Effects of 3D-Printing Technology and Cement Type on the Fracture Resistance of Permanent Resin Crowns for Primary Teeth

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Purpose: To evaluate the fracture resistance of permanent resin crowns for primary teeth produced using two different 3D-printing technologies (digital light processing [DLP] and stereolithography [SLA]) and cemented with various luting cements (glass ionomer, resin-modified glass ionomer, and self-adhesive resin cement), whether thermally aged or not. ***Materials and Methods:*** A typodont primary mandibular second molar tooth was prepared and scanned, and a restoration design was created with web-based artificial intelligence (AI) dental software. A total of 96 crowns were prepared, and 12 experimental groups were generated according to the cement type, 3D-printing technology (DLP or SLA), and thermal aging. Fracture resistance values and failure types of the specimens were noted. The results were statistically analyzed with three-way ANOVA and Tukey HSD tests (α = .05). ***Results:*** The results of the three-way ANOVA showed that there was an interaction among the factors (3D-printing technology, cement type, and thermal aging) (P = .003). Thermal aging significantly decreased the fracture resistance values in all experimental groups. DLP-printed crowns showed higher fracture resistance values than SLA-printed crowns. Cement type also affected the fracture resistance, with glass ionomer cement showing the lowest values after aging. Resin-modified glass ionomer and resin cements were more preferable for 3D-printed crowns. ***Conclusions:*** The type of cement and the 3D-printing technology significantly influenced the fracture resistance of 3D-printed permanent resin crowns for primary teeth, and it was decided that these crowns would be able to withstand masticatory forces in children.
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CAD/CAM technology in dentistry, consisting of data acquisition, processing, and manufacturing, has improved significantly in recent decades. This progress has been marked by the evolution of materials and the digitalization and automation of various work processes. In the latest innovation, artificial intelligence (AI) has been introduced to design dental crowns. Studies have demonstrated that AI can be used to design dental crowns that mimic the morphology of natural teeth.[1,2] Cho et al[3] reported that AI-designed crowns showed improved results in terms of working time and optimized dental crown design. It was reported that AI design resulted in less deviation in occlusal morphology. Shortened work time is often associated with improved work quality and fewer errors.[3] In another study, Cho et al[4] stated that AI-based dental software programs may yield optimized design outcomes in terms of tooth morphology, internal fit, cusp angle, and the number of occlusal contact points, with minimal need for modification. Thus, it could be a viable alternative to a technician-based design workflow for posterior crown restoration.

Until recently, CAD/CAM was primarily based on subtractive manufacturing, such that the CAM process was synonymous with subtractive manufacturing,[5,6] which has

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been extensively applied to dentistry, particularly in the design and production of crowns and bridges. However, this manufacturing method results in significant waste, as a substantial amount of material is removed compared to what is used in the final product.[5,7,8] A significant shift has since occurred from subtractive manufacturing to additive manufacturing.[5] 3D printing has the potential to overcome certain limitations associated with subtractive manufacturing. It can be used for the efficient construction of complex geometric objects and the fabrication of multiple objects per operation, and it offers a substantial reduction in material waste.[6,9]

There are several additive manufacturing methods with different printing techniques. Stereolithography (SLA) and digital light processing (DLP) are the common 3D-printing methods in dentistry. SLA and DLP technologies work similarly; however, these technologies use a different light source.[10] The fundamental principle of SLA is based on the layered construction of an object using a photosensitive liquid monomer. This monomer is polymerized and solidified through the precise application of a laser. In DLP technology, each layer can be cured through a single laser exposure with patterned laser light (pixel-based), so this technology provides more efficient and rapid layer curing.[6]

3D-printed technologies have gained popularity and become preferred alternatives to conventional prosthetic applications. However, it is worth noting that the use of these systems to produce primary tooth crowns in pediatric dentistry is still limited.[11–14] Recently, permanent crown resins for 3D printers from different companies have been introduced to the market for mid- to long-term use in the oral cavity.[15–17] Because primary teeth have a limited duration within the oral cavity, it has been suggested that crowns produced with permanent resin and 3D printing may be an esthetic, durable, and cost-effective alternative for restoring primary molar teeth with extensive caries lesions and/or those that have undergone endodontic treatment. In a recent study, Aktaş et al[18] evaluated the marginal and internal gaps of resin-based milled and 3D-printed crowns for primary teeth designed with different software programs (CAD and AI) by using micro-CT. It was reported that all of the tested groups showed clinically acceptable marginal and internal gap values. Furthermore, AI-designed and 3D-printed crowns showed the lowest marginal gap values among the experimental groups.[18]

Although these crowns demonstrated good adaptation, their mechanical performance should also be evaluated before recommending them for clinical use. Understanding the fracture resistance of a restorative material is essential for predicting its clinical durability. Several factors can significantly influence the clinical performance of restorations, including the microstructure of the prosthetic materials, the cements and cementation procedures, and the aging effects of the oral environment.[19,20] There is no definitive evidence regarding whether conventional cementation or adhesive techniques are superior for cementing 3D-printed pediatric crowns, and comprehensive data elucidating the optimal clinical practice in this domain are absent. The purpose of this study was to evaluate the effects of 3D-printing technology (DLP and SLA) and cement type on the fracture resistance of permanent resin crowns for primary teeth, whether thermally aged or not. The null hypothesis was that the 3D-printing technology and cement type (glass ionomer, resin-modified glass ionomer, or self-adhesive resin cement) would not affect the fracture resistance of permanent resin crowns for primary teeth.

MATERIALS AND METHODS

Three-way ANOVA analysis was used to investigate the effects of 3D-printing technology, cement type, and aging on fracture resistance data. Minimum sample size was calculated with a large effect size (f = 0.40), 0.05 type 1 error value, and 0.90 power value. Accordingly, the minimum sample size was calculated (G*power version 3.1.9.4) for each group (2 × 3 × 2 = 12 groups) and manufacturing method, cement type, and aging interaction and found to be ~7.

An artificial primary mandibular right second molar tooth was prepared on a typodont model (AK-6/2M, Frasaco) for a pediatric crown. The tooth preparation was performed considering the anatomical shape of the primary tooth and yielded a 1-mm chamfer margin and 1-mm axial and 1.5-mm occlusal reductions, avoiding sharp edges and undercuts. The maxillary typodont model with the prepared tooth and the mandibular model were scanned (Cerec Omnicam, Dentsply Sirona), and virtual models were created (Cerec SW 4.4.4, Dentsply Sirona) (Fig 1a). Then, the images of the virtual models were converted to standard tessellation language (STL) format. This file was uploaded to the website of the AI design software, and a restoration design was done in this web-based AI dental software (DentBird Solutions, Imagoworks) (Fig 1b). The cement thickness was set at 50 μm, and the restoration was designed for a primary mandibular second molar tooth on the virtual cast. Manual adjustments were not made to the marginal aspect of the design. For the 3D-printing process, an AI design was exported in STL file format. Then, 96 permanent resin crowns were prepared using two different 3D printers, SLA and DLP (n = 48). Each printing system had its own resin material, so two different resins were used for the production of 3D-printed crowns.

The production of the restorations was carried out in accordance with the printing parameters recommended by the manufacturers. The occlusal plane of the restorations was positioned with 0-degree orientation, facing

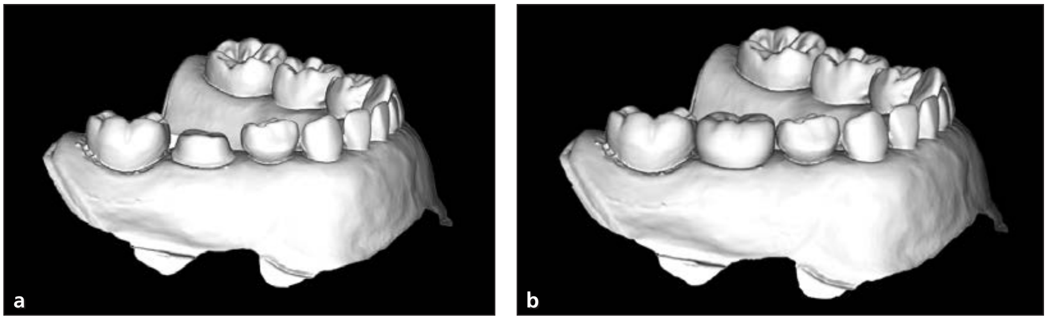

Fig 1 *(a and b)* Virtual model and restoration design on the AI software, respectively.

Table 1 Materials Used

Product	Type	Content	Manufacturer
Permanent Crown Resin (methacrylic acid ester-based resin)	SLA	Organic matrix: 50 to < 75wt% Bis-EMA esterification products of 4.4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid. Silanized dental glass methyl benzoylformate, diphenyl [2,4,6-trimethylbenzoyl] phosphine oxide. Inorganic filler: Silanized dental glass (particle size 0.7 µm) (30–50wt%).	Formlabs
Crowntec permanent crown resin (methacrylic acid ester)	DLP	Esterification products of 4,4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, silanized dental glass, pyrogenic silica, initiators. The total content of inorganic fillers (particle size 0.7 µm) is 30%–50% by mass.	Saremco Dental
GC Fuji I	Glass ionomer luting cement	Powder: glass, oxide, chemicals (polyacrylic acid). Liquid: polybasic carboxylic acid.	GC America
GC Fuji CEM Evolve	Resin-reinforced glass ionomer luting cement	Paste A: 2-hydroxyethyl methacrylate (HEMA), dimethacrylate, urethane dimethacrylate (UDMA), butylated hydroxytoluene, stabilizer. Paste B: ytterbium trifluoride, polyacrylic acid, polybasic carboxylic acid, quartz (SiO_2).	GC America
G-CEM ONE	Resin cement	Paste A: dimethacrylate, urethane dimethacrylate (UDMA), titanium dioxide, monomer, synergist, photo initiator, stabilizer, initiator. Paste B: urethane dimethacrylate (UDMA), dimethacrylate, phosphoric acid ester monomer, initiator, stabilizer.	GC America

the building platform in a horizontal position, and the printing thickness was selected as 50 µm. In the DLP 3D-printing method, the STL file was transferred to the printer software to produce 48 specimens using Saremco Print Crowntec (Saremco Dental). The specimens from the DLP group were printed using a 3D printer (Asiga Max UV, Asiga) following the standardized printing protocol provided by the manufacturer. In the SLA 3D-printing method, the STL file was subsequently imported into the PreForm software (Formlabs) to generate support structures automatically. The specimens were printed using permanent crown resin (Formlabs) with a dental 3D printer (Form 3B, Formlabs). After printing, post-processing was applied to the specimens according to manufacturer recommendations. The specimens underwent a cleaning procedure employing Form Wash (Formlabs) to eliminate residual uncured resin. Then, the specimens were subjected to a curing process in Form Cure (Formlabs). Following the curing process, the support structures were meticulously removed, and airborne particle abrasion was performed to eliminate any surface particles. Subsequently, the specimens underwent an additional post-curing step for 20 minutes at 60°C within the Form Cure device. Printing parameters (the position of the build platform, printing thickness, and orientation) were identical in the DLP and SLA groups. After the printing process, the specimens were removed from the platform and cleaned of excess material by immersion in alcohol (96%) and wiping with a cloth. The specimens were then retrieved and dried and underwent polymerization in an ultraviolet (UV) curing machine (Otoflash G171, NK Optik). Specifically, two sets of 2,000 flashes were applied, with a rotation after every 2,000 flashes.

After crown fabrication, the fit of the crowns was visually checked, and each 3D-printing group was randomly divided into three luting cement groups (n = 16). Three different cements (glass ionomer, resin-modified glass ionomer, and self-adhesive resin cement) were used for the cementation. These cements were selected because resin cements are recommended for the cementation of 3D-printed resin crowns by the manufacturers and glass ionomer and resin-modified glass ionomer cements are commonly used materials in pediatric dentistry. During cementation, manufacturer instructions were observed. The materials used in the study and the cementation procedures are presented in Tables 1 and 2, respectively. The restorations were cemented on the 3D-printed resin dies, which were also fabricated by using the 3D data of

Table 2 Cementation Strategies for the Luting Cements

Cement	Type	Procedure
GC Fuji I	Glass ionomer luting cement	The powder and liquid (1:2) were rapidly mixed on the mixing pad with a plastic spatula for 20 s. The internal surface of the crown was coated with sufficient cement, and the crown was seated immediately. Moderate pressure was maintained, and excess cement was removed.
GC Fuji CEM Evolve	Resin-reinforced glass ionomer luting cement	The required amounts of two pastes were mixed for 10 s on the mixing pad using a plastic spatula. The internal surface of the crown was coated with sufficient cement, and the crown was seated immediately on the preparation with moderate pressure. Once the excess cement reached a rubbery consistency, it was removed with a probe. Each crown surface was cured by a light-curing unit for 3 s, and the excess cement was removed.
G-CEM ONE	Resin cement	G-Multi Primer was applied to the bonding surface as a silane coupling agent and was dried with an air syringe. The automatically mixed cement was placed directly into the crown with the GC Automix Tip. The internal surface of the restoration was coated with sufficient cement and was seated immediately. Moderate pressure was maintained, and curing was performed by waving the light guide of a curing light over the excess cement for 1 s until it reached a solid rubbery consistency. Excess cement was removed with a probe.

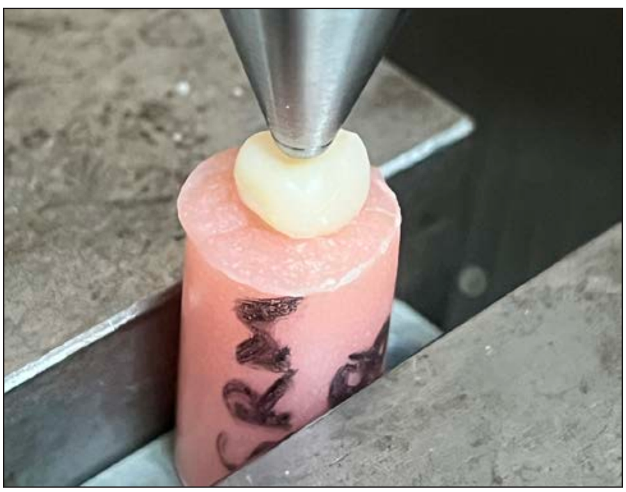

Fig 2 Fracture resistance test.

the prepared typodont tooth. Each crown was silanized (G-Multi Primer, GC America) and glazed with a nano-filled polymerized glaze system (Optiglaze, GC America). The specimens were positioned and embedded into acrylic resin for both the thermocycling procedure and fracture resistance test. The specimens were divided into two groups according to whether they were subjected to thermocycling. Half of the specimens were subjected to 10,000 thermal cycles in 50° to 55°C water baths with 30-second dwell time in a thermocycling device (MTE 101, MOD Dental). This thermal cycling corresponds to 1 year of aging in the oral environment.[21]

The specimens were then fixed on the universal testing machine (LR 50K, Lloyd Instrument). The round-ended loading tip was placed toward the central fossa of each crown to represent an opposing tooth, and three-point contact between the loading tip and occlusal surface of each crown was ensured before loading. Then, load was applied at the central fossa of each crown at a loading rate of 0.5 mm/minute until failure (Fig 2). The load at fracture (N) was recorded as fracture resistance for each specimen. The workflow of the study is summarized in Fig 3.

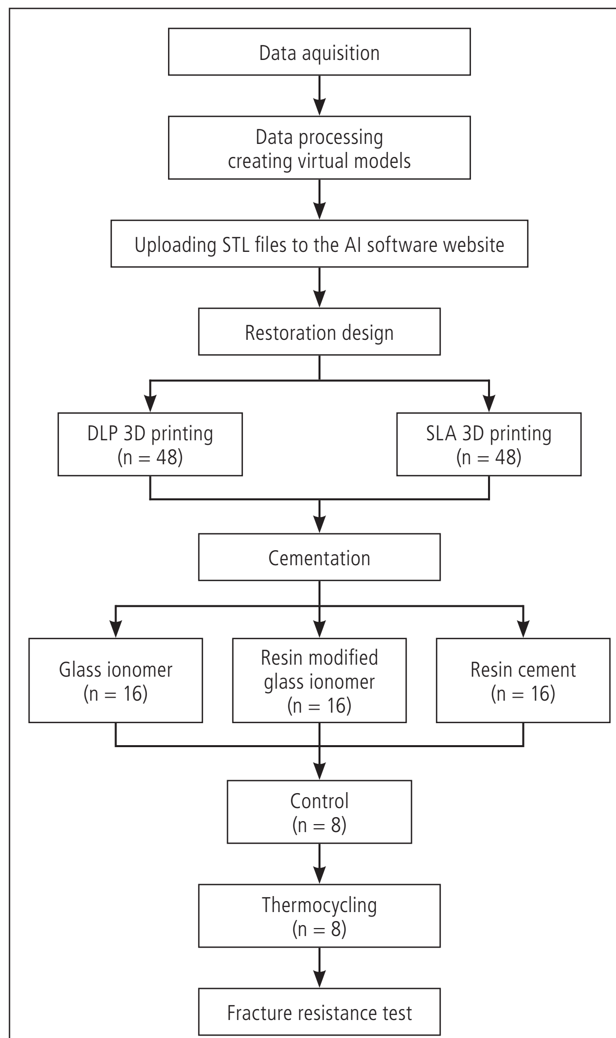

Fig 3 Workflow of the study.

Each fractured specimen was classified based on the failure type described by Oğuz et al.[22] The failure types were categorized into six classes as follows: (I) crack formation not visible with the bare eye but visible

Table 3 Fracture Resistance Values (N) and Comparisons Between Experimental Groups

Cement type	Aging	Fracture resistance	95% CI for mean Lower bound	95% CI for mean Upper bound
DLP				
GIC	Control	1,908.13 ± 121.06^{A,a,1}	1,806.92	2,009.33
	Aging	629.75 ± 128.28^{A,b,1}	522.50	737
RMGIC	Control	1,170.13 ± 280.10^{B,a,1}	935.95	1,404.30
	Aging	793.38 ± 94.21^{A,b,1}	714.62	872.13
RS	Control	1,741.75 ± 246.08^{A,a,1}	1,536.02	1,947.48
	Aging	791.38 ± 138.06^{A,b,1}	675.95	906.80
SLA				
GIC	Control	1,342.5 ± 69.44^{AB,a,2}	1,284.45	1,400.55
	Aging	694.63 ± 228.43^{B,b,1}	503.65	885.60
RMGIC	Control	1,261 ± 244.47^{B,a,1}	1,056.62	1,465.38
	Aging	801.75 ± 112.74^{AB,b,1}	707.5	896
RS	Control	1,471.63 ± 364.87^{A,a,2}	1,166.59	1,776.66
	Aging	956.13 ± 246.06^{A,b,1}	750.41	1,161.84

GIC = glass ionomer cement; RMGIC = resin-modified glass ionomer cement; RS = self-adhesive resin cement.
Fracture resistance is reported as mean ± SD of 8 crown specimens per group.
Same superscript lowercase letters indicate no significant difference between the aging groups in the same printing technology and cement groups ($P > .05$).
Same superscript uppercase letters indicate no significant difference between the cement groups in the same printing technology and aging groups ($P > .05$).
Same superscript numbers indicate no significant difference between the printing technology groups in the same cement and aging groups ($P > .05$).
[AU: Legend ok?]

with stereomicroscope; (II) visible crack formation with unseparated sides; (III) crack formation with separated sides; (IV) crown fracture with less than half of the crown displaced and intact die; (V) crown fracture with more than half of the crown displaced and intact die; and (VI) crown fracture accompanied by die.

Statistical Analyses

The fracture resistance data were analyzed with a statistical software program (SPSS for Windows, version 20.0, IBM). The normalities of the data were tested with Shapiro-Wilk test. Three-way ANOVA and Tukey HSD tests were performed to evaluate the effect of three independent variables (cement type, 3D-printing technology, and thermocycling) on the fracture resistance values. Results were considered statistically significant for $P < .05$.

RESULTS

The results of three-way ANOVA showed that there was an interaction between the factors (3D-printing technology, cement type, and aging) ($F[2,84] = 6,249$; $P = .003$). The mean fracture resistance values and SDs of the experimental groups are shown in Table 3. In all the experimental groups, thermal aging caused significant reductions in the fracture resistance values ($P < .05$). In the DLP groups, the cement type did not have a significant effect on the fracture resistance values of the aged specimens ($P < .05$). However, the glass ionomer (1908.13 ± 121.06) and resin cement (1741.75 ± 246.08) groups had higher values ($P = .114$) than the resin-modified glass ionomer cement group (1170.13 ± 280.10) in the control groups of the DLP specimens ($P < .05$). In the SLA groups, the fracture resistance values were significantly different between the control groups of resin-modified glass ionomer (1261 ± 244.47) and resin cements (1471.63 ± 364.87) ($P = .046$; $P < .05$); however, aging caused significant difference between the glass ionomer (694.63 ± 228.43) and resin cements (956.13 ± 246.06) ($P = .014$; $P < .05$). The lower fracture resistance values were observed in aged groups of both DLP and SLA cemented with conventional glass ionomer cement. The specimens in these groups were de-cemented during thermocycling, and a fracture resistance test was performed by placing the crown on the resin die. When the 3D-printing technologies were compared, significant differences were observed between the control groups of glass ionomer and resin cements ($P < .05$). The failure types and their numbers are presented in Table 4. Failure type class I was not observed in any experimental group, as all the fractures were visually perceptible. Most specimens showed crown fracture with more than half of the crown displaced and intact die (class V), followed by the combination of crown and die fracture (class VI).

Table 4 Number of Failure Types in Each Experimental Group

Cement type	Aging	Failure type I	II	III	IV	V	VI
DLP							
GIC	Control	0	0	0	0	8	0
	Aging	0	0	0	0	8	0
RMGIC	Control	0	1	0	2	2	3
	Aging	0	0	0	2	5	1
RS	Control	0	1	0	1	3	3
	Aging	0	0	0	0	1	7
SLA							
GIC	Control	0	0	0	3	5	0
	Aging	0	0	0	0	8	0
RMGIC	Control	0	4	0	2	2	0
	Aging	0	1	1	1	4	1
RS	Control	0	4	0	4	0	0
	Aging	0	0	0	0	0	8

Eight crown specimens were included in each group.

DISCUSSION

In the present study, the effects of 3D-printing technologies (DLP and SLA) and cement type (glass ionomer, resin-modified glass ionomer, and self-adhesive resin cement) on the fracture resistance of permanent resin crowns for primary teeth, whether thermally aged or not, were assessed. The null hypothesis of the study was that the 3D-printing technology and cement type would not affect the fracture resistance of the tested crowns. The results showed that there was an interaction between the three factors, and 3D-printing technology, cement type, and thermocycling had an effect on the fracture resistance values. Thus, the null hypothesis was rejected.

Using 3D-printed permanent resin crowns is a new solution for restoring primary molars. These crowns can be custom fabricated for each patient, unlike other prefabricated stainless steel or zirconia crowns.[13] Al-Halabi et al[11] evaluated the clinical outcomes of two different esthetic crowns produced using 3D-printing and CAD/CAM systems and concluded that 3D-printed and CAD/CAM-produced polymethyl methacrylate (PMMA) crowns can be effectively used for primary molar restorations. 3D-printed resin crowns showed better clinical properties than the PMMA crowns.[11] Kim et al[13] investigated the fracture resistance, biaxial flexural strength, and dynamic mechanical analysis of two 3D-printed resin crowns (Graphy and NextDent) and a prefabricated zirconia crown (NuSmile) for esthetic primary molar restorations. The fracture resistance values of 0.7-mm-thick 3D-printed resin crowns were not significantly different from prefabricated zirconia crowns, and it was concluded that 3D-printed crowns could be alternatively used for primary teeth.

Recent digital technologies for additively manufactured 3D-printed crowns include DLP and SLA techniques.[23] The present study focused on the fracture resistance of 3D-printed permanent resin crowns for primary teeth. In a recent study, it was reported that 3D-printed crowns produced with an SLA technique demonstrated good marginal and internal adaptation.[18] Thus it was decided to use and compare both DLP and SLA 3D-printing technologies before and after thermocycling. Furthermore, the crown design was done using a web-based AI software. To the best of authors' knowledge, there is no existing study regarding the fracture resistance of AI-designed, 3D-printed primary crowns.

Fracture resistance is one of the main properties to define the mechanical behavior of restorations and is influenced by many factors, such as the luting cement, cementation procedures, restoration material,[20,24] and manufacturing methods. Al-Wahadni et al[25] investigated the marginal and internal gaps, surface roughness, and fracture resistance of provisional crowns fabricated with milling and SLA and DLP 3D printing. Specimens were subjected to 10,000 mechanical cycles (at 50 N) with simultaneous thermal cycling. It was reported that CAD/CAM milled crowns had better adaptation and less surface roughness than 3D-printed crowns. Milled (493.6 ± 105.6) and SLA-printed (404 ± 105.6) crowns also showed higher fracture resistance than DLP-printed crowns (252.4 ± 15.8). In the present study, primary crowns fabricated with both DLP and SLA manufacturing showed higher fracture resistance because permanent resin materials of each system and permanent luting cements were used. Alkhateeb et al[26] investigated the effect of different printing parameters (printing orientation and post-curing time) on the fracture load of provisional fixed prostheses fabricated from two different resins with DLP 3D printing. The highest fracture load was observed in the groups with 45-degree angulation and 90 to 120 minutes post curing. Increasing post-curing time increased the fracture load. In the two manufacturing methods used in the present study, the specimens were oriented at 0 degrees, and supports were placed in the occlusal region, avoiding the central fossa.

It has been well-investigated in the literature that fracture is the main cause of restoration failure after years of use because of aging with thermal changes and cyclic loads in the oral cavity. Thus, evaluating the effects of aging on the mechanical properties of restorative materials is beneficial to predict their clinical performance. In the present study, the fracture resistance values of control groups were between 1,170 N and 1,908 N. After 10,000 cycles of thermal aging, the values were between 630 N and 956 N. It was observed that thermal aging decreased the fracture resistance of the 3D-printed crowns in all experimental groups. Giugovaz et al[27] also reported that thermocycling decreased the flexural strength values of bar-designed specimens, which were produced by milling, 3D-printing, and a combination of these two methods. Braun et al[28] reported that the maximum bite force was 78 N at 6 to 8 years. In another study, it was reported that the maximum bite force was 176 N in the early primary dentition, and it increased to 433 N in the late mixed dentition.[29] Othman et al[23] investigated the fracture resistance of 3D-printed and milled temporary crowns. The fracture resistance of incisor crowns was similar for both milled and 3D-printed crowns. Milled molar crowns had higher fracture resistance than 3D-printed crowns; however, it was stated that both types of provisional crowns would withstand occlusal forces in the molar region. Similar to these results, the results of the present study showed that non-aged and aged DLP and SLA 3D-printed crowns cemented with different types of cement could withstand reported maximum masticatory forces in children. When the DLP and SLA methods were compared, the fracture behavior of the SLA-printed crowns seemed to be more resistant to aging. The tested specimens were subjected to 10,000 thermal cycles, which is approximately equivalent to 1-year of intraoral aging.[21] When evaluating the results of the present study, it should be considered that primary second mandibular molars typically erupt around 2.5 to 3 years of age and remain functional for approximately 7 to 8 years.[30,31]

There is limited data about the effect of the mechanical properties of cement on the fracture resistance of restorations,[20] but the cement thickness and elastic modulus affect the mechanical behavior of restorations.[32] It has been reported that cement thicknesses < 300 μm provide higher fracture resistance.[33] In the present study, the cement thickness was set as 50 μm in the design process. Another factor that affects cementation procedures is the microstructure of the restorative material.[19] Anuntasainont et al[20] evaluated the effect of the restoration thickness (1.5 mm and 0.8 mm) and cementation procedure on the fracture resistance of two different CAD/CAM-produced resin matrix ceramic restorations. They stated that 1.5-mm-thick specimens that were cemented with light-cured cement to dentin showed greater resistance.[20] In the present study, the occlusal thickness of the specimens was set to 1.5 mm. However, direct comparisons could not be made because of the differences between the materials and methodology of the two studies. Rizzatto et al[19] investigated the effects of self-adhesive and universal-adhesive resin cement on flexural strength and load in two CAD/CAM resin matrix ceramics after aging, and they reported that the type of resin cement did not have an effect on the tested mechanical properties. In the present study, three types of luting cement (glass ionomer, resin-modified glass ionomer, and resin cements) were used. The cement type was found to affect the fracture resistance of 3D-printed crowns. Although glass ionomer cement groups showed comparable results before aging, they showed the lowest fracture resistance values in both DLP and SLA groups after aging. Furthermore, crowns that were cemented with glass ionomer cement were de-cemented during thermal aging. Although the manufacturer of DLP crowns stated that glass-ionomer cements have limited uses due to their opacity, it was decided that resin-modified glass ionomer and resin cements may be more preferable for 3D-printed permanent resin crowns.

This study has some limitations. The restorations were cemented onto the resin dies, and it must be kept in mind that the primary teeth and resin dies have different bonding mechanisms with cement. Thermal cycling was used to evaluate the effect of aging on the fracture resistance of the 3D-printed resin permanent crowns. However, restorations are also subjected to mechanical loads during chewing function. Further research either simulating the oral conditions with increased cycles of artificial thermomechanical aging or reporting the clinical success and failure types will be beneficial to evaluate the mechanical performance of 3D-printed permanent crowns.

CONCLUSIONS

3D-printing technology, cement type, and thermal cycling affected the fracture resistance of permanent resin crowns. Thermal cycling decreased the fracture resistance of the permanent resin crowns. Both DLP and SLA 3D-printed crowns cemented with different types of cement could withstand masticatory forces in children. Resin-modified glass ionomer and resin cements may be more preferable for 3D-printed permanent resin crowns.

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The authors declare no conflicts of interest.

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