Fracture Strength of Six-Unit Anterior Fixed Provisional Restorations Fabricated Using Various Dental CAD/CAM Systems

Gyu-Won Yoon, MS

Department of Dental Laboratory Technology, Graduate School of Clinical Dentistry, Ewha Womans University, Seoul, Republic of Korea.

Eun-Jin Park, DDS, MMSc, PhD

Department of Prosthodontics, School of Medicine, Ewha Womans University, Seoul, Republic of Korea.

Purpose: This study compares the fracture strengths of long-span fixed provisional restorations fabricated via digital additive and subtractive methods to those fabricated via conventional heat-processing techniques. ***Materials and Methods:*** A six-unit anterior partial restoration was designed as an anatomical and morphologic structure using a dental CAD/CAM system. The provisional restorations (N = 40) of four different fabrication methods (n = 10 per group) were used for the failure loading test: stereolithography apparatus (SLA), liquid crystal display (LCD), milling (MIL), and heat-processed temporary (HPT). The specimens were subjected to a maximum load-to-fracture test using a universal testing machine, and the representative fracture patterns were observed. Statistical analysis was performed using Shapiro-Wilk, Kruskal-Wallis, Mann-Whitney *U*, and Bonferroni post hoc tests ($P < .05$). ***Results:*** The four groups showed significant differences in fracture strength according to the materials and manufacturing methods used ($P < .001$, except between SLA and HPT groups). The fracture strengths of MIL and LCD digitally fabricated groups were significantly higher than that of the HPT group ($P < .001$). ***Conclusions:*** The subtractive method is ideal for fabricating long-span fixed provisional restorations for long-term use. Additionally, LCD additive manufacturing technology could soon be a good alternative for restorations. *Int J Prosthodont 2024;37(suppl):s49–s54. doi: 10.11607/ijp.8530*

With the advent of implant surgery and prosthetic treatment in modern dentistry, the scope and duration of provisional restorations have gradually increased. Therefore, high fracture strength is essential for satisfactory long-term function of these restorations in patients with occlusal and temporomandibular joint problems or full-mouth rehabilitation accompanied by periodontal treatment and implant surgery. The fracture of provisional restorations is a common cause of restoration failure, resulting in patient discomfort and higher treatment costs.[1] Fractures can occur even during normal masticatory function because concentrated stresses increase with longer spans.[2]

Incomplete polymerization of the resin during the hand-mixing process used to fabricate fixed provisional restorations using traditional self-curing resins results in poor surface texture, low strength, and inconsistent working conditions, all of which frequently cause prosthesis failure.[3] While the heat-processing method increases the fracture strength of provisional restorations, its use is gradually decreasing due to polymerization shrinkage deformation, fine cracks, and higher manpower requirements and manufacturing times.[4]

Correspondence to:
Dr Eun-Jin Park,
prosth@ewha.ac.kr

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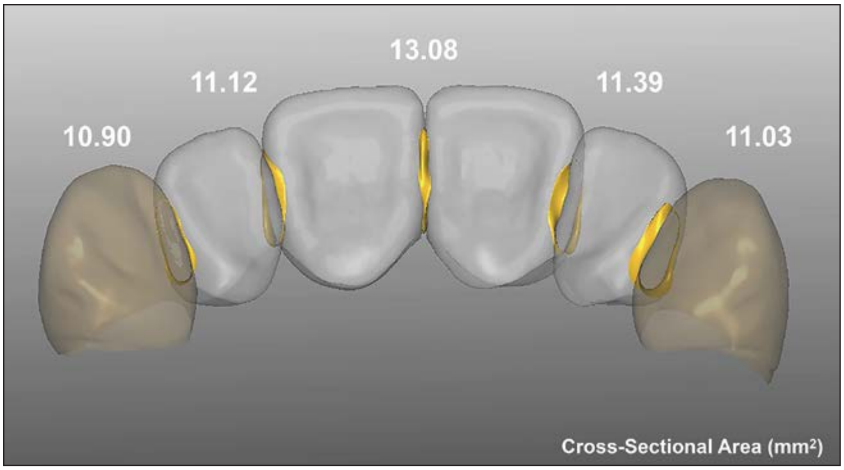

Fig 1 Connector design of a six-unit provisional partial restoration. The connectors were designed in an oval cross-sectional shape with an average cross-sectional area of 12 mm^2.

Dental CAD/CAM systems with improved technology offer superior prostheses for patients requiring long-lasting multiunit provisional restorations. The intraoral or working model is scanned, and the prostheses are fabricated via digital machining using the desired material. Machining methods are divided into subtractive and additive manufacturing, of which the subtractive milling was primarily used based on the development of digital production technology.[5] It offered a wide range of materials and good fit but wasted milling blocks and burs, and there were wide variations in the outcomes when reproducing complex and detailed forms depending on equipment specifications.[6,7] Additive manufacturing has gradually gained interest and demand owing to a wide range of applications in dentistry and the development of materials and technologies. Because tool movement has no restrictions, reproducing complex shapes is easy[8]; additive manufacturing also allows multiple products to be printed, thereby reducing production time and enabling mass production.[9] However, it requires separate washing and posttreatment processes.

With the increasing number of implant treatments, the demand for stronger long-span provisional restorations is increasing, and digital manufacturing methods and materials are also rapidly developing. Although many previous studies have compared the mechanical properties of provisional materials,[10–12] restorations used in clinical practice have nonuniform shapes and thicknesses. Moreover, their fracture strength may differ depending on the length and arch of the defect, and there has been no study on the fracture strength of digitally fabricated long-span resin partial restorations. While other studies on fracture resistance have shown varied results owing to different research methods, the materials and manufacturing methods of provisional restorations have been primarily limited to existing traditional procedures and subtractive techniques.[13,14] In addition, closely comparing the fracture load values was difficult due to the nonstandardized experimental conditions and measurement methods.

Therefore, this study examined the fracture strength of long-span fixed provisional restorations for long-term use using various digital fabrication techniques, including the latest liquid crystal display (LCD) additive technique compared with traditional heat-processing technique. Also, a preliminary test was conducted using International Organization for Standardization (ISO)-standard specimens prepared by applying the same manufacturing method. Although it is advantageous to use the mandibular anterior partial restoration for vertical load test, this experiment focused on the characteristics, materials, and strength of the long-span bridge, intending to obtain clearer results by selecting a maxillary anterior partial restoration with a larger area than a mandibular anterior bridge. The null hypothesis of this study was that no significant difference would be observed in the fracture strength of long-span fixed provisional restorations based on the manufacturing method.

MATERIALS AND METHODS

After removing four maxillary incisors from a standard dentiform, the canine teeth were prepared with a chamfer margin (1 mm wide, 2 mm thick) at the incisal edge to form a working model for a six-unit anterior partial restoration. After obtaining the scans of the working model using a dental CAD/CAM system, zirconia blocks (Natura M2, DMAX) were milled and sintered to fabricate dies for the prosthesis. A dental arch–formed abutment model was bonded to a custom-made metal jig. A six-unit anterior partial restoration was designed using the scan data and CAD software (Zirkonzahn). The provisional restoration was fabricated to be 2 mm thick at the incisal edge and 1.5 mm thick at the side surface to obtain sufficient strength. Further, the connectors were designed with an average cross-sectional area (CSA) of 12 mm^2 in an oval shape (Fig 1).[15–18] The cement space between the crown and zirconia die was set to 0.035 mm. Then, an STL file for a single partial prosthesis was used for uniform fabrication.

The specimens were divided into four groups based on the materials and manufacturing methods, and a total of 40 specimens were fabricated (Fig 2). The manufacturing groups were as follows (n = 10 specimens per group): stereolithography apparatus (SLA), LCD, milling (MIL), and heat-processed temporary (HPT). Table 1 details the resin materials used for fabricating the experimental provisional restorations.

Among the additive manufacturing groups, the SLA specimens were fabricated using a photosensitive liquid resin (Tera Harz TC-80DP, Graphy) and an SLA 3D printer (Sindoh A1+, Sindoh). The LCD specimens were fabricated using the same photosensitive liquid resin and an LCD 3D printer (Sindoh A1SD, Sindoh). For these two methods, all specimens were fabricated with a uniform layer thickness and 0-degree build orientation.[19,20] Postcuring was performed after a cooling time of 360 seconds in a UV curing machine (MP300, Veltz). MIL specimens were fabricated via subtractive manufacturing using polymethyl methacrylate (PMMA) blocks (Highlight PMMA, Hasem) and a milling machine (M1 Milling Unit, Zirkonzahn). HPT specimens were fabricated using a conventional heat-processing method. Wax blocks (Easymill Wax, High Dental Korea) were milled (M1 Milling Unit) to obtain wax patterns and create a mold using the dental flask. According to the manufacturer's instructions, mixed dough stage PMMA resin (Bio-T, High Dental Korea) was injected into the mold, and excess resin was removed after applying pressure slowly with a dental press. Using clamps, the flasks were placed in a heat-pressure pot and thermally processed at 30 psi in 38°C water for 20 minutes.[21] The completed provisional restorations were cemented to the zirconia dies using a temporary cement (Temp-bond, Kerr); these specimens were then stored in distilled water at 37°C for 24 hours.

The center of the specimen was placed in the center of the cylindrical metal indenter, and the incisal edges of both central incisors were in contact with the device to apply the uniform load (Fig 3).[15] An axial compressive load was applied to the

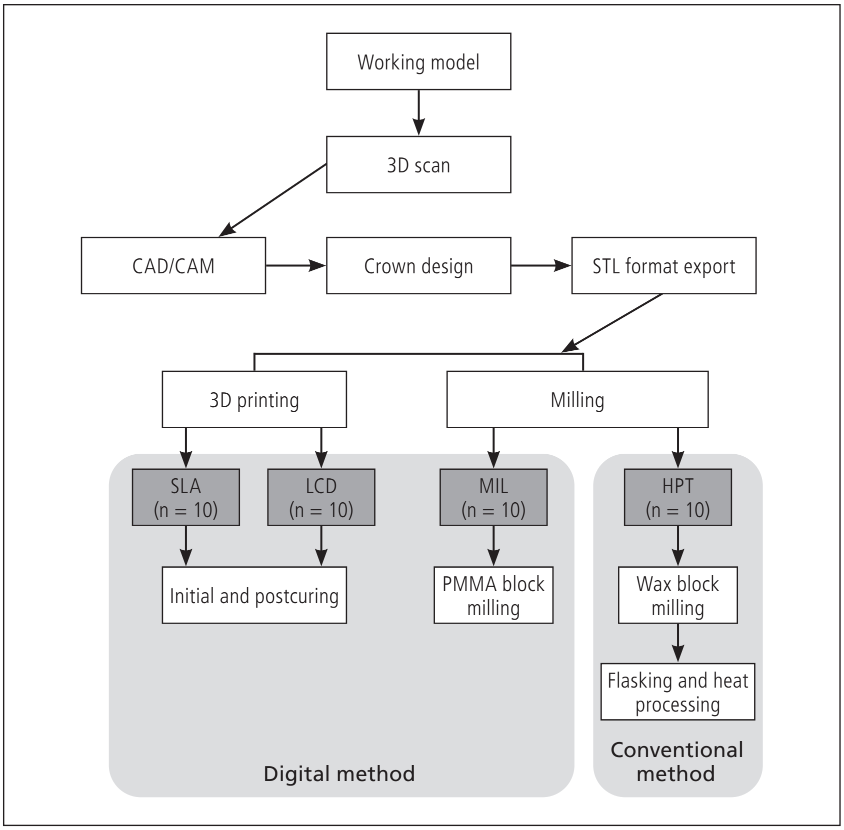

Fig 2 Study workflow.

Table 1 Composition and Strength of the Provisional Resin Materials

Material	Manufacturer	Composition	Flexural strength
Tera Harz TC-80DP	Graphy	Oligomer,* photoinitiator, pigments, etc	≥ 220 MPa
Highlight PMMA	Hasem	PMMA	≥ 50 MPa
Bio-T	High Dental Korea	PMMA	≥ 50 MPa

*Aliphatic urethane acrylate oligomer.

center of the specimens with a 1.0 mm/minute crosshead speed using a universal testing machine (Model 5942, Instron). Accordingly, the maximum load values and fracture patterns were observed. Using SPSS for Mac (IBM), statistical analysis was performed via Shapiro-Wilk, Kruskal-Wallis, Mann-Whitney *U*, and Bonferroni post hoc tests. $P < .05$ was considered statistically significant.

RESULTS

The average fracture load was the highest in the MIL group (503.53 ± 32.27 N), followed by the LCD group (428.32 ± 41.15 N), SLA group (249.15 ± 40.59 N), and HPT group (233.54 ± 25.98 N). The MIL and HPT specimens exhibited the highest and lowest load-to-failure values, respectively. Among the 3D-printed specimens, the LCD group demonstrated greater fracture resistance than the SLA group. The fracture strengths of

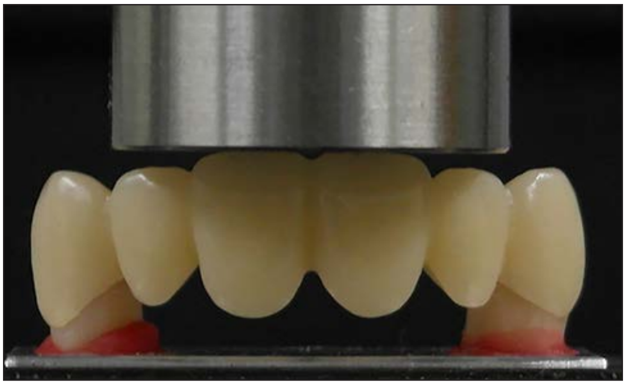

Fig 3 Load-to-failure tests were performed using a universal testing machine.

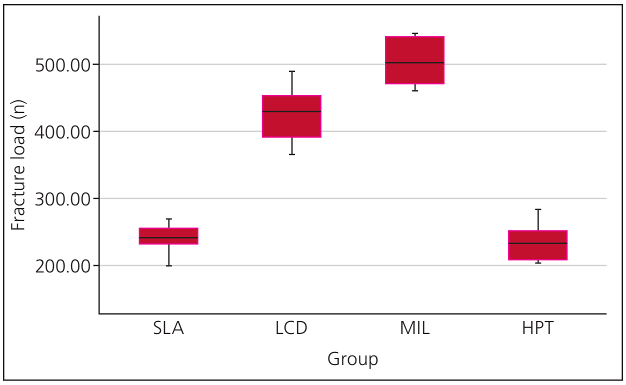

Fig 4 Box plot of fracture strength values for each group.

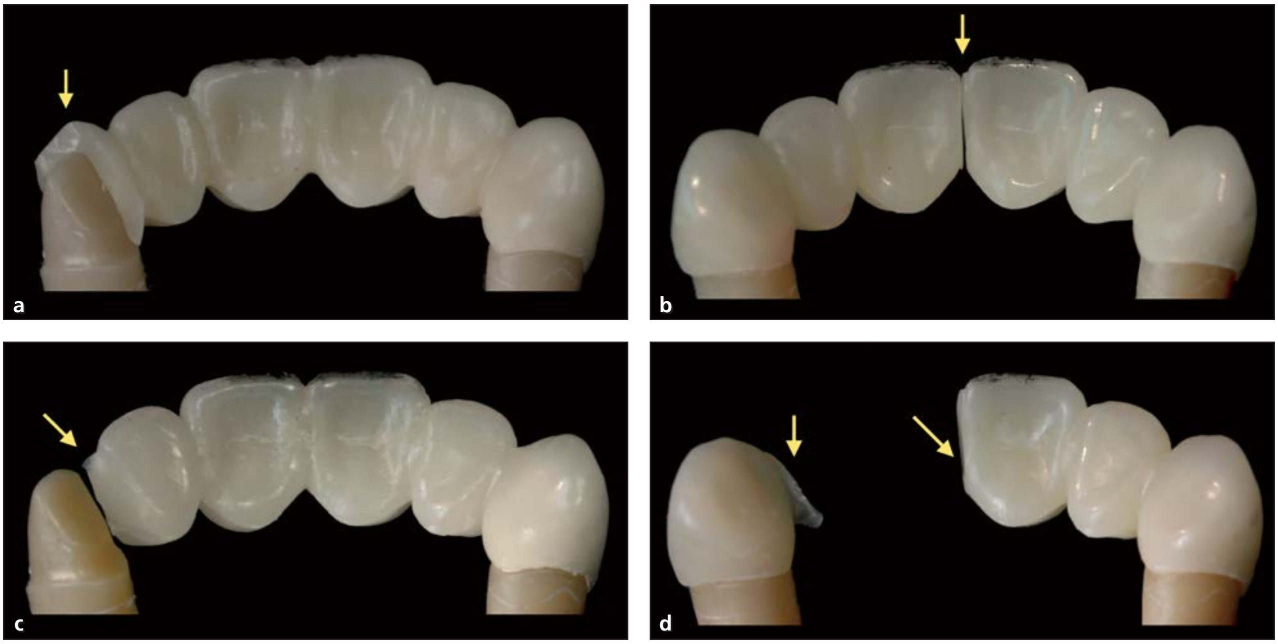

Fig 5 Representative failure types according to the fracture location: *(a)* Type I (abutment), *(b and c)* Type II (connector), and *(d)* Type III (combination).

MIL and LCD groups (digitally fabricated) were significantly higher than that of the HPT group ($P < .001$). A statistically significant difference was observed among all groups ($P < .001$) except between SLA and HPT groups. Figure 4 shows the fracture strength values for each group.

The fracture patterns were classified into three types based on the fracture location: abutment site, connector site, or a combination of the two (Fig 5, Table 2). Fractures were primarily initiated at the connector site in the SLA and LCD specimens and at the abutment site in the MIL and HPT specimens. The HPT specimens fractured and fragmented into multiple pieces, whereas the digitally fabricated specimens (SLA, LCD, and MIL) exhibited a single cross-section fracture pattern.

DISCUSSION

Based on the present results, the null hypothesis was rejected due to the specimens showing differences in fracture strength depending on the manufacturing method.

The flexural strength of a material is important for the long-term use of a long-span fixed prosthesis. If the flexural strength is high, prosthesis bending occurs at the start of compression, absorbing the initial stress with a lower likelihood of damage. To compare the fundamental flexural strength of the resin, a 25 × 2 × 2–mm specimen[22] was produced using the same technique as in the present study, and a pilot study was conducted by unifying all of the experimental conditions except the specimen form. Subsequently, the present study was conducted similar

Table 2 Classification of Fracture Types According to the Fracture Location of the Specimen

Group	SLA	LCD	MIL	HPT
Type I (abutment)	20%	30%	100%	80%
Type II (connector)	60%	60%	0%	10%
Type III (combined)	20%	10%	0%	10%

Table 3 Fracture Strength of the Pilot Group Tested

Group	SLA	LCD	MIL	HPT
Mean	35.19 N	40.20 N	44.16 N	22.68 N

to the three-point bending test, and the flexural strength of the samples decreased in the following order: MIL > LCD > SLA > HPT; these results were consistent with the pilot study (Table 3). The pilot study became one criterion to help judge the effect on strength compared to the main experiment. Accordingly, as the other variables were well controlled, a change in the fracture strength of the provisional restoration was observed depending on the fabrication method and resin material.

Among the digital manufacturing methods, there is a method of stacking molding through a light source. While previous studies primarily used SLA and digital light processing, a close comparison or analysis of the fracture strength was difficult, as the materials, equipment, and manufacturers varied for each study.[10,11] The present study compared the SLA technology, one of the oldest and most reliable 3D-printing technologies, to the latest LCD technology. The test conditions were standardized by unifying the type of photosensitive liquid resin, printing, and postcuring methods. The printing angle was set to 0 degrees for the horizontal plane, with a layer thickness of 100 μm to obtain maximum strength at fracture.[19,20] As a result, both the SLA and LCD specimens showed higher fracture resistance than the HPT specimens, with a significant difference in fracture resistance between them. Factors such as temperature, printing angle, and layer thickness could produce different results for the 3D-printed specimens; however, as the other variables were controlled, the observed change in fracture strength was due to the stacking principle. The SLA 3D printer used a UV laser, with the irradiation method implemented on a point-by-point basis, onto a resin tank containing photosensitive liquid resin as a light curing medium. Although it was possible to obtain precise and excellent surface conditions, the error rate was relatively high during stacking and showed relatively low bonding force and long printing times. The LCD 3D printer used a liquid crystal display as an imaging system, and each layer was irradiated face-to-face and photopolymerized. This is thought to be the reason for fast printing speeds and high durability, and the face-to-face bonding method showed higher fracture strength compared to the SLA group. However, the completeness of the output may vary depending on the location of the platform due to the difference in light intensity between the edge and the middle part. The SDs of the SLA and LCD groups were 40.59 N and 41.15 N, respectively, which were larger than those of the MIL (32.27 N) and HPT (25.98 N) groups, indicating relatively low equipment stability. When fabricating provisional restorations using photocurable 3D printing, stacking or modeling failures must be considered due to the use of liquid resin and the sensitive manufacturing environment.

The MIL specimens showed the highest fracture resistance, with a significant difference compared to the other groups. High-polymerization PMMA blocks for CAD/CAM are manufactured under controlled industrial conditions, such as high temperature and pressure, to prevent polymerization heat and shrinkage and to improve mechanical properties.[23] The MIL specimens had the best surface roughness and precision and presumably affected the high fracture strength.

Another factor that may have influenced the fracture strength of fixed provisional restorations is the connector design, In clinical applications, the partial prosthesis design depends on the crown shape and the size and length of the defect. The prosthesis fracture strength tends to decrease with increasing span length. A study by Lüthy et al[15] reported that a wider CSA of the joint offered significant advantages and recommended a CSA > 7.3 mm^2. In the present study, the joint designed for the six-unit resin partial restoration had an oval shape and an average CSA of 12 mm^2 for higher fracture resistance.[15,16]

Finally, occlusal adjustment and stress distribution become more essential in the relationship between fracture strength and reconstruction as the length expands. In the fracture load test, a large area of contact was applied to avoid stress concentration at only one point; despite being a long-span partial restoration, it obtained a relatively higher fracture strength than the method where load is placed at the specimen's center point. Therefore, loads must be induced in stable occlusal relationships through detailed occlusal adjustments by removing initial contact points or removing occlusal interference during prosthesis restoration.

The present study found that the fracture pattern initiated primarily at the connector site in SLA and LCD specimens and at the abutment site in MIL and HPT specimens. The 3D-printed specimens exhibited brittle destruction owing to low shear strength and high tensile strength, and many fracture patterns were observed at the connector site due to these characteristics. Therefore, reducing the layer thickness or increasing the exposure time of the light source during output is necessary to increase the fracture strength by increasing the bonding strength between layers. The MIL specimens exhibited ductile failure, and the time from the maximum stress point to the fracture point and plastic deformation section was the longest. Because the elastic resin material has energy absorption and recovery powers according to load, it was assumed that the fracture occurred at the thinnest part of the crown. The HPT specimens also showed ductile fracture, and the time until fracture completion was relatively longer than that in the 3D-printed groups. This feature is also thought to be caused by the material's elasticity and flexibility, and the fracture pattern was primarily discovered in the thin, edge side of the crown (Type 1). The digitally fabricated group was easy to repair, as it exhibited a single-cross section fracture pattern. The MIL specimens maintained a bonding state for a long time despite the cracks, thereby minimizing damage and immediate inconvenience in the oral cavity.

The environmental conditions in the oral cavity that could affect fracture strength were reproduced in this study in a limited manner. Further, predicting the clinical prognosis using only the fracture load of the repair is difficult. Therefore, clinical and long-term evaluations are necessary to verify this correlation.

CONCLUSIONS

Based on this research, the following conclusions were drawn: *(1)* Digitally fabricated long-span fixed provisional restorations exhibit higher fracture strength than those fabricated using the conventional heat-processing method; *(2)* the average fracture load was the highest for MIL specimens; and *(3)* among the 3D-printed specimens, the LCD group demonstrated a higher fracture resistance than the SLA group, with a fracture resistance level close to that of the MIL group.

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