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Fracture Resistance of Ceramic Veneers with Different Preparation Designs

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Abstract

Purpose: The purpose of this study was to examine the fracture load of ceramic veneers with different preparation designs.
Materials and Methods: Seventy-five extracted, intact, human maxillary central incisors were prepared according to five preparation designs (P) (n: 15) as follows: (1) P2e: 2-mm incisal reduction, preparation entirely in enamel; (2) P4e: 4-mm incisal reduction, preparation entirely in enamel; (3) P2d: 2-mm incisal reduction, preparation entirely in dentin; (4) P4d: 4-mm incisal reduction, preparation entirely in dentin; and (6) Pc: Unrestored, intact teeth as control. All preparations had a butt joint incisal finish line, rounded internal line angles, and cervical finish lines 1 mm above the cementoenamel junction. Ceramic veneers were fabricated with IPS Empress (Ivoclar Vivadent AG, Schaan, Liechtenstein) and cemented with Syntac Classic Adhesive system and Variolink II (Ivoclar) resin cement. Veneers were loaded until fracture at a 90° angle to the lingual surface of the test tooth following the thermocycling process (5° to 55°, 3500 times). Statistical analyses were performed using analysis of variance (ANOVA) and Tukey's Multiple Range Test.
Results: The mean fracture loads (SD) were (in N) as follows: (1) P2e: 262 (63); (2) P4e: 189 (40); (3) P2d: 239 (53); (4) P4d: 162 (36); and (5) Pc: 277 (66). The amount of incisal reduction exhibited a significant influence on fracture resistance regardless of the preparation depth ($p < 0.05$).
Conclusions: Ceramic veneers with preparation designs entirely on dentin with 4-mm incisal reduction yielded lower fracture loads than those prepared with 2-mm incisal reduction. Veneers with 2-mm incisal reduction exhibited fracture resistance similar to that of intact teeth for preparation designs supplied on both enamel and dentin.

Ceramic veneers, which are chosen to provide excellent esthetics, are a well-established treatment method for conservative esthetic restoration of malformed, discolored, misaligned, traumatized, fractured, and worn anterior teeth. The recommended superficial preparation within the enamel and adhesive luting facilitates restoration with minimal loss of healthy tooth structure.[1,2] Edelhoff and Sorensen[3] reported that tooth preparations for porcelain laminate veneers required 3% to 30% of tooth structure by weight and one-quarter to one-half the amount of tooth reduction of conventional complete-coverage crowns.

The success rate of porcelain veneers has been clinically evaluated and has shown a range from 18 months up to 15 years; the rate of success reported in these studies varies between 75% and 100%. Fracture, microleakage, and debonding are types of failures seen in ceramic veneers.[1,4-6]

Different designs of tooth preparations have been described as the feathered incisal edge, incisal 0.5- to 1-mm bevel, the intraenamel (or window), and the overlapped incisal edge preparations.[6-8] Castelnuovo et al[9] reported that elimination of the palatal chamfer for ceramic veneers with incisal butt joints resulted in stronger restorations and simplified tooth preparation. They also suggested that the faciopalatal path of insertion allowed easier seating of multiple veneers and eliminated the risk of fracture of thin, unsupported palatal ceramic ledges.

Ceramic veneers are mainly recommended for margins located in enamel to provide reliable marginal integrity; however, Nattress et al found a high risk for dentin exposure at the cervical margins, even with preparation margins located coronally to the cementoenamel junction (CEJ).[10] Also, advanced periodontal disease therapy often results in exposed root surfaces and wide interproximal spaces. Instead of full-crown preparations, this situation might be solved with ceramic veneers. Previous in vitro studies have shown that the dentin–composite resin interface of veneers with cervical margins in dentin was more susceptible to microleakage than all-enamel preparations.[11,12] In recent years, new bonding techniques and materials have been introduced that have improved the bond strength of porcelain veneers to dentin with strengths close to the bond to enamel. Recently, with the use of dentin bonding agents, a considerable increase in bond strength and quality of marginal adaptation has been achieved; however, the long-term resistance of veneers with preparations in dentin has yet to be proven.

The hypothesis of this study was that the fracture resistance of laminate veneers could be increased with preparations in enamel. The purpose of this in vitro study was to examine the fracture load and the mode of failure of ceramic veneers with preparations on either enamel or dentin.

Materials and methods

For this study, 75 extracted, intact, human maxillary central incisors with homogeneous dimensions were selected. The incisocervical, mesiodistal, and labiopalatinal dimensions were measured. Each tooth was free of dental caries or restorations. They were cleaned by scaling and stored in distilled water at room temperature.

Teeth were divided into five groups of 15 specimens each.

- P2e: 2-mm incisal reduction with butt joint finish line, preparation entirely in enamel.
- P4e: 4-mm incisal reduction with butt joint finish line, preparation entirely in enamel.
- P2d: 2-mm incisal reduction with butt joint finish line, preparation entirely in dentin.
- P4d: 4-mm incisal reduction with butt joint finish line, preparation entirely in dentin.
- Pc: Unrestored intact teeth as control.

The 75 maxillary central incisors were mounted individually in acrylic resin (Meliodent Denture Material, Heraeus Kulzer, Berkshire, UK) with the long axis parallel to the center of the ring with the guidance of a dental surveyor (Kavo EWL, Type 990, Kavo Elektrotechnisches Werk GmbH, Leutkirch im Allgau, Germany). Each tooth was suspended in the middle of the ring by means of a 0.8-mm-thick orthodontic wire (Leowire round spring hard wire, 0.8 mm; Leowire s.p.a., Firenze, Italy), which engaged the tooth at the CEJ and rested on the edges of the ring.

The teeth in P2e and P4e were prepared to accommodate veneers of equal thickness by using the Laminate Veneer Preparation Kit (LVS Set for porcelain veneers, Gebr. Brasseler GmbH & Co. KG., Lemgo, Germany). In P2e and P2d the teeth were prepared with an incisal reduction of 2 mm. In P4e and P4d, a 4-mm incisal reduction was performed. A self-limiting depth-cutting disk of 0.5 mm was used to define the preparation depth, and 1.2-mm chamfer diamond burs were selected to refine the preparation. In P2e and P4e, facial reduction was 0.5 mm, and all tooth preparations were completed entirely in enamel, with rounded line angles. The teeth in P2d and P4d were prepared with two sets of facial reduction to ensure that the preparation was entirely on dentin. On the facial side, the cervical finish lines were prepared 1 mm above the CEJ. Interproximally, the preparation was extended to include the contacts using diamond burs and water coolant.

Table 1 Materials used for the fabrication of ceramic veneers

Material	Manufacturer	Batch number
Virtual putty fast set	Ivoclar Vivadent	GL4067
Virtual light body fast set wash material	Ivoclar Vivadent	GL4084
GC Fujirock EP	GC Europe N.V.	200401091
IPS Empress ingot O2	Ivoclar Vivadent	C40018
IPS Empress 2 Speed investment material powder	Ivoclar Vivadent	F97072
IPS Empress 2 Speed investment material liquid	Ivoclar Vivadent	F97131
IPS Empress etching gel	Ivoclar Vivadent	G06773
Total etch	Ivoclar Vivadent	G07234
Monobond S	Ivoclar Vivadent	G08933
Syntac primer	Ivoclar Vivadent	G17146
Syntac adhesive	Ivoclar Vivadent	G16562
Heliobond	Ivoclar Vivadent	G11840
Liquid strip	Ivoclar Vivadent	C31096
Variolink II Base transparent	Ivoclar Vivadent	G13283
Variolink II catalyst	Ivoclar Vivadent	G12766
Low viscosity/Transparent		

The materials used in this study are listed in Table 1. An additional silicone-impression material (Virtual, Ivoclar Vivadent AG) was used for the impressions of prepared teeth. Custom acrylic trays were used, and each tray allowed an impression of four specimens. Impressions were cast in vacuum-mixed die stone (GC Fujirock EP, GC Europe N.V., Leuven, Belgium). Stone dies were recovered from impressions, and two coats of die spacer (Yeti Dental Clear Spacer, Yeti Dentalprodukte Gmbh, Engen, Germany) were painted 1 mm short of the finish lines of the preparations.

Ceramic veneers were made of a leucite-reinforced glass ceramic material, IPS Empress 1 (Ivoclar Vivadent AG). The veneers were fabricated using the Empress staining technique, according to the manufacturer's recommendations. The veneers in P2e and P4e were waxed to a uniform thickness of 0.6 mm and, in P2d and P4d, to 1.1 mm with beige wax and sprued. Ceramic veneers were then pressed after investment. After divestment, the veneer fit was verified on the stone die. High spots on the veneers were removed with diamond medium-grit round bur. All-ceramic veneers were then reduced to the preparation thickness and glazed. The fit of the veneers was controlled using a binocular light microscope at 10×.

The laminate veneers were adhesively luted using Variolink II high-viscosity composite resin cement (Ivoclar Vivadent AG) according to the manufacturer's recommendations. The veneers were etched with a 5% hydrofluoric acid (IPS Empress etching gel; Ivoclar Vivadent) for 60 seconds, and rinsed with water for 30 seconds. A silane agent (Monobond-S; Ivoclar Vivadent) was applied to the etched surface and allowed to dry for 60 seconds. An unfilled resin-bonding agent (Heliobond; Ivoclar

Table 2 Mean fracture load of different designs for tooth preparation (N)

	Mean fracture load	SD (standard deviation)	Minimum fracture load	Maximum fracture load
P2e	262	63	160	400
P4e	189	40	104	241
P2d	239	53	131	338
P4d	162	36	107	239
Pc	277	66	192	386

Vivadent) was applied with a brush and homogeneously sprayed with air for 5 seconds. The enamel was etched for 30 seconds with 37% phosphoric acid (Total Etch; Ivoclar Vivadent), and the teeth were rinsed with water and dried. A primer for dentinal adhesive (Syntac Primer; Ivoclar Vivadent) was then applied and allowed to act for 15 seconds and dried. Dentinal adhesive (Syntac Adhesive; Ivoclar Vivadent) was applied for 10 seconds and dried. An unfilled resin-bonding agent (Heliobond) was then applied with a brush and air thinned. All veneers were luted with Variolink II high-viscosity composite resin cement. A combination of 50% Variolink base and 50% transparent catalyst was mixed and applied to both prepared teeth and ceramic veneers. The ceramic veneers were seated on the prepared teeth with light finger pressure, excess cement was removed with an explorer, and an oxygen barrier was applied to the margins (Liquid Strip; Ivoclar Vivadent). Photo-polymerization was performed for 40 seconds for facial and palatal margins of each ceramic veneer. Margins were then finished with finishing diamond burs. All specimens were thermocycled (Nüve Sanayi, Ankara, Turkey), alternating between 5°C and 55°C for 3500 cycles with a dwell time of 30 seconds.

The fracture loads were determined using a universal testing machine (Testometric Micro 500, Testometric Company Ltd., Lancashire, UK). The load was applied at a 90° angle to the lingual surface of the test tooth. This orientation was standardized with a mounting jig. The load was consistently applied at 1 mm from the incisal edge. A customized plunger was used for this purpose. The plunger was attached to the load cell, and the cross-head speed was 0.5 mm/min.

Modes of failures were analyzed after specimen testing for both veneers (intact; fracture; bond failure; and fracture) and teeth (intact; coronal fracture; cervical fracture; and root fracture). Statistical analyses were performed using ANOVA and Tukey's Multiple Range Test.

Results

Table 2 presents the fracture load means and standard deviations for the groups. ANOVA and Tukey's multiple range test disclosed significant differences between fracture loads (Table 3). P4d yielded a lower fracture load than P2e, P4e, and P2d. The difference between the unprepared control group and the preparation designs with 2-mm incisal reduction was not statistically significant. There was significant difference between P2e and P4e–P4d. Tables 4 and 5 present the failure modes for veneers and teeth, respectively. All failures involved the production of two fragments. The fracture pattern was primarily oblique. In P2d and P4d (preparations in dentin), there was more bond failure on the labial surface than for P2e and P4e (preparations on enamel). In P4d (4-mm incisal reduction and preparation on dentin), two of the veneers debonded without fracture.

Discussion

In this study, recently extracted human central incisors were used to optimally represent the clinical situation.[8,13] To standardize the size of the teeth, measurements were made, and the thickness of the restoration was adjusted.

Many studies suggest a 0.5-mm minimal thickness for tooth preparations for ceramic veneers.[9,14–16] According to Nattress et al,[10] freehand preparation can result in variable depth of preparation with dentin exposure. To minimize variations, the tooth preparation was controlled with a 0.5-mm self-limiting depth-cutting disk. In the groups with preparations in dentin, two sets of facial reduction were performed to ensure that all the enamel was removed.[17]

There are different reports as to whether the incisal edge should be included in the preparation for ceramic veneers.[1,4–10] Castelnuovo et al[9] reported that a 2-mm incisal reduction without palatal chamfer (butt joint) resulted in stronger restorations and simplified tooth preparation. In this study, butt joint incisal reductions of 2 mm and 4 mm were performed. The ceramic veneer design with 4-mm incisal reduction was included in this study as a restorative option for a fractured tooth.

Staining technique was used for the fabrication of veneers to standardize the restorations. In this study, high-viscosity resin cements were used for cementation. Christgau et al[2] examined the marginal adaptation of ceramic veneers to dentin at the cervical margin and to enamel at the palatoincisal margins using four dual-curing composite resin cements of different viscosities with their corresponding dentin bonding agents. They pointed out that high-viscosity composite resin cements with their matching bond system provided good marginal adaptation of ceramic veneers both to enamel and dentin.

Table 3 ANOVA summary ($p < 0.05$)

	Sum of squares	df	Mean square	F	Significance
Between groups	144041.47	4	36010.367	12.792	0.001
Within groups	197054.43	70	2815.063		
Total	341095.89	74			

Table 4 Frequency of veneers' failure modality (%)

	Intact			
	Bonded on fractured tooth structure	Debonding	Fracture	Bond failure and fracture
P2e	13.33	–	73.34	13.33
P4e	0	–	80	20
P2d	13.33	–	40	46.67
P4d	0	13.33	33.34	53.33

In this study, all specimens were thermocycled, with cycles alternating between 5°C and 55°C for 3500 cycles with a dwell time of 30 seconds. In other studies, different study protocols were performed to imitate the temperature ranges in the oral environment.[15,16,18]

Significant differences were found between the failure behavior created during traditional load-to-failure tests and that observed to have occurred during clinical failure of all-ceramic restorations. Much information in the literature may be misleading regarding comparative strengths of single-unit prostheses and the function of some clinically important variables, including tooth preparation, ceramic thickness, coping and veneering materials, cementation and bonding procedures, cement type and thickness, and coping design. Cracks that mimic clinical failure can be produced at realistic intraoral loads under modified testing protocols.[20] Recently, dynamic loading devices and chewing simulators have been used for testing all-ceramic restorations,[20] but there are no studies on the fracture resistance of laminate veneers using these devices because it would be difficult to prevent the device from sliding along the palatal surface of natural teeth.[9]

In this study, a customized plunger was produced, and all-ceramic veneers were loaded 1 mm cervical to the incisal edge at the lingual side of the teeth, to reproduce an average vertical overlap.[9] To prevent the universal testing device from sliding over the palatal surface of the natural tooth, a mounting jig was fabricated. Failure loads for laminate veneers were measured by other authors with different protocols.[8,9,19] Castelnuovo et al[9] applied a load at a 90° angle; Wall et al[19] compared 130 and 137° angles; and Hui et al[8] compared fracture strength by loading the specimens directly at the incisal edge, parallel to the long axis of the tooth.

Kelly[20] reported that clinically the failures initiated from flaws and stresses existing at the cementation medium, but that in traditional laboratory tests, failure initiated from indentation damage at the occlusal surface. Kelly also mentioned that extremely high loads are required in laboratory tests, and failures involved the production of a great number of fragments (versus two fragments typical of clinical failure). In this study, all failures involved two fragments, and the failure loads were comparable with natural biting forces.[21]

Table 5 Frequency of tooth-failure modality (%)

	Intact	Coronal	Cervical	Root
P2e	80	13.33	6.67	–
P4e	100	–	–	–
P2d	66.67	20	13.33	–
P4d	86.67	13.33	–	–
Pc	–	66.67	13.33	20

Castelnuovo et al[9] reported the highest fracture load for preparations with 2-mm butt joint incisal reduction. In this study, P4d yielded a lower fracture load than P2e, P4e, and P4d. The difference between the unprepared control group and the preparation designs with 2-mm incisal reduction was not statistically significant. There were significant differences among P2e, P4e, and P4d.

Within the 2-mm incisal reduction groups, the preparation of veneer on enamel or dentin did not show any significant effect on the fracture resistance of laminate veneers. In the groups of 4-mm incisal reduction, however, the preparation of veneer on enamel was found to be effective, indicating that veneers prepared entirely on the enamel surface had superior fracture-strength values in comparison with those prepared entirely on dentin. Thus, the preparation design and amount of enamel should be evaluated carefully while restoring fractured or worn central incisors that have extensive incisal reduction. Long-term clinical follow-up studies are necessary to evaluate the outcomes of laminate veneers in cases with severe tooth loss resulting in extensive incisal edges of ceramic veneer.

Conclusion

Within the limitations of this study, the following conclusions were drawn:

1. Ceramic veneers with preparation designs entirely on dentin with 4-mm incisal reduction yielded lower fracture loads than those prepared with 2-mm incisal reduction.
2. Veneers with 2-mm incisal reduction exhibited similar fracture resistance to intact tooth for preparation designs supplied on both enamel and dentin.
3. Fracture load decreased as the amount of incisal reduction increased.

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