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Fracture resistance of composite resin restorations and porcelain veneers in relation to residual tooth structure in fractured incisors

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Abstract – The aim of the present study was to investigate whether there is a direct correlation between the amount of residual tooth structure in a fractured maxillary incisor and the fracture resistance of composite resin restorations or porcelain veneers after cyclic loading. Sixty human-extracted maxillary central and lateral incisors were mounted in an acrylic block with the coronal aspect of the tooth protruding from the block surface. The teeth were assigned to two groups: 2-mm incisal fracture and 4-mm incisal fracture. Then, the teeth were further divided into two different restoration subgroups, porcelain laminate veneer and composite resin restoration, therefore obtaining four groups for the study ($n = 15$). The specimens were subjected to 1000 cycles of thermocycling and were mechanically tested with a custom-designed cyclic loading apparatus for 2×106 cycles or until they failed. The specimens that survived the cyclic loading were loaded on the incisal edge along the long axis of the tooth with a flat stainless steel applicator until they fractured using a universal testing machine to measure the failure load. Two-way ANOVA was used to assess the significance of restoration, amount of fracture, and interaction effect ($\alpha = 0.05$). During the cyclic loading, for the composite resin group, two specimens with 2-mm fracture and three specimens with 4-mm fracture failed. For the porcelain veneer group, two specimens with 2-mm fracture and one specimen with 4-mm fracture failed. The 2-way ANOVA did not show statistical significance for restoration ($P = 0.584$), amount of fracture ($P = 0.357$), or interaction effect ($P = 0.212$). A composite resin restoration and a porcelain veneer could perform similarly for replacing a fractured incisor edge up to 4 mm. Other factors such as esthetic and/or cost would be considerations to indicate one treatment over the other.

For an incidence of anterior tooth fracture, reattachment of the broken fragment has been widely studied and showed clinically acceptable prognosis in terms of esthetics and function (1–3). However, not always the patient visits a dental office carrying along with the broken piece after tooth fracture, which could be solved only by restoration of the tooth using dental materials. Composite resin restorations and porcelain veneers are considered the most conservative types of treatment for the fractured incisors (4). These treatment modalities require a minimal tooth preparation, achieve reliable bond strength values with the use of enamel and dentin adhesive systems (5, 6), and obtain excellent esthetic outcomes (7).

One of the factors that could greatly influence the longevity of both direct composite resin and porcelain veneer restorations is the strength and long-term reliability of the adhesion to the tooth structure (8). In this sense, Farik et al. (9) tested the fracture strength of fractured incisors after reattachment of the fractured part using different experimental bonding agents and compared these with the strength of intact teeth. The results did not show significant difference between the fracture strength of teeth that were bonded with an experimental modification of Gluma, Panavia 21, or ScotchBond 1 (14.2–15.5 MPa) and that of intact teeth (16.3 MPa). Other investigators have shown that composite resin class III restorations on incisors, subjected to cyclic loading, exhibited only 7% of adhesive failure, while 93% failed because of cohesive fracture of the specimens (10).

In the same light, as cements used for luting porcelain veneers are ‘resin-based’, the formation of a hybrid layer, when dentin is exposed, is important for the veneers as well to reduce adhesive failure at the tooth–cement interface. In addition, in porcelain veneers, the interface between conditioned porcelain surface and the resin cement is another critical area for reliable bond and longevity. Peumans et al. (11) analyzed the ultrastructure of these areas with field-emission scanning electron microscopy. The imaging of the tooth/luting composite resin/porcelain interface showed micro-mechanical interlocking of the luting composite resin in the micro-retentive pits of the acid-etched tooth and porcelain surface.

Despite numerous clinical reports and expert opinions that have suggested different preparation designs for direct composite resin restorations and indirect porcelain veneers, there is still no conclusive evidence to guide a clinician whether, after an incisor tooth fractures, the extent of the remaining tooth structure would indicate a direct composite resin restoration or the fabrication of a porcelain veneer. Andreasen has conducted a study for a similar situation in which a fractured tooth was restored using porcelain laminate veneer without reattachment of the broken fragment, and the results reported that veneer restoration could reinforce the fractured tooth (5). However, this study investigated various restorative modalities for only one pattern of 2.5-mm tooth fracture, the protocol of which was suggested by Munksgaard (12). In addition, the study was conducted on the sheep teeth, not on the human teeth. Therefore, the aim of the present study was to investigate whether there is a direct correlation between the amount of residual tooth structure in a fractured maxillary incisor and the fracture resistance of composite resin restorations or porcelain veneers. The null hypothesis was that there would be no significant difference in fracture resistance between composite resin restorations and porcelain veneers. Also, it was hypothesized that there would be no significant difference in fracture resistance between the restorations on 2-mm fractured teeth and those on 4-mm fractured teeth.

Materials and methods

Thirty-two human-extracted maxillary central and 28 maxillary lateral incisors without caries and/or restorations were collected. Each individual tooth was mounted in an acrylic block (Acraweld Repair Resin; Henry Schein Inc, Melville, NY, USA) up to a level of 3 mm below the cemento-enamel junction, therefore leaving the coronal aspect of the tooth protruding from the block surface. The long axis of the tooth was oriented at 45° to the horizontal surface of the block, so that, during cyclic loading testing, the load would be applied in 135° to the long axis of the tooth (Fig. 1). Two matrices for each tooth were made covering the entire crown: matrix A was

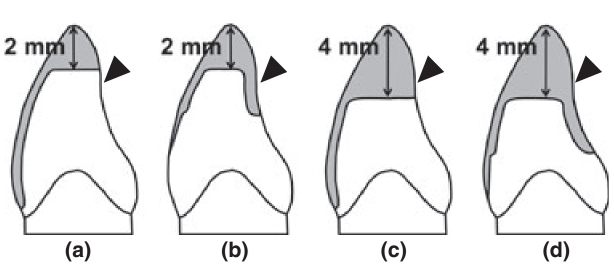

Fig. 1. Schematic drawing of four experimental settings. (a) porcelain veneer for 2-mm fracture; (b) composite resin restoration for 2-mm fracture; (c): porcelain veneer for 4-mm fracture; (d) composite resin restoration for 4-mm fracture. Arrowhead represents position and direction of cyclic loading (135° to axis of tooth).

made using polysiloxane putty (Lab-Putty; Coltène/Whaledent Inc, Cuyahoga Falls, OH, USA), while matrix B was made using a 1-mm-thick vacuum forming template (Biocryl; Great Lakes Orthodontics, Tonawanda, NY, USA).

The teeth were assigned to two groups: (i) 2-mm incisal fracture: the tooth was sectioned perpendicularly to its long axis with a coarse diamond bur (Chamfer 6856-025; Brasseler USA, Savannah, GA, USA) at the level of 2 mm from the incisal edge; (ii) 4-mm incisal fracture: the tooth was similarly sectioned, but at the level of 4 mm from the incisal edge. Then, the teeth were divided into two subgroups, according to prosthetic restoration, porcelain laminate veneer or composite resin restoration, therefore obtaining four groups in total ($n = 15$; 8 central and 7 lateral incisors).

For the veneer preparation, self-limiting (LVS1 834-021; Brasseler USA) and two-grit diamond burs (LVS4 6844-014; Brasseler USA) were used to achieve 0.8-mm axial reduction. As each tooth was already reduced incisally by 2 or 4 mm, the palatal aspect of the tooth was not further prepared. Matrix A was split longitudinally into two halves and was used during the preparation to ensure consistent labial reduction. The cervical chamfer finish line was positioned 0.5 mm coronal from the cemento-enamel junction without dentin exposure.

A custom tray was fabricated using light-polymerizing impression tray material (Custom Tray Material, Light Cure; Henry Schein Inc) after covering the prepared tooth with a layer of baseplate wax to act as a spacer (NeoWax; Dentsply International, York, PA, USA). The impression was made using a light-body consistency vinylpolysiloxane (VPS) material (President; Coltène/Whaledent Inc) and then type IV dental stone (Resin-Rock; Whip Mix Corp, Louisville, KY, USA) was used to make a definitive cast. Two coats of die spacer (P.D.Q. Spacer; Whip Mix Corp) were applied on the facial surface of each die up to 2 mm from the margin. Sculpturing wax (ProArt Wax; Ivoclar Vivadent AG, Schaan, Liechtenstein) was heated and placed into matrix B. While the wax was still liquid, this matrix was seated on the stone die, previously coated with wax lubricant (P.D.Q. Lubricant; Whip Mix Corp), to form the veneer wax pattern. After the wax had solidified, the pattern was finished, removed from the stone die, and invested (IPS Empress Esthetic Speed Investment Material and Liquid; Ivoclar Vivadent AG). After pressing leucite-reinforced glass ceramic (IPS Empress Esthetic Ingot; Ivoclar Vivadent AG) (Table 1), the veneers were divested and the sprues were cut. The veneer was then placed on the die to check for marginal accuracy and fit, then universal stain and glazing paste (IPS Empress Universal Glaze; Ivoclar Vivadent AG) were applied to the veneer and fired.

The intaglio of the veneer was etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent AG) for 1 min, rinsed by water for 30 s, silanated (Monobond-S; Ivoclar Vivadent AG), and then a bonding agent (ExciTE; Ivoclar Vivadent AG) was applied. The prepared tooth surface was etched with 37% phosphoric acid (Total Etch; Ivoclar Vivadent AG) for 20 s for enamel and 10 s for exposed dentin, rinsed

Table 1. Physical properties of restorative materials (information directly from the manufacturer)

Composite resin (4 Seasons; Ivoclar Vivadent AG)		Leucite-reinforced glass ceramic (IPS Empress Esthetic Ingot; Ivoclar Vivadent AG)	
Flexural strength (MPa)	135	Flexural strength (MPa)	160
Flexural modulus (MPa)	9000	Fracture toughness (MPa $m^{0.5}$)	1.3
Compressive strength (MPa)	260	CTE[1] (100–500°C) (10^{-6} K^{-1})	17.5
Vickers hardness (MPa)	570	Vickers hardness (MPa)	6200

[1]Coefficient of thermal expansion.

for 30 s, then the bonding agent (ExciTE; Ivoclar Vivadent AG) was applied and polymerized using intense light (Bluephase; Ivoclar Vivadent AG). The veneer was cemented with resin cement (Variolink Veneer; Ivoclar Vivadent AG) following manufacturer's instructions.

For the composite resin restoration group, 3-mm-long preparation extending apically from the 2-mm or 4-mm incisal cut was made reducing half-thickness of enamel all around the tooth with a chamfer finish line. Additional 3-mm bevel was made on the labial surface for better esthetic outcome. The enamel margins and exposed dentin were etched using 37% phosphoric acid for 20 and 10 s, respectively, and rinsed for 30 s with water. The bonding agent (Optibond Solo Plus; Kerr USA, Orange, CA, USA) was applied and polymerized using intense light. A layer of composite resin (4 Seasons; Ivoclar Vivadent AG) (Table 1) was placed on the lingual side of the tooth to replace the lingual surface first, and then polymerized for 40 s. The remaining restoration was built by repetition of layering and polymerization, and the final layer was shaped using the matrix B. The restoration was polished using a rubber point (Jiffy Polishers; 'Ultradent Products Inc, South Jordan, UT, USA'.) and silica polishing paste (Prisma-Gloss; Dentsply Caulk, Milford, DE, USA).

All the specimens were stored in 0.9% saline solution at 34°C for 6 weeks. The saline solution was changed every week. The specimens were then subjected to 1000 of cycles of thermocycling of 70 s each, which consisted of 5 s dwell time in two baths of 5 and 55°C with a 30-s transport time between the baths. Each specimen was mechanically tested with a custom-designed cyclic loading apparatus. This apparatus delivered simultaneous unidirectional cyclic loading at 135° to the long axis of the tooth to simulate the force application to a maxillary incisor, at an average frequency of 250 rpm or 4.16 Hz with a load of 49 N (13) simulating force application during function in the region of a maxillary central incisor. The load was applied to the lingual aspect of the specimens at a level 3 mm apical to the incisal edge, using a round stainless steel indenter of 6 mm diameter (14).The frequency was monitored at least once a day during each testing with a contact tachometer (Model 461891; rpm range, 0.5–19 999; accuracy, 0.05%; Extech Instruments Corp., Waltham, MA, USA). Each specimen was kept continuously wet by applying saline solution with a custom-made delivery system and was loaded for 2×10^6 cycles or until it mechanically failed. The failure was defined as bulk fracture of tooth and/or restoration, not simple crack growth.

The specimens that survived the cyclic loading were further tested as follows: They were loaded on the incisal edge in a direction parallel to the long axis of the tooth with 8-mm-diameter flat stainless steel piston until fracture, using a universal testing machine (MTS Alliance; MTS, Eden Prairie, MN, USA) at a crosshead speed of 1.5 mm min^{-1}. To decrease the possibility that a localized stress application could determine fracture of the porcelain, a 1-mm layer of tin was interposed between the crown and the loading apparatus. For statistical analysis, a 2-way ANOVA was used to find the significances of restoration, amount of fracture, and interaction effect ($\alpha = 0.05$).

Results

During the cyclic loading, in the porcelain veneer/2-mm fracture group, two specimens failed (both adhesive/cohesive failures) (Figs 2 and 3). For the composite resin restoration/2-mm fracture group, two specimens failed

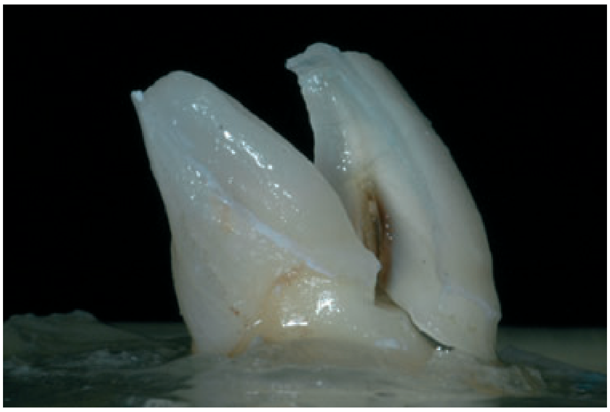

Fig. 2. Restoration and crown fracture from porcelain veneer/2-mm fracture group (central incisor).

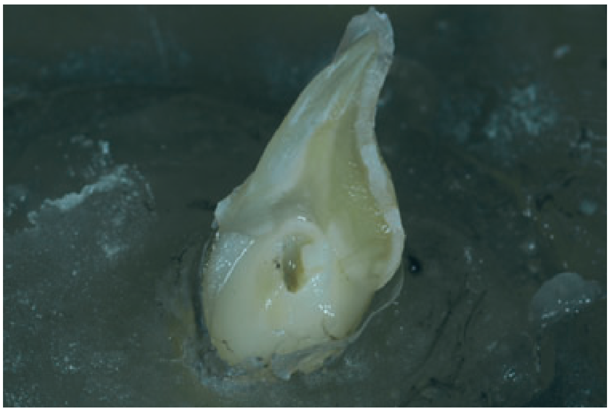

Fig. 3. Crown fracture from porcelain veneer/2-mm fracture group (lateral incisor).

Fig. 4. Root fracture from porcelain veneer/4-mm fracture group (lateral incisor).

Fig. 5. Restoration fracture (adhesive failure) from composite resin restoration/4-mm fracture group. Tooth was left intact (central incisor).

Table 2. Number and characteristics of failure after cyclic loading

Group (*n* = 15) Restoration	Fracture (mm)	Number of failure	Failure characteristics (number of specimen)
Porcelain veneer	2	2	R + C (1), C (1)
Composite resin	2	2	R + C (1), Rt (1)
Porcelain veneer	4	1	Rt (1)
Composite resin	4	3	R (2), Rt (1)

R, restoration fracture; C, crown fracture; Rt, root fracture.

during the cyclic loading and one of them was a root fracture (the other one was adhesive/cohesive failure). For the porcelain veneer/4-mm fracture group, one root fracture (Fig. 4) occurred during the cyclic loading. For the composite resin restoration/4-mm fracture group, three specimens failed during the cyclic loading and they were two restoration fractures (both adhesive failures) (Fig. 5) and one root fracture (Table 2).

For the load-to-failure test results, the failure load for those teeth that failed during cyclic loading was automatically recorded as of 49 N. The mean of load-to-failure test results ranged from 1039.3 to 1459.2 N (Table 3), and the 2-way ANOVA did not show significance of restoration ($P = 0.584$), amount of fracture ($P = 0.357$), or interaction effect ($P = 0.212$) (Table 4).

Discussion

For the present study, two null hypotheses were addressed: 1) there would be no significant difference in fracture resistance between composite resin restorations and porcelain veneers and 2) there would be no significant difference in fracture resistance between the restorations of 2-mm fractured teeth and those of 4-mm fractured teeth. As a result, both hypotheses were not rejected after the statistical analysis.

During the experiment, thermocycling and wet cyclic loading were executed before measuring failure load. It was to simulate clinical situations in the mouth where the restorative materials experience frequent occlusal force in the wet condition with frequent temperature change depending on ingested food and/or drinks. It was reported in an earlier study that temperature change could substantially affect stress pattern at interfaces of the bonded restoration because the attached components (dentin, resin cement, and restoration) have different coefficient of thermal expansion (15). Consequently, it was believed that increased tensile stress at the interface could affect crack propagation in the ceramic restorative material. Another recent study reported the effect of wet

Table 4. Results of 2-way ANOVA for failure load

Source of variation	df	SS	MSS	*F*	*P*
Material	1	166 481.45	166 481.45	0.30	0.584
Fracture	1	475 103.37	475 103.37	0.86	0.357
Material × fracture	1	878 092.20	878 092.20	1.60	0.212
Error	56	30 802 951.67	550 052.71		

Table 3. Results of failure load test

	2-mm Fracture					4-mm fracture				
Material	*n*	Mean (*N*)	SD	Min	Max	*n*	Mean (*N*)	SD	Min	Max
Composite	15	1386.59	712.16	49[1]	2500	15	1322.61	716.16	49	2254
Porcelain	15	1039.29	592.96	49	1893	15	1459.21	910.25	49	3691

[1]For load-to-failure test results, failure load of 49 N was assigned for those teeth that failed during cyclic loading.

condition on failure load of the ceramic material (16). In this study, wet storage alone showed significant decrease in failure load of the specimen and further decrease was observed when the specimen underwent wet cyclic loading. Intuitively, testing restorative materials under the wet condition more closely simulates the oral condition, and also the failure load from the wet condition appeared to be closer to the normal range of occlusal force compared with that from dry condition which typically reported extremely higher force than normal occlusal force. Therefore, by applying both thermocycling and wet cyclic loading process, more clinically relevant *in vitro* study results could be obtained. When the restoration and/or tooth failed during cyclic loading process, failure load of 49 N was assigned to the specimen for statistical analysis.

As shown in the results of the present study, eight specimens failed under thermocycling and cyclic loading of 49 N. It is substantially lower force than that might be recorded by normal occlusion (17), but during the thermocycling and cyclic loading treatment, internal flaws could have been propagated to cause mechanical failure at such a lower force. Depending on the location of the major flaws, the specimens might have showed crown fracture, root fracture, material fracture, debonding of the restorative material, or combination of them. When the tooth failed (either crown or root fracture), the crack line passed through enamel and dentin, whereas two specimens that experienced debonding of the restorative material left intact. The other 52 specimens that survived the cyclic loading were tested under the unidirectional loading machine, and they showed the failure load ranging from 367.5 to 3690.6 N. Again, because those specimens underwent thermocycling and cyclic loading treatment, internal flaws could have been propagated to cause mechanical failure under the unidirectional load test at various levels of load depending upon quantity and quality of the flaws in the individual specimen.

In the porcelain veneer group, three specimens failed and veneer fracture occurred in only one specimen. The veneer broke with the crown, and the other two failures were a crown fracture and a root fracture without the breakage of the veneers. The composite resin restoration/2-mm fracture group showed similar results that the fractures occurred on either restoration with the crown or the root without composite resin failure. However, the composite resin restoration/4-mm group showed a different result that two specimens failed at the material–tooth interface where the bonding was achieved (adhesive failure). There was one more failure in the composite group and it was a root fracture. In a summary, only the composite resin restoration/4-mm group showed complete debonding of the restoration.

From the mechanical point of view, 4-mm fracture was a less favorable situation than that of 2-mm fracture in that the occlusal force was applied directly on the restoration (Fig. 1). For this reason, there might have been higher risk of adhesive failure in the composite resin restoration/4-mm fracture group. However, on the other hand, the bond strength of the veneer appeared to be adequate and predictable for long-term clinical success for replacing broken incisal edge up to 4 mm as no veneer specimen showed adhesive failure. As it was shown in the present study, the veneer of the preparation design without palatal extension seems to provide adequate resistance to cyclic loading.

As for the failure load, neither the type of restoration nor the amount of tooth fracture affected the results. Even though the mean failure load of the porcelain veneer/2-mm fracture group appeared less than those of other three groups, there was no statistical significance. From the material point of view, porcelain veneer and composite resin restoration did not show significant difference. Considering the results of the present study, both materials are believed to survive long-term clinical use and could be recommended to restore the fractured incisors. From the remaining tooth structure point of view, it was an interesting finding that two different amounts of the remaining tooth structure did not show significantly different failure load. The bond strength between the restoration and the tooth might have been sufficient to offset the influence of material thickness on the failure load. As this was an *in vitro* study, the bond strength was likely to be maximized by performing the procedures in ideal conditions. For the veneer group, the preparation was made on a sound enamel layer without dentin exposure, and the bonding procedure was performed in a dry condition. For the composite resin group as well, the bonding procedures were performed without the risk of saliva or blood contamination on the tooth surface. The reliability of the bonding achieved in this *in vitro* study is also indirectly suggested by the fact that most failures occurred cohesively within the tooth and/or restoration. This result may provide clinicians a guideline for the selection of restorative treatment modality when they restore a broken incisor. It appeared that the mechanical strength of material would not be a determining factor, but other factors such as predictable and durable esthetics and/or the cost of treatment could be determining factors to select the specific restoration.

Regarding methodology of the current study, it could be argued that the exposed tooth surface as a result of trauma may be different from the one that was artificially created using the diamond bur in roughness, and it could affect the quality of bonding between the surface and restoration materials. In fact, there was a study which reported that the surface characteristics of a tooth fractured by mechanical impact were different from those of a tooth sectioned using a grinding machine (18). Another study also reported that the sectioned teeth by grinding did not show any significant difference in bonding strength among various bonding protocols for reattachment, whereas the quality of bonding was affected by the various protocols when the teeth were fractured (19). For the current study, it was decided to use grinding method with some reasons: (i) for standardization purpose, grinding might be better as it was proven not to affect the bonding strength according to various protocols, (ii) it would be more difficult to obtain the specimens of certain amount of fracture, which was main interest of the current study, and (iii) in clinical situations when reattachment is not available owing to loss of the fragment, the exposed surfaces tend to be altered using dental burs to remove sharp edges, to clean debris out of the surface, or to create ideal shape for restoration. Therefore, simulating the artificial tooth fracture using the diamond bur was believed to be clinically relevant.

Before the results of the present study are applied to the clinical situations, some limitations of the study design need to be reminded. For the present study, only one particular preparation design for each material was used, and they were not identical. For the veneer preparation, the preparation design without palatal extension was selected so as to achieve the most conservative reduction of the tooth structure, whereas the palatal extension was included for the composite resin restoration for achieving 360-degree bevel all around. Also, combining both maxillary central and lateral incisors in the study would be argued that they might compromise standardization and affect the statistics. However, in the clinical situations, both teeth experience traumatic injury with the equally highest frequency being located next to each other, and therefore both types of tooth needed to be the subjects of interest. To minimize any possible statistical effect from the different types of tooth, they were evenly distributed into the four groups by eight central and seven lateral incisors. Finally, it should be reminded that the experiment for the present study was performed using specific materials such as leucite-reinforced glass ceramic and fifth-generation bonding agent. Use of similar but different materials from those described for the clinical situations may yield various outcomes.

Consequently, for future research directions, a conventional feldspathic porcelain veneer may need to be tested instead of the leucite-reinforced glass ceramic. The feldspathic porcelain veneer is indicated to restore the clinical situation when high translucency is required, and it is mechanically weaker than the leucite-reinforced glass ceramic (20). Although bonding agents might provide reliable strength to the veneer, it is unknown whether the result of this study could be applicable to feldspathic porcelain veneers. Also, applying different preparation designs for both porcelain veneer and composite resin restoration could be the subject of interest for future study.

Conclusions

Within the limitations of the present study, neither type of restoration nor remaining tooth structure of the fractured incisors affected fracture resistance.

Acknowledgements

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