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Evaluation of fracture resistance of indirect composite resin crowns by cyclic impact test: Influence of crown and abutment materials

Kenji SAKOGUCHI[1], Hiroyuki MINAMI[2], Shiro SUZUKI[3] and Takuo TANAKA[1]

[1] *Department of Fixed Prosthetic Dentistry, Advanced Therapeutic Course, Kagoshima University Graduate School of Medical and Dental Sciences, 8-35-1 Sakuragaoka, Kagoshima 890-8544, Japan*
[2] *Fixed Prosthetic Clinic, Kagoshima University Medical and Dental Hospital, 8-35-1 Sakuragaoka, Kagoshima 890-8544, Japan*
[3] *Department of Prosthodontics, University of Alabama at Birmingham, School of Dentistry, 1919 7th Ave. South, Birmingham, AL 35294-0007, USA*
Corresponding author, Hiroyuki MINAMI; E-mail: minami@dent.kagoshima-u.ac.jp

This study evaluated the effect of abutment materials on the fracture resistance of composite crowns for premolars. Composite crowns were fabricated using two different indirect composite resin materials (Meta Color Prime Art or Estenia C&B) and cemented onto either a metal (Castwell M.C. 12) or composite resin (Build-It FR and FibreKor) abutment with resin cement (Panavia F2.0). Twenty-four specimens were fabricated for four groups (n=6 each) and subjected to 280-N cyclic impact loading at 1.0 Hz. The number of cycles which caused the composite crown to fracture was defined as its fracture resistance. All data were statistically analyzed using ANOVA and the Bonferroni test (α=0.05). Composite crowns cemented onto resin abutments showed higher fracture resistance than those cemented onto metal abutments.

Keywords: Composite crown, Cyclic impact test, Premolar tooth, Abutment material

INTRODUCTION

Use of metal-free dental restorations is on the rise because of medical and esthetic reasons. Medically, the use of dental metals poses biological risks because they cause metal allergies and metal ion-induced oral pigmentation[1]. Esthetically, increased awareness for a more appealing cosmetic appearance fuels the demand for metal-free restorations, even in the posterior region[2].

A representative metal-free dental restoration is the all-ceramic crown system. It boasts of several significant features that address the shortcomings of full cast crowns: biocompatibility[3], esthetic appeal[4], wear resistance, and color stability. However, all-ceramic restorations are not without drawbacks. They are fragile[5] and expensive, cause extensive abrasive wear of antagonist dentition[6], require more tooth reduction[6] and longer chairside time due to their complicated bonding procedure[7].

A cost-effective substitute to all-ceramic crowns is found in indirect composite resin crowns. Unlike ceramics, they are relatively inexpensive, easy to fabricate, and cause low wear of the opposing dentition. However, like ceramics, indirect composite resins are superior in esthetics, mechanical properties[8], and wear resistance[9]. Fracture toughness of indirect composite resin crowns was reported to be similar to that of metal-ceramic restorations[10]. When subjected to fatigue testing, metal-free composite crowns exhibited similar fracture resistance before and after fatigue testing[11], and that they survived compressive cyclic loading with neither fractures nor microcracks[6]. However, in clinical practice, chipping or fractures of composite crowns are occasionally encountered.

Premolars are visible in the daily life. For premolars that are restored with full-coverage crowns, patients usually demand uncompromising esthetic results. Compared to anterior teeth, premolar teeth receive greater occlusal forces[12]. This means that composite crowns cemented onto premolars must have uncompromising strength and fracture toughness to withstand high occlusal loading. However, to date, no quantitative analyses have been carried out to assess the longevity of composite crowns installed on premolar teeth.

The purpose of this study was to evaluate the fracture resistance of composite crowns fabricated using two different materials, which were cemented onto premolar abutments fabricated using two different materials, against cyclic impact loading. The null hypothesis was that materials used for crown and abutment fabrication would not affect the fracture resistance of composite crowns installed on premolars.

MATERIALS AND METHODS

Materials

Materials used in this study are presented in Tables 1–3. Two types of indirect composite resins were used to fabricate the crowns (Table 1). Similarly, two types of materials were used to fabricate the abutments (Table 2). Cast abutments were fabricated using a silver-palladium-copper-gold alloy. Resin abutments were composed of a dual-cure composite resin core and a glass fiber post of 1.125 mm diameter. An adhesive resin cement was used as the luting material (Table 3).

Color figures can be viewed in the online issue, which is available at J-STAGE.

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Table 1 Indirect composite resins used to fabricate crowns

Product name	Composition	Manufacturer	Code	Lot No.
Meta Color Prime Art Body Paste A3-B	Filler: TMPT filler, hydrophobic colloidal silica (73.1 wt%) Matrix: UDMA, TEGDMA, *etc.*	Sun Medical Co. Ltd., Shiga, Japan	MP	EF14
Meta Color Prime Art Top Opaque A3-O	Filler: Hydrophobic ultrafine silica Matrix: UDMA,TEGDMA	Sun Medical Co. Ltd.		TK13
Estenia C&B Body Paste DA3	Filler: Alumina particles, aluminosilicate glass particles (92 wt%) Matrix: UDMA, UTMA, *etc.*	Kuraray Noritake Dental Inc., Tokyo, Japan	ES	0076AA
Estenia C&B Body opaque OA3	Filler: Hydrophobic ultrafine silica Matrix: Bis-GMA, *etc.*	Kuraray Noritake Dental Inc.		0100AA

TMPT: Trimethylolpropane trimethacrylate, UDMA: Urethane dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate, UTMA: Urethane tetramethacrylate, Bis-GMA: Bisphenol-A-glycidyl methacrylate

Table 2 Materials used to fabricate abutments

Material	Product name	Composition	Manufacturer	Code	Lot No.
Metal alloy	Castwell M.C. 12	Au: 12%, Pd: 20%, Ag: 46%, Cu: 20%, *etc.*	GC Corp., Tokyo, Japan	ME	701091
Composite resin	Build-It FR	Bis-GMA, UDMA, HDDMA, silane-treated bariumborosilicate glass fibers, *etc.*	Pentron Clinical Technologies, LLC, Wallingford, CT, USA	CR	143239
Resin-coated glass fiber	FibreKor	Fiber: E-glass (40%) Matrix: UDMA, TEGDMA	Pentron Clinical Technologies		200879

HDDMA: Hexanediol dimethacrylate

Table 3 Luting, priming and silane coupling agents used in this study

Material	Product name	Composition	Manufacturer	Code	Lot No.
Luting cement	Panavia F2.0	Paste A: MDP, Bis-MPEPP, hydrophobic and hydrophilic DMAs, BPO, CQ, silica filler	Kuraray Noritake Dental Inc.	PA	0501AA
		Paste B (white): Bis-MPEPP, hydrophobic and hydrophilic DMAs, DEPT, sodium 2,4,6-TPBSA, silica filler, barium glass filler, TiO_2, NaF			0114AA
Metal primer	Alloy Primer	VBATDT, MDP, acetone		—	00413A
Silane coupling agent	Clearfil Porcelain Bond Activator	3-methacryloxypropyltrimethoxysilane, Bis-GMA		—	0270AA
	Clearfil Mega Bond Primer	DEPT, hydrophilic dimethacrylate, MDP, HEMA, CQ, water		—	1080AA

MDP: 10-methacryloyloxydecyl dihydrogen phosphate, Bis-MPEPP: 2,2-bis[(4-methacryloxy polythoxy)phenyl]propane, DMA: Dimethacrylate, BPO: Benzoyl peroxide, CQ: d,l-Camphorquinone, VBATDT: 6-(4-vinylbenzyl-*n*-propyl)amino-1,3,5-triazine-2,4-dithiol, DEPT: N,N-Diethanol-*p*-toluidine, Sodium 2,4,6-TPBSA: Sodium 2,4,6-triisopropyl benzene sulfinate NaF: Sodium fluoride, HEMA: 2-hydroxyethyl methacrylate

Fabrication of metal and resin abutments

An epoxy tooth model (A20A-500, Nissin Dental Products Inc., Kyoto, Japan) for right upper first premolar was used as a master die to be restored with the composite crown. The die was 4.0 mm in height with a 6-degree convergence angle and 0.8-mm round-shoulder finish line. It was vertically fixed on a poly(methyl methacrylate) base (Fig. 1). Impressions of the die were made using polyvinyl siloxane impression materials (Exafine putty type and injection type, GC Corp., Japan) using a two-step impression technique. The impressions were used as silicone molds for the duplication of abutment teeth.

Melted wax (Inlay Wax Hard, GC Corp.) was poured into the silicone mold to make a wax pattern. Wax pattern was invested and cast with Castwell M.C. 12 to fabricate the metal abutments (Fig. 1).

To fabricate the resin abutments, core build-up resin was first poured into the silicone mold. A glass fiber post was inserted into buccal cusp region parallel to the long axis of the tooth and photopolymerized for 40 s using a light curing unit (G-Light, GC Corp.). To complete resin abutment fabrication, core build-up resin was chemically cured at room temperature (22±2°C) for 4 min (Fig. 1).

Fabrication of composite crowns

To obtain identical-shaped composite crowns, a master crown was fabricated on the master die using a polycarbonate temporary crown (JM Poly-Crown, Nissin Dental Products Inc.) and an autopolymerizing resin (Unifast II, GC Corp.). At lingual and buccal cusps, occlusal surface thicknesses were 2.0 and 1.5 mm respectively. A translucent autopolymerizing resin (Unifast II Clear, GC Corp.) was used to make a two-piece split mold with four spillways to produce identical crowns.

Each abutment tooth was coated with a separating medium (Prime Sep., Sun Medical Co. Ltd., Japan). An opaque resin (Meta Color Prime Art Top Opaque, Sun Medical Co. Ltd.; or Estenia C&B Body Opaque, Kuraray Noritake Dental Inc., Tokyo, Japan) was then applied using a brush-on technique. Opaque resin was applied in multiple layers into a final thickness of approximately 0.2 mm with two increments. Thickness of each increment was measured using a customized periodontal probe with a precision of 0.1 mm. Each increment was photopolymerized using a laboratory light curing unit (α-Light II, J. Morita Corp., Tokyo, Japan) for 90 s.

Indirect resin composite (Meta Color Prime Art Body Paste, Sun Medical Co. Ltd., coded as MP; or Estenia C&B Body Paste, Kuraray Noritake Dental Inc., coded as ES) of 0.5 mm thickness was built up on opaque resin. Initial curing using the laboratory light curing unit (α-Light II, J. Morita Corp.) was performed for 30 s on MP and 90 s on ES. After coating the intaglio surface of translucent mold with separating medium, indirect resin composite was packed into the mold and firmly seated on the opaque resin-coated abutment, which had received initial curing. Light irradiation through the translucent mold was performed for 90 s on MP and 180 s on ES.

The crown was carefully removed from the mold and abutment. Definitive irradiation was performed for 180 s on MP and 300 s on ES using the laboratory light curing unit (α-Light II, J. Morita Corp.). For ES crowns, heat polymerization was further carried out using a heat-curing unit (KL-310, J. Morita Corp.) at 110°C for 15 min. Excess resin overflow through the spillways was removed, and unpolymerized layer on the crown surface was wiped away using an alcohol swab. All composite crowns were finished with silicone polishing points (Ceramage Polishing Kit, Shofu Inc.).

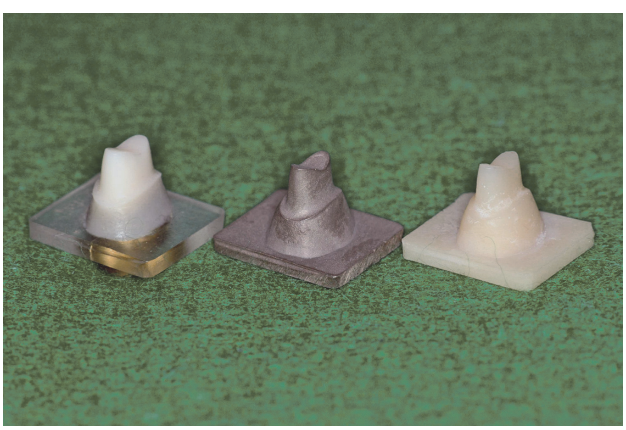

Fig. 1 Epoxy model and fabricated metal and composite resin abutments.

Fabrication of crown-abutment specimens

Table 4 shows the surface treatment methods for abutments and crowns. Resin abutments and the intaglio surfaces of crowns were airborne particle-abraded with 50-µm aluminum oxide particles (Hi Aluminas, Shofu Inc.) under 0.4 MPa for 2 s. Silane coupling treatment was administered *via* a combination of a drop of silane coupling agent (Clearfil Porcelain Bond Activator, Kuraray Noritake Dental Inc.) and a drop of primer (Clearfil Mega Bond Primer, Kuraray Noritake Dental Inc.). Metal abutments were airborne particle-abraded and then applied with a metal primer (Alloy Primer, Kuraray Noritake Dental Inc.).

After the composite crowns were cemented onto the abutments, 0.5-kgf static load was applied for 10 s. Excess resin was irradiated with a light curing unit (G-Light, GC Corp.) for 5 s and then carefully removed using a dental explorer. Definitive irradiation was performed for 20 s.

A total of 24 specimens (n=6 per group) were fabricated for four test groups involving different combinations of two crown materials and two abutment materials. All specimens were left at room temperature (22±2°C) for 1 h and then stored in 37°C distilled water for 24 h.

Table 4 Surface treatment methods for abutments and composite crowns

	Surface treatment
Metal abutment (ME)	Airborne particle abrasion* + Metal primer**
Resin abutment (CR)	Airborne particle abrasion + Silane coupling agent***
Composite crown (MP or ES)	Airborne particle abrasion + Silane coupling agent***

*: 50-µm aluminum oxide at 0.4 MPa
**: Alloy Primer
***: Clearfil Mega Bond Primer+Clearfil Porcelain Bond Activator

Fig. 2 Cyclic impact tester.

Fig. 3 Positioning of crown-abutment specimen and stainless steel jig for cyclic loading test.

Cyclic loading test
A custom-made loading apparatus (Cyclic Impact Tester, Taniyama Technos, Kagoshima, Japan) was used to apply cyclic impact stresses (Fig. 2). Specimens were positioned such that an 8.0-mm-diameter hemispherical tip of the stainless steel jig was in contact with two points on the composite crown, at the inner ridges of both buccal and lingual cusps (Fig. 3). All specimens were wrapped in wet gauze to prevent drying out of the cements.

An impact load of 280 N was applied to each specimen at 1.0 Hz. Calibration loads were applied ten times to the pressure-sensitive film (Dental Prescale 50H Type R, Fuji Film Co., Tokyo, Japan) placed between the loading jig and specimen. Marks impressed on the film were subjected to computerized analysis (Occluzer 703, Fuji Film Co.). After calibration, loads were approximated to 280 N for all the specimens. The number of loading cycles that caused the crown to fracture was defined as its fracture resistance. Failure modes were assessed by visual observation.

Statistical analysis
Homoscedasticity among the four test groups was evaluated using the O'Brien test. Then, data were statistically analyzed using two-way analysis of variance (ANOVA) with the abutment material and crown material as independent factors. Multiple comparisons were performed using the Bonferroni test to identify significant differences among the test groups. Level of significance was set at 0.05 for all statistical analyses.

RESULTS

Figures 4 and 5 show the fracture resistance and statistical analysis results of MP and ES crowns respectively. For MP crowns (Fig. 4), the fracture resistance of MP/ME group was significantly lower than that of MP/CR group (p=0.0011). For ES crowns (Fig. 5), the fracture resistance of ES/ME group was significantly lower than that of ES/CR group (p=0.0003). Two-way ANOVA revealed significant differences in fracture resistance between the abutment materials, ME *versus* CR (p<0.0001). However, there were no significant differences between the crown materials, MP *versus* ES (p=0.2812). There was also no significant interaction between these two factors (p=0.8395) of abutment and crown materials for fracture resistance.

Table 5 presents the number ranges of loading cycles to failure and failure modes of all the four test groups. Failure mode was remarkably influenced by the abutment material, not crown material (Table 5).

For crowns cemented onto metal abutments (Fig. 6), a large remnant of the broken crown adhered on the abutment for majority of the failed specimens (4/6 for MP, 5/6 for ES) (Table 5). Resin cement remained either on the abutment or the intaglio surface of crown.

For crowns cemented onto resin abutments (Fig. 7), their failure modes were completely different. Crown and abutment were firmly bonded by the resin cement and behaved as they were an integrated body. For all the failed specimens, it was mixed failure involving a broken crown and a broken resin abutment (6/6 for MP, 6/6 for ES) (Table 5).

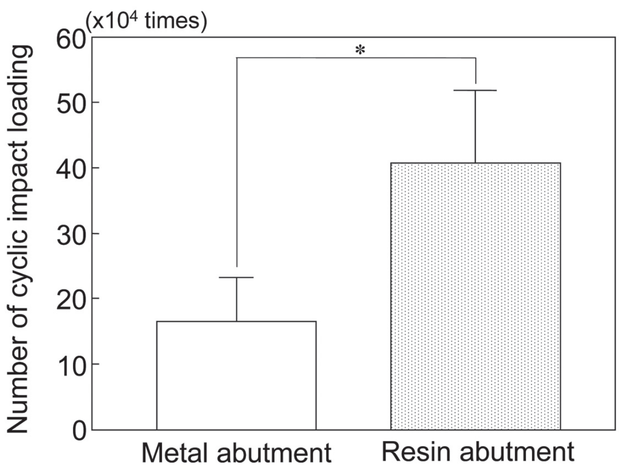

Fig. 4 Fracture resistance results of composite crowns fabricated with MP. Asterisk denotes a significant difference (p<0.05).

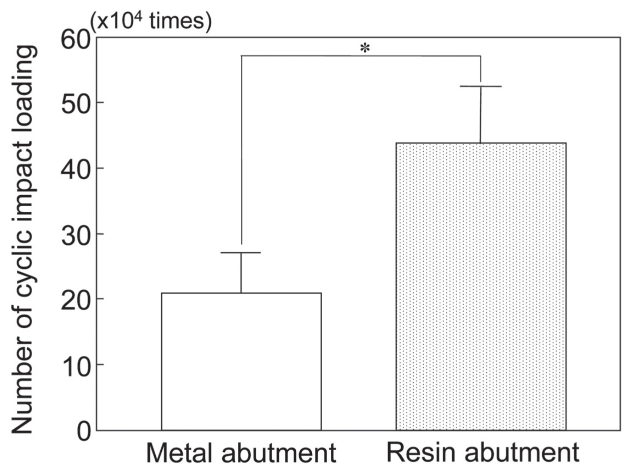

Fig. 5 Fracture resistance results of composite crowns fabricated with ES. Asterisk denotes a significant difference (p<0.05).

Table 5 Number ranges of loading cycles to failure and failure mode distributions for all test groups in this study

Abutment material	Composite crown material	Number of loading cycles (Mean±SD)	Failure mode		
			Composite crown only (No or small fragment of broken composite crown remained on abutment)	Composite crown only (Large fragment of broken composite crown remained on abutment)	Both composite crown and abutment
Metal (ME)	MP	55,528–205,829 (165,538±65,961)	2	4	—
	ES	149,659–291,718 (209,959±54,410)	1	5	—
Resin (CR)	MP	253,667–539,796 (407,301±112,229)	—	—	6
	ES	284,917–523,471 (437,832±87,029)	—	—	6

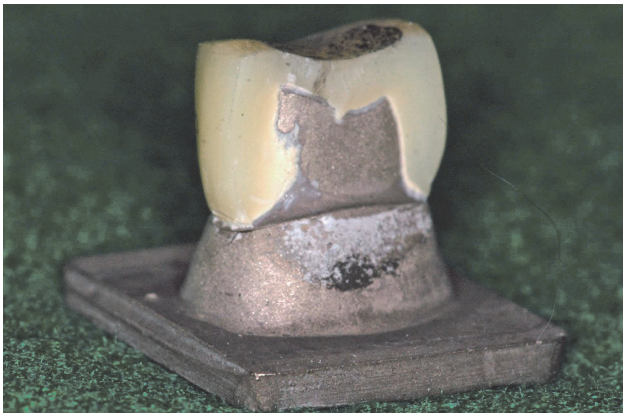

Fig. 6 Representative failed specimen on metal abutment (failure mode: crown only). Large remnant of broken crown adhered on abutment.

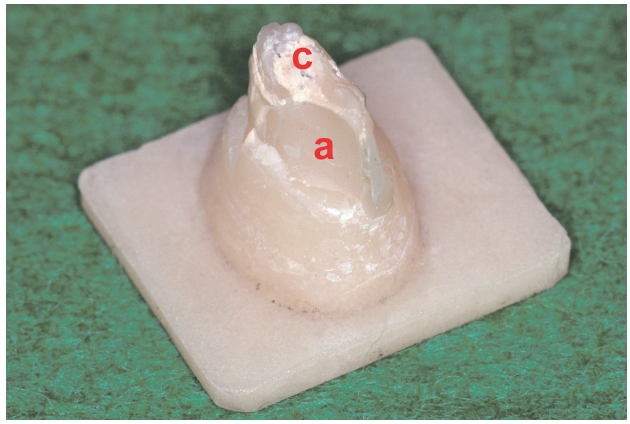

Fig. 7 Representative failed specimen on resin abutment (failure mode: mixed failure of both crown and abutment).
a: abutment; c: crown.

DISCUSSION

The null hypothesis of this study was partially accepted. Highest fracture resistance was obtained when composite crowns were installed on resin abutments, regardless of crown material. Therefore, abutment material affected the fracture resistance of indirect composite crowns installed on premolars.

For crowns fabricated with brittle materials such as ceramics and composite resins, a slew of factors influence their durability: mechanical properties of crown materials and luting materials, adhesive strength of luting materials, and elastic modulus of each of the materials used —including the abutment material.

Effect of elastic compatibility on fracture resistance

Fiber posts and cores have elastic moduli similar to that of dentin. Such a close match of elastic moduli reportedly reduced stress concentrations at the post-dentin interface and ameliorated the risks of catastrophic or irreparable root fractures[13,14].

To improve the durability of restorations which comprise multiple layers including the abutment, luting cement, and restorative material, it was highly recommended that each layer possess similar elastic modulus[15]. In the present study, the elastic moduli of resin abutment materials (8.9 GPa for Build-It FR core, 29.2 GPa for FibreKor post) were close to those of composite crown materials (28.6 GPa for ES, 4.5 GPa for MP) and adhesive resin cement (7.4–10.0 GPa for Panavia F2.0)[16,17]. When three layers possessing similar elastic moduli are firmly bonded together, they might behave as if they were one integrated body. This seemed to be the case of MP/CR and ES/CR specimens as manifested by their failure mode (Fig. 7).

The higher fracture resistance of MP/CR and ES/CR groups (Figs. 4 and 5) could also be attributed to the elastic characteristics of both abutment and crown materials, which enabled them to better absorb the impact stresses applied during the cyclic impact test.

Combined effects of adhesive strength and elastic modulus mismatch on fracture resistance

The metal abutment used in this study had a high elastic modulus (95 GPa for Ag-Pd-Cu-Ag alloy). This property minimized the distortion in metal abutments when under repetitive impact loading. For composite crowns firmly cemented onto the metal abutments, their distortion should presumably be minimal[18]. It was suggested that crowns fabricated with brittle materials could be reinforced by firm adhesion to abutments such as natural teeth or core build-ups[19]. In this study, the firm cementation of composite crowns to the metal abutments, coupled with controlled distortion of the crowns, was expected to result in high fracture resistance.

However, the fracture resistance values of composite crowns installed on metal abutments were significantly lower than those installed on resin abutments, regardless of the composite crown material used. Therefore, the fracture resistance of crowns fabricated with brittle materials was influenced by two factors: adhesive strength to abutment and matching of elastic modulus between crown and abutment materials.

ES contained 92 wt% of inorganic fillers[20] and Bis-GMA monomer as a main component of its resin matrix. Bis-GMA monomer increases crosslinking density and results in high flexural strength[21]. In the present study, the combined effects of light- and heat-curing further rendered the ES resin matrix a high degree of polymerization[21]. Compared to conventional composite resins such as MP (4.5 GPa elastic modulus), the elastic modulus of ES was therefore 1.7–9.0 higher (28.6 GPa)[21].

When the elastic modulus of crown material is considerably lower than that of abutment material, the composite crown would deform easily under repetitive impact loading even when firmly fixed to the abutment because of elastic modulus mismatch.

Limitations of present study

1. Validity of fatigue testing method and results

Cyclic loading test and thermal cycling test are two available fatigue testing methods for predicting the longevity of restorations in oral conditions. The thermal cycling test is already established for its reproducibility and comparability. Data can be directly compared among studies if investigations were performed under the same thermal cycling conditions using specimens with the same configurations. However, universally accepted testing conditions are yet to be established for the cyclic loading test. Therefore, it is difficult to compare data directly among studies that performed cyclic loading tests with their own loading conditions.

In the present study, the loading rate of 1.0 Hz was deemed adequate. Mastication rate reportedly ranged between 0.89 Hz[22)] and 1.57 Hz[23)], and that average mastication rate was approximately 1.0 Hz[24,25)]. Under this load frequency of 1.0 Hz, Group ES/CR exhibited the highest facture resistance with the number of loading cycles ranging between 285,000 and 523,000 cycles (Table 5). Based on an average of 250,000 masticatory cycles per year[26,27)], the maximum number of loading cycles obtained in this study was roughly equivalent to one or two years of intraoral use.

However, results of fatigue tests are highly influenced by the weight of impact load, load frequency, and specimen size[28)]. If mean masticatory force ranges between 70.6 and 146.1 N as reported by Anderson[29,30)], the 280-N impact load employed in this study would be deemed comparatively high. This meant that given the results of this study, composite crowns possessed acceptable durability for clinical application.

2. Inadequate simulation of clinical conditions

In clinical practice, finish lines are prepared in enamel or dentin with round-shoulder margins. In the present study, these clinical conditions were not simulated as abutments were entirely fabricated with metal or composite resin.

Loading was applied at two points on the occlusal surface of composite crowns to simulate the load of mastication transmitted along the long axis of tooth. In clinical situations, masticatory movements include both vertical and lateral directions. Therefore, investigations which better simulate the clinical conditions of applying vertical and lateral forces on the occlusal surface need to be carried out for more reliable fracture resistance evaluation.

As universally accepted impact loading conditions remain to be established for cyclic impact testing, experimental results need to be verified against clinical outcomes by tracking the prognosis of installed crowns. Leveraging on the findings of this study, further research is needed to investigate the effects of different types of abutment materials on the durability of composite crowns.

CONCLUSION

This study evaluated the effects of two abutment materials on the fracture resistance of composite crowns fabricated using two types of indirect composite resins.

Results of cyclic impact loading test showed that composite crowns had higher fracture resistance when they were cemented onto resin abutments than they were on metal abutments, regardless of crown material.

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