fig. 1). The specimen with support structure was then sliced with z-axis thickness of 100 μm. Specimens manufactured using a DLP printer (DP-150; Veltz 3D Co.), with the build directions of 0°, 30°, 45°, 60°, and 90° (Table 2, Fig. 2). For each group, 15 specimens were manufactured. When the 3D printing was finished, specimens were cleaned using 100% isopropyl alcohol to remove the excessive resin monomer, and underwent post-cure processing for 120 minutes by post-curing machine (Denstar-300; Denstar Co., Daegu, Korea) (Fig. 3).

The metal jig was fixed at the center of the universal test machine (Instron8871; Instron Co., Norwood, OH, USA), and the rod with the indenter was placed in the middle. The provisional restoration was placed on the abutment of the metal jig, and pressure was applied with the indenter at the speed of 1 mm/min. The maximum pressure before the breaking point

Table 2. Specifications of devices

Specification	Information
Printer	DLP (D-150)[a]
Manufacturer	Veltz 3D Co.
Build volume (mm)	150×84.3×100
Layer thickness (μm)	25~100
Spot size (μm, laser spot diameter)	405
Power (W)	150

DLP: digital light processing.
[a]Serviced by the manufacturer, published on online.

Table 1. Composition and mechanical properties of specimen materials

Manufacturing method	Product name	Manufacturer	Basic materials	Flexural strength (MPa)[a]	Flexural modulus (MPa)[a]
DLP	C&B	NextDent Co.	Poly methyl methacrylate	85	2,100

DLP: digital light processing.
[a]Serviced by the manufacturer, published on online.

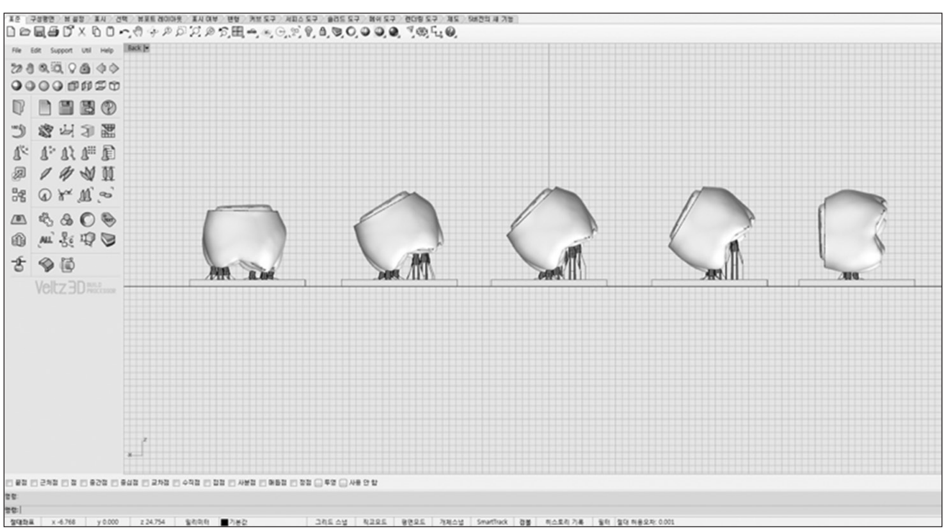

Fig. 1. Designed virtual specimen and supports with various build directions.

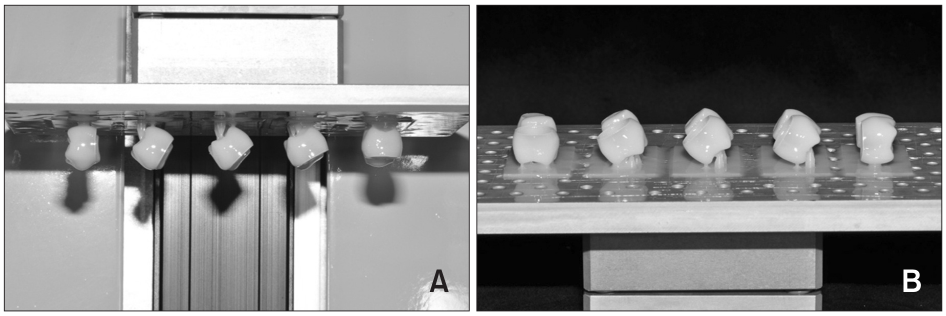

Fig. 2. Three-dimensional (3D) printed provisional fixed dental prostheses. (A) Immediately after 3D printing procedure. (B) Printed products on the build platform before detaching procedure.

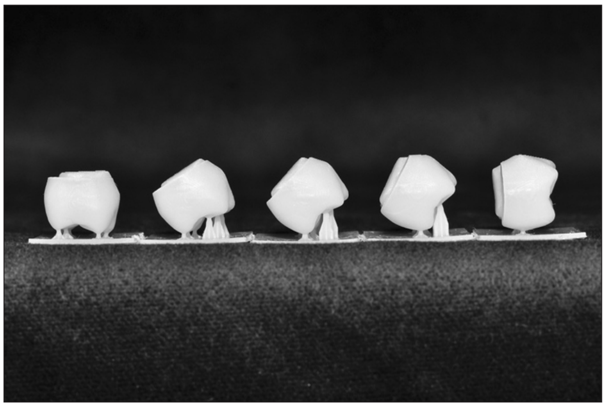

Fig. 3. Completed fixed dental prostheses after post-cure processing.

Table 3. Mean flexural strength of 3-unit provisional fixed dental prostheses with build direction of 0°, 30°, 45°, 60°, and 90° (unit: N)

Build direction	Mean±SD (n=15)
0°	1,053±168[ab]
30°	1,183±188[a]
45°	1,178±81[a]
60°	1,166±133[a]
90°	949±170[b]

SD: standard deviation.
Different uppercase letters indicate statistical difference between build direction groups (P<0.05).

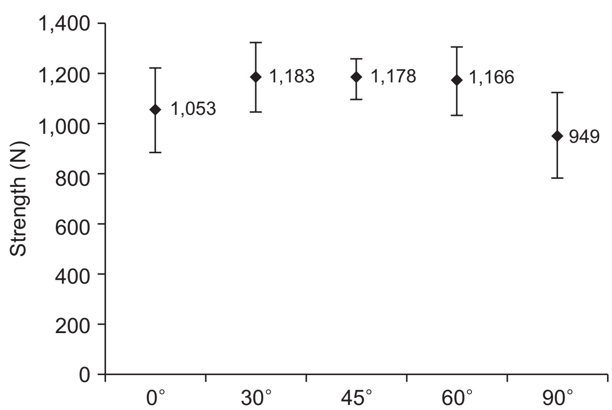

Fig. 4. Flexural strength of three-dimensional printed provisionals fabricated by different build directions.

was measured.

For the statistical analysis of flexural test measurement, the build directions of the specimens were considered the independent variables. The dependent variable was the flexural strength. The one-way analysis of variance was performed with Tukey's honestly significant difference multiple comparisons test (α=0.05). The statistical analysis was performed using a commercially available software program (IBM SPSS Statistics ver. 23.0; IBM, Armonk, NY, USA).

Result

The mean flexural strength of the build direction of 0° was 1,053±168 N; it was 1,183±188 N at 30°, 1,178±81 N at 45°, 1,166±133 N at 60°, and 949±170 N at 90° (Table 3, Fig. 4). Although no significant difference was observed among the 0°, 30°, 45°, and 60° groups (P>0.05), the highest and lowest mean flexural strengths were observed in the 30° and 90° groups, respectively. The build direction of 30° had the highest flexural strength on average among the various build direction groups. No significant difference in flexural strength was observed between 90° and 0° groups (P=0.278) and among 0°, 30°, 45°, and 60° groups (P>0.05). Nevertheless, the flexural strength was significantly lower when the build direction was 90° than when it was 30°, 45°, or 60° ($P<0.05$). The flexural strength was significantly higher when the build direction was 30° than when it was 90° ($P<0.01$), but it was not significantly high compared to the other groups.

Discussion

The flexural strength of 3D printed FDP was different among the groups with various build directions. Therefore, the null hypothesis was rejected. It was found that the specimen with a build direction of 90° had the lowest flexural strength. It could be inferred that the inter-layer bonding is weaker than the intra-layer bonding when building the specimens. This is the same conclusion as that of Alharbi et al.[10]. However, the flexural strengths of 30°, 45°, and 60° groups were significantly higher than that of 90° group and not significantly different with that of 0° group. Therefore, it is possible that the build direction with the highest flexural strength is not at 0° or 90° but between 0° and 90°. This finding implies that the factor for flexural relation is not limited to the idea that the intra-layer bonding is better than inter-layer bonding. Thus, it is worth considering that the effects of the relationship between the build direction and the flexural strength on the inter-layer and intra-layer bonding should be considered preferentially. And the area where the inter-layer or intra-layer bonds break first determines the flexural strength.

Therefore, how the build direction affects the flexural strength should be considered. The following formula represents the σ (stress) of the standardized specimen[13].

$$\sigma = \frac{3FL}{2wd^2}$$

Here, F is the external force, L is the length of the specimen, w is the width of the specimen, and d is the thickness of the specimen (Fig. 5). It can be assumed that Fa is the force applied at the moment of fracture on the specimen A, and Fb is the force applied at the moment of fracture on the specimen B. If there is absolutely no inter-layer bonding or friction between the two layers of specimen B, the force is applied to both the layers equally. If the two specimens should be fractured at the same time, the applied force before each layer fractured must be sum of two. According to the formula given above, the applied force to fracture the specimen is proportional to d^2; therefore Fa:Fb can be represented as follows:

$$Fa : Fb = d^2 : \left(\frac{d^2}{4} + \frac{d^2}{4}\right) = 2:1$$

If the inter-layer bonding exists between the two layers on specimen B, the flexural strength of the specimens A and B will be the same as the inter-layer bonding force increases to the same degree as the intra-layer bonding force. Therefore, as the inter-layer bonding force converges to the intra-layer bonding force, the flexural strength comes closer to Fa, and as the inter-layer bonding force comes closer to 0, the flexural strength converges to Fb. It can also be said that the flexural strength is lower when the number of layers is increased. Considering the build direction, the number of layers increases when the build direction decreases and vice versa. Therefore, it

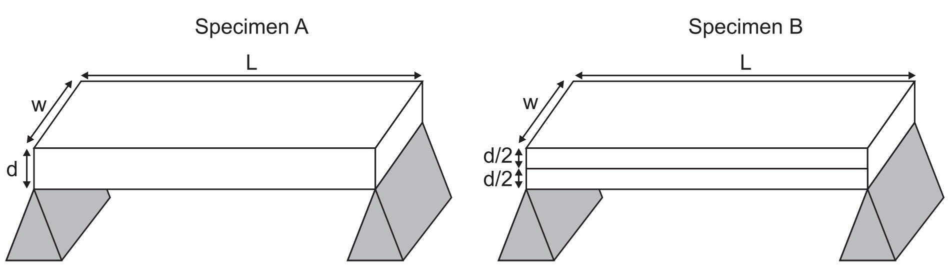

Fig. 5. Dimension of specimens. (A) Standardized specimen. (B) Double layered specimens with a thickness of d/2 in each layer. L: length of the specimen, w: width of the specimen, d: thickness of the specimen.

can be inferred that the intra-layer bonding is broken more quickly when the build direction is closer to 0°. However, the trend becomes different when the inter-layer bonding is considered. Inter-layer delamination occurs more quickly when the build direction is closer to 90°, as the direction of the shear strength approaches the direction of the layer.

Considering two factors, the number of layers and the tendency of delamination with respect to the build direction, it was observed that the specimen exhibited the highest strength when the build direction was not 90° but 0° or more and under 90°. If the intra-layer bonding was higher than inter-layer bonding, then the flexural strength was higher when the build direction was 0° than when it was 90°. Although the results of this study do not perfectly show a significant tendency as discussed above, they reveal a probable tendency. Hence, further research is needed to identify this tendency more clearly.

The build direction of 3D printing also affects the accuracy of the product. The optimal build direction for SLA printing was reported to be 120°[14], while those for DLP printing was concluded to be 135° in the other article[15]. In general, the build direction of 90°, shown in Fig. 4, is not recommended for the manufacturing of dental prostheses because the supports would be in contact with the margins of the product. The supports should be in contact with the area that is built first during the printing process.

For the application of the 3D printing technology in daily practice, additional studies must be performed not only on the flexural strength but also on compressive, tensile, shear, and fatigue strengths along with solubility and permeability. Several factors determine the physical properties of the resin prosthesis. Flexural strength may change when the resin specimen is surrounded by a solvent[16]. Fibers reinforce the wear resistance or tensile strength[17]. Therefore, the physical properties of resin prosthesis with respect to many factors should be studied in the future.

Conclusion

Among the build directions 0°, 30°, 45°, 60°, and 90°, the build direction with the lowest flexural strength was 90° group, and the build direction with the highest flexural strength was 30°, 45°, or 60° groups. Hence, an orientation of 30° is recommended as the effective build direction.

Conflict of Interest

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

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