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Original Article

Comparison of the pull-out bond strength of endodontically treated anterior teeth with monolithic zirconia endocrown and post-and-core crown restorations

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Abstract

Purpose: The purpose of this study was to assess the pull-out bond strength (PBS) of endodontically treated anterior teeth that had been restored with monolithic zirconia endocrowns using different extension depths (EDs) and post-and-core crowns after chewing simulation.
Methods: Thirty-six maxillary central teeth were used (n = 12). Group I: Glass fiber post-and-core crown, Group II: Endocrown with 3-mm EDs, Group III: Endocrown with 5-mm EDs. Restorations were fabricated from monolithic zirconia blocks using a CAM (computer-aided manufacturing) device. For cementation, conventional resin luting agent (Multilink N) was used. All samples were aged with a chewing simulator and PBS tests were conducted at a speed of 1 mm/min using an electromechanical servo universal testing machine. The values were recorded in MPa by dividing the failure load by the bonding area. One-way ANOVA and the *post-hoc* Tukey test were used for statistical analysis (P = 0.05).
Results: Group III demonstrated significantly greater PBS values than Groups I and II (P = 0.001). No significant difference was found between Groups I and II (P = 0.072).
Conclusion: Increasing the ED of an endocrown influences the PBS of endodontically treated anterior teeth restored with monolithic zirconia endocrowns.

Keywords: CAD-CAM, chewing simulator, endocrown, fiber post, monolithic zirconia

Introduction

There are various methods for the restoration of endodontically treated teeth. Because the amount of remaining tooth structure in these teeth is insufficient, post placement is necessary to ensure the retention of crown restoration [1]. The presence of a ferrule for optimal biomechanics contributes to clinical success [2]. Sometimes, however, endodontically treated teeth do not have adequate remaining structure for the ferrule. Posts made of metal, ceramic, and fiber-reinforced composite (FRC) are used to restore such inadequate tooth structure [1]. Since FRC posts show greater similarity to dentin in terms of their elastic properties, they allow a relatively homogeneous distribution of stress to the tooth and surrounding tissues, thus reducing the possibility of root fracture [3]. During the preparation of a post space after endodontic treatment, especially with thin roots, the amount of remaining dental tissue decreases, thus increasing the risk of fracture [4]. Therefore, for teeth with significant tissue loss, treatments such as ceramic inlay/onlay and endocrown restorations are applied [4].

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In comparison to other treatment options, endocrowns can be easily fabricated with minimally invasive preparation because they do not require many technical steps such as post insertion into the root canal and shaping of the core structure [5]. *In vivo* and *in vitro* studies have demonstrated the efficacy of endocrown restorations for the treatment of endodontically treated teeth with excessive material loss [6]. Endocrowns are all-ceramic or all-composite overlays that totally or partially replace the coronal part of a weakened tooth with an endo-core that extends into the pulp chamber (multi-rooted teeth) or root canal (single root). For molars, this extension depth aids stabilization of the restoration within the cavity, particularly during the cementation process. Furthermore, this extension depth improves retention of the adhesive in the root, as a function of the amount and quality of the tissue remaining for adhesion in the case of premolars and single-rooted teeth with severe material loss. In this context, while the ratio of the length of the intra-root portion to post-retained crown restorations is frequently discussed [7], only a limited number of studies have investigated anterior endocrowns and their extension depth.

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology can be used to produce endocrowns. With CAD-CAM technology, the design and manufacturing process is faster, less technically sensitive, and only one step is required, unlike the traditional method [8]. The use of zirconia-based materials in dentistry has increased recently due to their biocompatibility, high flexural strength, and esthetics [5]. However, the main disadvantage of zirconia is its low potential for adhesion to resin luting agent. A strong bond between the resin luting agent and ceramic requires mechanical and chemical retention. Numerous surface treatments, including tribochemical silica coating, air abrasion, and laser application, have been suggested for the bonding of resin to zirconia. [9]. These procedures help to increase the surface area and surface energy, thus increasing the bond between the zirconia and the resin luting agent and also improving micromechanical adhesion [10]. Although the use of conventional ceramic primers alone is ineffective on zirconia [11], primers containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) have been reported to bond chemically to zirconia [12].

Although many studies have focused on ways to increase the bond strength of zirconia [13,14], there has been no research on the pull-out bond strength of endodontically treated anterior teeth restored with monolithic zirconia endocrown restorations with different extension depths and post-and-core crowns after chewing simulation. The null hypothesis of the present study was that different designs would have no effect on the pull-out bond strength of monolithic zirconia restorations applied to endodontically treated anterior teeth.

Materials and Methods

This study was performed in line with the principles of the Declaration of Helsinki. The study protocol was approved by the Necmettin Erbakan University Faculty of Dentistry Ethics Committee (decision no: 2021/01-08).

The sample size was estimated at a 95% confidence interval with a power of 86%. Thirty-six caries-free, single-rooted maxillary central teeth of similar size were used. The teeth were examined under a magnifier and those with cracks or fractures were excluded from the study. Teeth with narrower apical openings were included. The working length was set at 1 mm less than the apical foramen. In accordance with the manufacturer's instructions, root canals were prepared using an endodontic motor; ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) X1 (17.04),

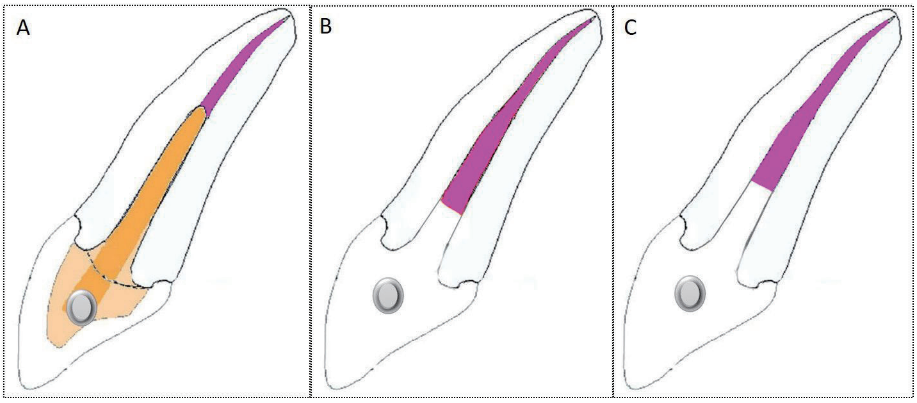

Fig. 1 Schematic view of endodontically treated anterior teeth with different prosthetic restorations. A: post-and-core crown. B: endocrown with a 3-mm extension depth. C: endocrown with a 5-mm extension depth

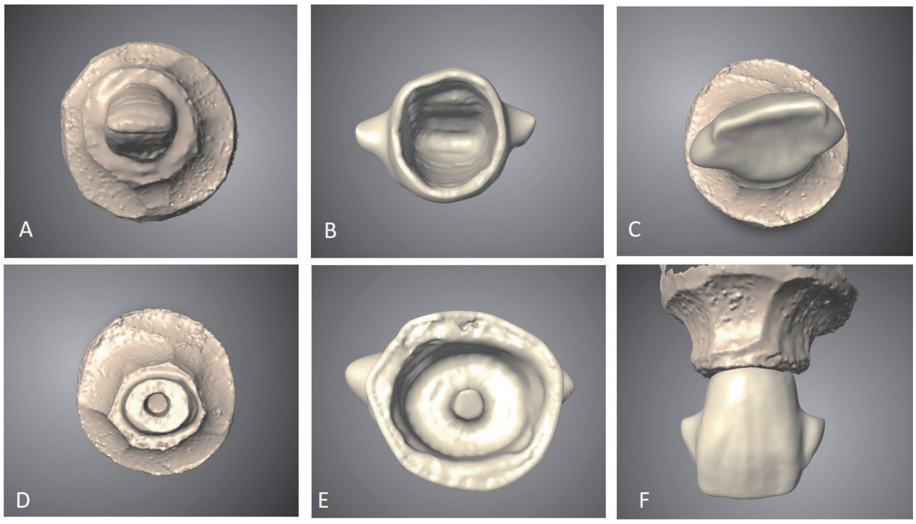

Fig. 2 Digital models of the prepared teeth were scanned with a model scanning device (Dental Wings Inc., Montreal, Canada). A: occlusal view of prepared anterior teeth after post-core application. B: inner view of crown. C: occlusal view of the anterior tooth with mesial and distal retentive areas of the crown. D: occlusal view of prepared single-rooted anterior teeth for endocrown. E: inner view of the endocrown. F: buccal view of the anterior tooth with mesial and distal retentive areas of the endocrown

X2 (25.06), X3 (30.07) files were used in sequence. After each file change, 2 mL of 2.5% sodium hypochlorite was used to irrigate the root canals. To remove the smear layer, all samples were irrigated for 1 min with 5 mL of a 17% EDTA solution. All samples were then dried using ProTaper X3 paper points (Dentsply Maillefer) after being irrigated with 5 mL of saline solution. Gutta-percha (Roeko, Langen, Germany) and canal sealer (AH Plus; Dentsply DeTrey, Konstanz, Germany) were used to fill the root canals utilizing the lateral condensation technique. Then, the teeth were cut 2 mm above the cementoenamel junction (CEJ). Following this process, the specimens were randomly divided into three groups (n = 12):

Group I: A 10-mm fiberglass post (GC Fiber Post; GC Corp., Tokyo, Japan) was used, 7 mm of which was inserted into the root canal after the gutta-percha had been removed with a 1.4-mm drill (GC Fiber Post Drill), leaving a 4-mm root filling to maintain the apical seal. The post was coated with bonding agent (Clearfil DC Bond; Kuraray Noritake Dental Inc., Okayama, Japan), and then left to air dry for 30 s. Microbrushes were used to apply the materials into the canals (Microbrush International, Grafton, WI, USA). Dual polymerized resin (Panavia F 2.0; Kuraray Noritake Dental Inc.) was used for cementation of the post. After the post had been luted, the core was formed using the same adhesive system and application technique as that described above. A dual cure core material (Clearfil DC Core Automix One; Kuraray Noritake Dental Inc.) was used to achieve the core build-up. Then, light curing was done for 40 s. Diamond burs were used to finish the core preparation. The measurements of the test sample placed on the resin block are shown in Fig. 1A. There was a 2-mm ferrule effect on all crown margins in the dentin.

Group II: The working length was prepared as 5 mm, 3 mm of which was placed into the root canal. The space between the dowels was prepared using a calibrated diamond rotary cutting instrument specially developed for the post system used. The preparation of the endocrown was limited to the retention zone, the removal of the pulp chamber, and the direction of the pulp wall (Fig. 1B).

Group III: The working length was set at 7 mm, 5 mm of which was placed into the root canal. The same procedures as those described for Group II were performed (Fig. 1C).

The prepared teeth were scanned using a model scanning device (Dental Wings Inc., Montreal, Canada) and then converted to digital media to create digital models. Endocrowns and crowns were designed using the integrated software program DWOS (Dental Wings Inc.) on the scanned models. After the model axes had been determined, the luting agent film thickness in the restoration parameters was set at 50 µm. Margins were plotted on the virtual model. Some modifications were made to create retentive areas in the pull-out test at the mesial and distal contact points of the restorations designed by the software (Fig. 2). Twenty-four endocrowns and 12 crowns were fabricated from monolithic zirconia blocks (Vita YZ T; VITA Zahnfabrik, Bad Säckinger, Germany) with a five-axis CAM device (Yenamak D50, Yenadent Ltd., Istanbul, Turkey). Then, the restorations were air-abraded with 50 µm alumina (Al_2O_3) powder at 10 mm under 0.2 MPa pressure. After air abrasion, the restorations were ultrasonically cleaned for 5 min each, and then dried with oil-free air. A universal primer (Monobond Plus; Ivoclar Vivadent, Schaan, Liechtenstein) containing 10-MDP was applied to the inner surface of the restorations, then cementing with conventional resin luting agent (Multilink N; Ivoclar Vivadent) was performed in accordance with the manufacturer's instructions. All restorations were light-cured in a light-curing device (Led.B; Guilin Woodpecker Medical Inst., Guangxi, P.R. China) for 10 s before removal of the overflowing

Table 1 Restorative materials used in this research

Material	Manufacturer	Composition	Lot
Clearfil DC Bond	Kuraray Noritake Dental Inc., Okayama, Japan	liquid A: HEMA, MDP, dimethacrylate monomer, catalyst, water liquid B: HEMA, MDP, microfiller, dimethacrylate monomer, catalyst	39007 94005
Monobond Plus	Ivoclar Vivadent, Schaan, Liechtenstein	ethanol, 3-trimethoxysilypropyl methacrylate, 10-MDP, sulfide methacrylate	V21266
GC Fiber Post	GC Corp., Tokyo, Japan	silicate glass, copolymer of methacrylate, Bis-GMA	2001291
Clearfil DC Core Automix One	Kuraray Noritake Dental Inc.	paste A: hydrophobic ARDM, hydrophobic ALDM, Bis-GMA, hydrophilic ALDM, dl-CQ, filler, pigments, initiators paste B: hydrophilic ALDM, hydrophobic ARDM, TEGDMA, accelerators, filler	370283
Panavia F 2.0	Kuraray Noritake Dental Inc.	paste A: hydrophobic ARDM, 10-MDP, hydrophobic ALDM, hydrophilic ALDM, fillers paste B: hydrophilic ALDM, hydrophobic ALDM, hydrophobic ARDM, fillers (filler load 70.8%)	051374
Multilink N	Ivoclar Vivadent	HEMA, dimethacrylate, barium glass, yttrium trifluoride, spheroid-mixed oxide	Y26001
VITA YZ T	VITA Zahnfabrik, Bad Säckinger, Germany	zirconium oxide 90.9-94.5%, hafnium oxide 1.5-2.5%, yttrium oxide 4.0-6.0%, aluminum oxide 0.0-0.3%, iron oxide 0.0-0.3%	63320

CQ, camphorquinone (photo-initiator); Bis-GMA, bisphenol A-glycidyl dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; ARDM, aromatic dimethacrylate; ALDM, aliphatic dimethacrylate; MDP, 10-methacryloyloxydecyl dihydrogen phosphate; TEGDMA, triethylene glycol dimethacrylate

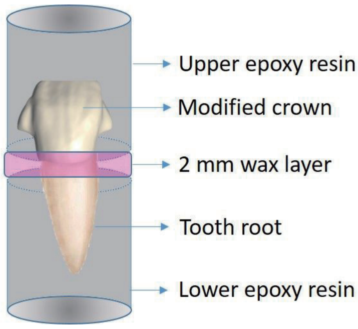

Fig. 3 Preparation of anterior teeth with the crown modified for the pull-out bond strength test

luting agent. Table 1 lists the restorative materials utilized in this research.

Afterward, each surface of the restorations was light-cured for 20 s, and polymerization of the luting agent was completed. All restorations were incubated at a humidity of 100% at 37°C for 24 h. To simulate clinical conditions, all of the teeth were aged in a chewing simulator (50 N load ×6,000 cycles, 2.1 Hz frequency) with a thermal cycle feature (5-55°C). During aging, a force of 50 N was performed 3 mm below the cutting edge of the prosthetic restoration at 45°. After the aging process, a wax layer was placed so that it protruded 1 mm from the cervical region to the apical and coronal region to prevent epoxy resin from entering the restoration connection interface. The coronal restorations were also embedded in epoxy resin for pull-out bond strength testing (Fig. 3).

Pull-out bond strength measurement

Pull-out bond strength values were measured using an electromechanical servo universal testing machine (Besmak Ltd., Ankara, Turkey). The samples were fixed to the epoxy resins with two vice grips and pull-out was performed at a speed of 1 mm/min until the restoration material was removed. The pull-out bond strength values were recorded in MPa by dividing the failure load (Newton) by the bonding area (mm^2). The bonding areas of the samples were calculated by importing the digital 3D models into the software program SolidWorks 2016 (Dassault Systèmes, Vélizy-Villacoublay, France).

Failure mode

Failure modes (adhesive, cohesive, mixed) of the restoration materials were evaluated under a stereomicroscope (SZTP; Olympus Optical Co., Tokyo, Japan) at ×10 magnification. Four different parameters were taken into account for evaluation of adhesive failure after the pull-out bond strength test: adhesive luting agent-dentin failure; separation of the crown restoration from the tooth with its luting agent, adhesive post-luting agent failure; separation of the fiber post from the root with the crown due to the pulling process, cohesive failure; separation of the luting agent material within itself, and mixed failure was defined as the presence of luting agent material in the crown and tooth.

Table 2 Mean and standard deviations (SD) of pull-out bond strength (MPa) in the groups

Groups	*n*	Mean	SD	*P*-value
Group I (post-and-core crown) [a]	12	8.82	1.99	0.001
Group II (endocrown 3 mm) [a]	12	10.98	2.58	
Group III (endocrown 5 mm) [b]	12	13.83	2.33	
Total	36	11.21	3.06	

The same letters indicate that there is no significant difference between the groups at $P < 0.05$.

Statistical analysis

The program IBM SPSS 22.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. The normality of the data distribution was analyzed with the Shapiro-Wilk test ($P > 0.05$) and the Levene test indicated homogeneity among variances ($P > 0.05$). As the data were distributed normally, parametric one-way analysis of variance (one-way ANOVA) and the *post-hoc* Tukey test were used. Differences at $P < 0.05$ were considered to be statistically significant (95% confidence level).

Results

Table 2 shows the results of the pull-out bond strength tests for various prosthetic anterior restorations. There were statistically significant differences among the groups with regard to the maximum force values obtained in the pull-out bond strength test ($P = 0.001$). Group III (13.83 MPa) showed a notably higher pull-out bond strength than Group I (8.82 MPa) and Group II (10.98 MPa). No significant difference in force resistance was evident between Group I and Group II ($P = 0.072$).

The failure modes of the restoration materials are shown in Fig. 4. Group II and Group III showed equal adhesive luting agent-dentin failures. In Group I, adhesive post-luting agent failure was observed at the post-dentin interface.

Discussion

This study investigated the pull-out bond strength of endodontically treated anterior teeth restored with monolithic zirconia endocrowns with different extension depths and post-and-core crowns. The results showed that monolithic zirconia endocrowns with a 5-mm extension depth had the maximum pull-out bond strength value. Therefore, the null hypothesis was rejected.

Before the pull-out bond strength tests, the restorations were subjected to thermal cycling and chewing simulation to realistically mimic clinical conditions [15]. Based on data for anterior tooth fatigue testing, a chewing force of 45° with respect to the vertical axis of the tooth was applied to the sample [16]. All restorations survived after the thermal cycling and chewing simulation. There was no root, post or core fracture, or crown

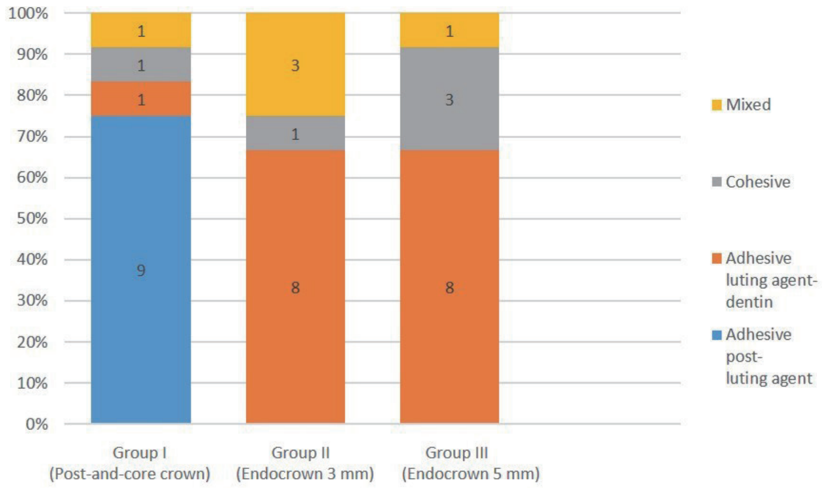

Fig. 4 Failure modes in the groups

loss, during the aging process, and all of the teeth were applicable to the pull-out bond strength test.

According to Soares et al. [17], laboratory studies should model chewing force absorption properties through bone and periodontal ligament to more effectively mimic clinical situations. However, most previous studies have not simulated the periodontal ligament [18,19]. Simulation of the periodontal ligament can compromise study results due to artifacts from real study materials and increase the risk of tooth dislocation during mechanical cycling. Also, sample roots can be dislodged by pull-out tests. For these reasons, the periodontal ligament was not simulated in this study.

Here, the teeth were set to have a 2-mm ferrule. The presence of a 1.5-2-mm ferrule has a positive effect on the fracture resistance of teeth that have previously been treated endodontically [20]. Also, Silva-Sousa et al. [21] reported that endocrowns with a ferrule can be an acceptable form of treatment for endodontically treated anterior teeth.

Intracanal post placement for the restoration of endodontically treated teeth is necessary to increase the retention and resistance properties of the core material in cases of severe coronal tooth loss [3], but posts with a high elastic modulus can cause irreparable fractures. Therefore, it is advisable to use a post with a low modulus of elasticity, such as glass fiber [22]. However, it has been stated in many studies that post-core systems increase the risk of root fracture when there is an insufficient ferrule effect on the tooth tissue [23,24]. Ramírez-Sebastià et al. [25] reported that anterior teeth can be restored without using a post. The advantage of not using a post for restoration is that more tooth tissue can be preserved, and it is easier to complete the clinical procedure. As has been reported previously [25,26], this study showed that endodontically treated teeth can be restored without the use of a post; this is advantageous for preserving more dental material and simplifying the clinical procedure.

Monolithic zirconia restorations have advantages over zirconia-based restorations, such as simpler and shorter CAD-CAM processing and absence of layering [27]. For this reason, problems such as veneering ceramic delamination/chipping and veneer ceramic-zirconia ceramic mismatches that characterize zirconia-based restorations are not seen in monolithic zirconia restorations [28]. In this study, crowns and endocrowns were produced from monolithic zirconia with CAD-CAM technology.

One of the most common mechanical surface treatments is air abrasion, which cleans and activates the zirconia surface before cementation and increases the adhesion surface [29]. The zirconia surface oxides and resin luting agent are chemically bonded to the bifunctional phosphate monomer 10-MDP. It has been reported that this provides better long-term results [30]. In the present study, the inner surface of each monolithic zirconia restoration was roughened with Al_2O_3, and then cementation was performed using a resin luting agent (Multilink N) with the universal primer Monobond Plus.

Endocrowns and short-post crowns have been reported to be mechanically superior to long-post conventional crowns [6,25]. In this study, while there was no statistically significant difference in pull-out bond strength between endocrowns with a 3-mm extension depth and post-and-core crown restorations, endocrown restorations with a 5-mm extension depth had the highest pull-out bond strength values. This difference is thought to be due to the greater adhesion surface area of endocrowns with a 5-mm extension depth.

The results of this study showed that most failure modes were adhesive luting agent-dentin (47.22%). However, the adhesive failure of the post-and-core crowns involved separation of the post from the root with the crown. In other words, the bond strength at the glass-fiber post-dentin interface was lower than the core-crown bond strength, perhaps due to the different luting agent and post cementation procedures. The ratio of the free and restrained composite surface area of a dental restoration is known as the C-Factor [31]. The cementation of endodontic posts to root canal dentin has a C-factor greater than 200 [32], whereas it generally ranges from 1 to 5 in intracoronal restorations [31]. Therefore, the greater adhesion surface area of endocrowns with a 5-mm extension depth may exceed the crown-luting agent-dentine bond strength, causing more cohesive failure than endocrowns with a 3-mm extension depth. However, one limitation of this study was the classification of the various types of failure. Therefore, examination with a scanning electron microscope, which reveals residues that cannot be detected by light microscopy, can increase the precision of the results.

Within the limitations of this study, it has been shown that increasing the endocrown extension depth influences the pull-out bond strength of endodontically treated anterior teeth restored with monolithic zirconia endocrowns. While previous studies have compared endocrowns and posts for resistance to fracture [6,25,26], no study to date has examined the pull-out bond strength of endocrowns and posts in anterior teeth. Clinical research on endocrown reconstruction of anterior teeth is still limited. More research will be required to confirm the validity of using endocrown restorations for anterior teeth.

Conflict of interest

The authors have no conflicts of interest to declare.

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