J-STAGE Advance Publication: August 19, 2022
Journal of Oral Science

Original article

Effect of surface treatment, ferrule height, and luting agent type on pull-out bond strength of monolithic zirconia endocrowns

Emine B. Buyukerkmen[1)], Durmuş A. Bozkurt[2)], and Arslan Terlemez[2)]

[1)] Department of Prosthodontics, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey
[2)] Department of Endodontics, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey

(Received April 7, 2022; Accepted July 12, 2022)

Abstract

Purpose: To evaluate the effect of different surface treatments, ferrule heights, and luting agents on the pull-out bond strength (PBS) of computer-aided design/computer-aided manufacturing (CAD-CAM) monolithic endocrowns.

Methods: After endodontic treatment and preparation for two endocrown designs (ferrule height 0 mm or 2 mm), CAD-CAM monolithic zirconia endocrowns were fabricated for 80 mandibular molars. Each endocrown design group was then divided on the basis of surface treatment into two groups: half were air-abraded and half were air-abraded/laser-irradiated. Then, all treated groups were further divided into two subgroups (n = 10) and cemented to teeth with either a 10-methacryloyloxydecyl dihydrogen phosphate (MDP)–containing resin luting agent (Panavia SA) or a combination of MDP-containing primer and MDP-free resin luting agent (Monobond Plus/Multilink Automix). PBS was measured with a universal test machine after simulated chewing and thermocycling. Three-way ANOVA and the *post-hoc* Bonferroni test were used for statistical analysis.

Results: PBS was significantly associated with type of surface treatment, type of luting agent, and ferrule height. Air-abraded/laser-irradiated endocrowns with a 2-mm ferrule that were cemented with Monobond Plus/Multilink Automix had the highest PBS ($P < 0.05$).

Conclusion: Surface treatment with air abrasion/laser irradiation, presence of a ferrule, and priming with an MDP-containing primer increased the PBS of monolithic zirconia endocrowns.

Keywords: CAD-CAM, chewing simulation, endocrown, ferrule, monolithic zirconia

Introduction

The success of endodontic restorations depends on the quality and type of coronal restoration [1,2]. Postoperative fracture risk can be reduced by proper restorative design and materials, both of which increase longevity [3,4]. Because of developments in adhesive dentistry, teeth with extensive coronal damage can be reconstructed without intraradicular posts by using inlays, onlays, and endocrowns that fit along the entire extension of the pulp chamber [5,6]. Macromechanical retention for endocrowns is attained by fixing the restoration to the cavity borders and the interior of the pulp chamber, while micromechanical retention is achieved by using adhesive cementation [7,8].

Endocrowns have been used to restore endodontically treated premolars and molars with severe structural damage [9,10]. Clinical performance was better for molar endocrowns than for premolar endocrowns, perhaps because the bonding surface is larger for molars. Furthermore, molars have a lower restoration height, which improves the mechanical properties of the endocrown [7,9-11]. The presence of a ferrule is important for restoration rehabilitation. A properly designed ferule decreases stress during chewing. Several studies recommend a ferrule with a height of 1.5 to 2 mm for optimum retention and resistance [12,13].

Monolithic endocrowns are produced by using various systems, including computer-aided design and computer-aided manufacturing (CAD-CAM) technology [8,14,15]. Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramics have satisfactory biocompatibility and aesthetics, high fracture resistance, and flexural strength [16]. However, because zirconia does not contain amorphous silica and has an acid-resistant polycrystalline structure, traditional porcelain surface applications such as etching with hydrofluoric acid or silane primer are not ideal for reinforcing the bond between the tooth and zirconia restoration [17]. Various methods, such as air abrasion, laser irradiation, and nanograde aluminum coatings, are used to create surface impurities that enhance the micromechanical bond between zirconia and resin-based luting agent [18]. Air abrasion with Al_2O_3 particles is the most common surface treatment method [18,19]; however, lasers can also be used to create surface impurities [20]. A properly configured Er:YAG laser successfully created surface impurities on the surface of zirconia [21]. Because the micromechanical bond between zirconia and resin-based luting agent is not sufficient after only surface modifications, clinicians create a chemical bond by using various primers combined with resin-based luting agent to reinforce the bond [22]. Optimal cementation of zirconia restorations requires the use of new single-step self-adhesive resin-based luting agents and new universal adhesives that contain 10-methacryloyloxydecyl dihydrogen phosphate (MDP) [22,23].

Few studies have evaluated the pull-out bond strength (PBS) of monolithic zirconia endocrowns. The aim of this study was to assess the effect of different surface treatments and luting agents on the PBS of endocrowns with different ferrule heights. The null hypothesis was that the PBS of CAD-CAM monolithic zirconia endocrowns would not be affected by type of surface treatment, ferrule height, or type of luting agent.

Materials and Methods

This study received ethics approval from the Ethics Committee of Necmettin Erbakan University Faculty of Dentistry (Decision No: 2021/02-21).

Eighty previously extracted mandibular molars of approximately equal size were studied. Soft-tissue residue and debris on the root surface were removed with periodontal curettes, and the teeth were stored in a 0.9% saline solution. All teeth were endodontically treated, as previously described [11], and divided into two main groups. The first group was decoronated from the cementoenamel junction of the tooth by creating a horizontally parallel plane with a low-speed, water-cooled precision saw (Buehler, Germany). In the second group, to ensure a standard 2-mm ferrule height, teeth were cut off with a precision saw at 2 mm from the cementoenamel junction with the aid of a parallelometer (F4 basic, Dentsply, Hanau, Germany). A water-cooled turbine (Perfecta 900, W&H, Laufen, Germany) with fissure diamond burs (Gebr. Brasseler, Lemgo, Germany, Lot. No. 975066) that were marked at a 2-mm distance from the tip were used to prepare the circular surface of the tooth, to confirm a uniform preparation angle of 10° with a 1.0-mm cervical finish line. To simulate human periodontium, the root surfaces of the teeth were covered with a 0.1-mm–thick layer of silicone (Anti-Ruts; Wenko, Wenselaar, Germany), 2 mm below the cementoenamel junction. They were then placed into self-curing acrylic resin (Integra; United Group Dental, Ankara, Turkey), with the long axis of the tooth perpendicular to the horizontal axis (Fig. 1), and

Correspondence to Dr. Emine Begum Buyukerkmen, Department of Prosthodontics, Faculty of Dentistry, Necmettin Erbakan University, Beysehir Cad. Baglarbası Sok., Meram, Konya 42090, Turkey
Fax: +90-332-220-00-45 E-mail: bbuyukerkmen@erbakan.edu.tr

Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.22-0147
DN/JST.JSTAGE/josnusd/22-0147

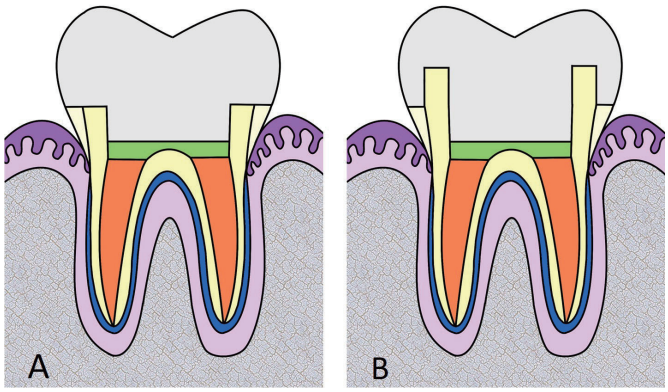

Fig. 1 Illustrations of endocrowns. A. ferrule 0 mm; B. ferrule 2 mm

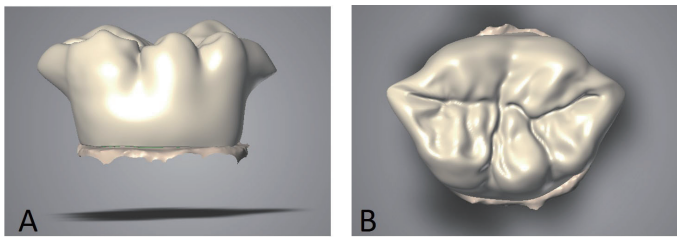

Fig. 2 Wing modifications of endocrowns. A. buccal view; B. occlusal view

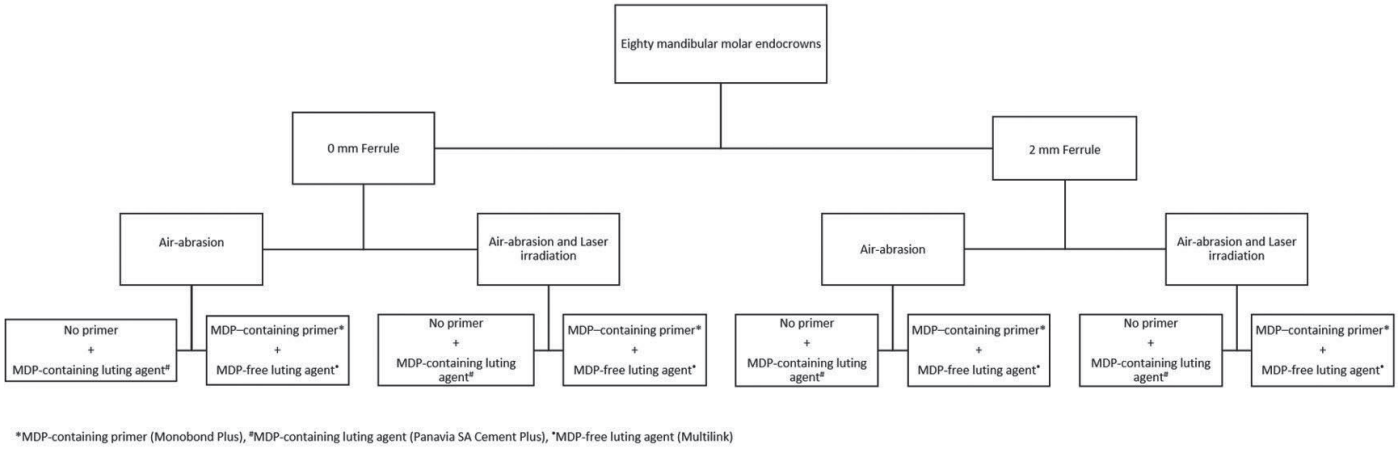

Fig. 3 Diagram summarizing the groups, subgroups, and variables studied

prepared by the same researcher. After preparation to obtain a 2-mm–deep pulp chamber parallel to the occlusal plane of the endocrown, self-etch adhesive (Clearfil SE; Kuraray America, Houston, TX, USA) and composite were applied to the pulp chamber. The prepared teeth were scanned and digitized with a model scanning device (Dental Wings Inc., Montreal, Canada), and the endocrown prostheses were designed on these scanned models by using Dental Wings Open System (DWOS; Dental Wings Inc.) software. Wing modifications (2 mm) were made to the digitally produced restorations to create retentive areas in the tensile test at the mesial and distal contact points (Fig. 2).

A five-axis CAM device (Yenamak D50, Yenadent Ltd., Istanbul, Turkey) and zirconia burs with diameters of 1 mm and 2 mm were used to create the endocrowns from monolithic zirconia blocks (diameter, 98.4 mm; height, 18 mm; Vita YZ T, Vita Zahnfabrik, Bad Säckingen, Germany). The monolithic zirconia endocrowns were placed in a sintering device in accordance with the manufacturer's instructions and sintered for 4.5 h at 1,450°C. After that, all endocrowns were divided into two groups according to the surface treatment to be applied.

Air abrasion: The inner surfaces of endocrowns were abraded with 50-µm Al_2O_3 particles from a distance of 10 mm and a pressure 0.3 MPa for 15 s.

Air abrasion/laser irradiation: After air abrasion, endocrowns were irradiated with an Er:YAG laser at 2.94 µm. The laser parameters were a power output of 4W, pulse penetration rate of 10 Hz, energy of 400 mJ, and pulse duration of 100 µs. A non-contact probe was placed perpendicular to the surface from 10 mm, and the surfaces were irradiated, along with water irrigation, for 15 s.

After surface treatment, all endocrowns were cleaned in an ultrasonic cleaner and dried with air. Then, all samples were divided into two subgroups according to resin-based luting agent, namely, group M—an MDP-free resin-based luting agent (Multilink, Ivoclar Vivadent AG, Schaan, Liechtenstein) combined with an MDP-containing universal primer (Monobond Plus, Ivoclar Vivadent AG), and group P—an MDP-containing resin-based luting agent (Panavia SA Cement Plus, Kuraray-Noritake, Kurashiki, Japan). The endocrowns were cemented in accordance with the manufacturers' instructions. After light-curing for 10 s, all excess luting agent was removed, and final polymerization of the luting agent was completed with another 20 s of light-curing to each surface of the sample. Figure 3 shows the groups, subgroups, and variables studied.

All samples were subjected to artificial aging in a chewing simulator (6,000 cycles × 50 N load; frequency, 2.1 Hz) with thermocycle properties (5°C to 55°C) that mimicked the oral environment. To avoid contaminating the interfacial surface with epoxy resin, a wax layer was placed slightly into the coronal region, 1 mm apical to the horizontal margin. After covering the coronal restoration with epoxy resin, PBS was evaluated.

PBS values were measured with a servo-hydraulic universal testing machine (Besmak Ltd., Ankara, Turkey). Epoxy resin samples were stabilized and tested at a speed of 1 mm/min using two clamps, until the restorative materials were removed. Pull-out loading values, in Newtons (N), were recorded in a Microsoft Excel sheet.

Failure mode was evaluated with a stereomicroscope (SZTP; Olympus Optical Co., Ltd., Tokyo, Japan) at 10× magnification and classified as adhesive failure 1 (luting agent adhering only to the zirconia restoration), adhesive failure 2 (luting agent adhering to the tooth and zirconia restoration), and cohesive failure (presence of fracture line through the tooth crown).

Statistical analysis

A power analysis calculation performed with the G Power program (G * Power 3.1 software; Heinrich Heine University, Düsseldorf, Germany) indicated that 80 samples were required in order to obtain a power of 91%. Statistical analysis was performed by using SPSS Statistics version 22.0 software (IBM Corp., Armonk, NY, USA). Normality of the data distribu-

Table 1 Results of three-way analysis of variance (ANOVA)

	df	Mean square	*F*	Sig.	Partial eta squared
Luting agent	1	315308.78	9.337	0.003	0.115
Surface treatment	1	1165768.89	34.522	0.001	0.324
Design	1	1738164.38	51.472	0.001	0.417
Luting agent × surface treatment	1	503828.07	14.920	0.001	0.172
Luting agent × design	1	192935.51	5.713	0.019	0.074
Surface treatment × design	1	424054.18	12.557	0.001	0.149
Luting agent × surface treatment × design	1	142945.30	4.233	0.043	0.056

Luting agents: Panavia SA Cement Plus, Monobond Plus & Multilink. Surface treatments: air abrasion, air abrasion/laser irradiation. Designs: Ferrule-0, Ferrule-2

tion was analyzed with the Shapiro-Wilk test ($P > 0.05$). The Levene test indicated homogeneity among variances ($P > 0.05$).

The data were distributed normally, and parametric three-way analysis of variance (ANOVA) and the Bonferroni test were used for *post-hoc* analysis. A *P* value of less than 0.05 was considered to indicate statistical significance (95% confidence level).

Results

The results of three-way ANOVA are shown in Table 1. The PBS values of the tested groups were significantly associated with type of surface treatment, ferrule height, and type of luting agent ($P < 0.05$). Three-way ANOVA also revealed a significant interaction among these three factors ($P < 0.05$).

The mean (SD) values obtained from the PBS test are shown in Table 2. Regardless of surface treatment (air abrasion vs air abrasion/laser irradiation) or design (ferrule 0 vs ferrule 2), PBS values were higher for Multilink samples than for Panavia samples ($P < 0.05$). In addition, PBS values were higher for the ferrule 2 design than for the ferrule 0 design ($P < 0.05$). When samples were compared in relation to surface treatment, PBS values were higher for air-abraded/laser-irradiated samples than for air-abraded samples ($P < 0.05$), although there was no significant difference in relation to surface treatment in the ferrule 2 Multilink groups ($P > 0.05$).

Distribution of failure modes after PBS testing of monolithic zirconia endocrowns is shown in Table 3. After air abrasion, the 0-mm ferrule samples cemented with Panavia exhibited only adhesive failure 2, perhaps because these samples lacked a ferrule and did not undergo primer application. After both surface treatments, cohesive failure was observed only in 2-mm ferrule samples cemented with Multilink. Cohesive failure occurred only after primer application and in the presence of a ferrule; the failure patterns for the other samples were adhesive failure 1 and adhesive failure 2.

Table 2 Mean ± SD pull-out bond strength values (Newtons)

		Panavia mean ± SD	Multilink mean ± SD
Air abrasion	ferrule 0	$499.2 \pm 100.3^{A1*}$	$769.8 \pm 64.1^{B1*}$
	ferrule 2	$925.9 \pm 260.2^{A1*}$	$1223.9 \pm 339.8^{B1*}$
Air abrasion/laser irradiation	ferrule 0	$913.6 \pm 118.8^{A2*}$	$1129.53 \pm 164.5^{B2*}$
	ferrule 2	$1095.9 \pm 138.8^{A1*}$	$1245.5 \pm 110.3^{B1*}$

The presence of different superscript uppercase letters in a row indicates a significant difference between luting agents for specimens with the same design and surface treatment. The presence of different superscript numerals in a column indicates a significant difference between surface treatments for specimens with the same luting agent and design. *indicates a significant difference between designs for specimens with the same surface treatment and luting agent.

Table 3 Distribution of failure modes after pull-out bond strength testing of monolithic zirconia endocrowns

Surface treatment	Ferrule	Luting agent	Adhesive failure 1	Adhesive failure 2	Cohesive	Total
Air abrasion	0 mm	P	-	10	-	10
		M	6	4	-	10
	2 mm	P	5	5	-	10
		M	6	2	2	10
Air abrasion/ laser irradiation	0 mm	P	5	5	-	10
		M	6	4	-	10
	2 mm	P	5	5	-	10
		M	5	2	3	10
Total			28	47	5	80

P cemented with Panavia SA Cement Plus; M cemented with Monobond Plus and Multilink. Adhesive failure 1: luting agent adheres only to zirconia restoration; adhesive failure 2: luting agent adheres to tooth and zirconia restoration; and cohesive failure: fracture line through the tooth crown.

Discussion

Pull-out tests have been used to assess the effect of luting agents on the retentive force of zirconia restorations [24]. This study investigated the effect of type of surface treatment (air abrasion and air abrasion/laser irradiation), ferrule height, and type of luting agent on the PBS of monolithic zirconia endocrowns. The null hypothesis of this study was rejected because PBS was significantly higher for air-abraded/laser-irradiated specimens with a 2-mm ferrule that were cemented with an MDP-containing primer/resin-based luting agent.

Endocrowns offer advantages over post-cores and restorations: preparation and application of endocrowns are simple and require less clinical time. Lin et al. [24] concluded that longevity was similar for endocrowns and conventional prosthodontic restorations. Previous studies reported that endocrowns were an effective treatment option for restoring endodontically treated teeth with insufficient ferrule height [5,7]. Some *in vitro* studies of failure resistance of endocrown preparations with ferrule height found that preparations with ferrules increased the dentin surface available for bonding [25,26]. Endocrowns are suggested for use with molar teeth, because of the increased longevity and strength, minimally invasive preparation of tooth structures, and absence of damage to roots [13]. Thus, the present endodontically treated molars were restored with endocrowns.

Both mechanical and chemical retention are required in order to create a durable bond between resin-based luting agent and ceramic. Surface treatments such as air abrasion, laser irradiation, coating with tribochemical silica, and application of hydrofluoric acid were reported to increase bond strength between zirconia and resin-based luting agent [20]. In addition, researchers have tried to modify the surface properties of zirconia by using methods such as air abrasion [27]. These methods increase surface area and energy and further strengthen the bond and micromechanical retention between resin-based luting agent and zirconia [28]. A previous study recommended using low pressure and particles no larger than 50 μm during air abrasion, to avoid surface damage to zirconia [29].

Laser energy functions by converting light energy into heat and is an alternative to conventional surface treatments. Cavalcanti et al. [21] reported that use of an Er:YAG laser at energy settings of 400 mJ and 600 mJ was effective for modifying the morphological properties of zirconia [21]. Demir et al. [30] and Arami et al. [31] reported that both an Er:YAG laser (400 mJ) and airborne-particle abrasion increased surface roughness of zirconia. In the present study, PBS values were higher in the air-abraded/laser-irradiated groups than in the air-abraded groups.

Various luting agents, such as self-adhesive resin, glass ionomer, and traditional resin-based luting agents, are used for cementation of zirconia restorations. However, resin-based luting agents are preferred because of their greater retention and better interfacial filling in cementation of zirconia restorations [32,33]. The substantial bond between zirconium oxide ceramic and resin-based luting agent is the primary reason for the clinical success and longevity of these restorations [34]. Because zirconia ceramic contains metal oxides, use of primers containing functional monomer adhesive systems such as 10-MDP and other phosphate monomer adhesive systems is recommended for reinforcing the bond between resin-based luting agent and zirconia [35]. 10-MDP increases surfaces wettability, forms cross-link bonds between the methacrylate group of the resin-based luting agent, and forms siloxane bonds with the hydroxyl group of the ceramic surface [36].

Primer or resin containing MDP applied to the surface of air-abraded zirconia provides an excellent and reinforced bond interface. Use of self-

adhesive luting agents containing MDP offers a simple bonding procedure that does not require surface pretreatment of the tooth [37]. The present results show that PBS was greater for endocrowns cemented with a combination of an MDP-free resin-based luting agent and MDP-containing primer than for endocrowns cemented with an MDP-containing resin-based luting agent. Air abrasion and laser irradiation form impurities on the surface of zirconia and alter surface energy, surface wettability, and surface area, thus providing an excellent micromechanical locking interface between the ceramic and resin-based luting agent. MDP-containing primers increase surface wettability and greatly enhance the physicochemical interaction between zirconia and resin, through formation of P-O-Zr chemical bonds [38]. Because the viscosity of resin-based luting agents does not allow them to fully penetrate every micropore of the roughened surface, use of a universal primer in addition to surface treatment methods is highly effective in forming chemical bonds between resin-based luting agent and zirconia.

The present samples were subjected to *in vitro* procedures such as dynamic loading and thermocycling to simulate the effect of aging in the oral environment. *In vitro* thermal cycling and mechanical loading are used as a short-term solution for predicting mechanical performance and resistance to hydrolytic effects [39]. Therefore, simulated aging is an important method of predicting bonding forces in the intraoral environment. As was the case in previous studies, all teeth used in the present study were subjected to artificial aging in a masticatory simulator (6,000 cycles × 50 N load; frequency, 2.1 Hz) with thermocycling capabilities (5°C to 55°C) [40].

Adhesive and mixed failures were frequently observed in the monolithic zirconia–resin-based luting agent interface, which suggests that cohesive resistance of the resin-based luting agent is greater than its bond strength.

The present study had limitations. First, endocrown preparation was compromised by differences in tooth size and shape. Second, although this *in vitro* study was designed to simulate clinical conditions, *in vitro* studies should be supported by data from clinical studies of endocrowns.

In conclusion, the present study exhibited that PBS was significantly associated with type of surface treatment, presence of a ferrule, and type of luting agent. Combined surface treatment with air abrasion and laser irradiation improved PBS. The presence of a ferrule enhanced PBS of monolithic endocrowns. In addition, the results indicate that priming with an MDP-containing primer increases bond strength. In samples with a 2-mm ferrule, PBS was highest in air-abraded/laser-irradiated samples cemented with resin-based luting agent after an MDP-containing primer. Combined use of mechanical and chemical surface treatments therefore appears to be effective for bonding monolithic zirconia endocrowns to molars.

Conflict of interest

None declared.

References

1. Stavropoulou AF, Koidis PT (2007) A systematic review of single crowns on endodontically treated teeth. J Dent 35, 761-767.
2. Suksaphar W, Banomyong D, Jirathanyanatt T, Ngoenwiwatkul Y (2017) Survival rates against fracture of endodontically treated posterior teeth restored with full-coverage crowns or resin composite restorations: a systematic review. Restor Dent Endod 42, 157-167.
3. Lin CL, Chang YH, Liu PR (2008) Multi-factorial analysis of a cusp-replacing adhesive premolar restoration: a finite element study. J Dent 36,194-203.
4. Chang YH, Lin WH, Kuo WC, Chang CY, Lin CL (2009) Mechanical interactions of cuspal-coverage designs and cement thickness in a cusp-replacing ceramic premolar restoration: a finite element study. Med Biol Eng Comput 47, 367-374.
5. Pissis P (1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Pract Periodontics Aesthet Dent 7, 83-94.
6. Zarow M, Devoto W, Saracinelli MJ (2009) Reconstruction of endodontically treated posterior teeth--with or without post? Guidelines for the dental practitioner. Eur J Esthet Dent 4, 312-327.
7. Biacchi GR, Basting RT (2012) Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 37, 130-136.
8. Rocca GT, Rizcalla N, Krejci I (2013) Fiber-reinforced resin coating for endocrown preparations: a technical report. Oper Dent 38, 242-248.
9. Bindl A, Richter B, Mörmann WH (2005) Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 18, 219-224.
10. Dejak B, Młotkowski A (2013) 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater 29, e309-317.
11. Dartora NR, de Conto Ferreira MB, Moris ICM, Brazão EH, Spazin AO, Sousa-Neto MD et al. (2018) Effect of intracoronal depth of teeth restored with endocrowns on fracture resistance: in vitro and 3-dimensional finite element analysis. J Endod 44, 1179-1185.
12. Pereira JR, de Ornelas F, Conti PC, do Valle AL (2006) Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 95, 50-54.
13. Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M (2012) Ferrule effect: a literature review. J Endod 38, 11-19.
14. Ruse ND, Sadoun MJ (2014) Resin-composite blocks for dental CAD/CAM applications. J Dent Res 93, 1232-1234.
15. Choi S, Yoon HI, Park EJ (2017) Load-bearing capacity of various CAD/CAM monolithic molar crowns under recommended occlusal thickness and reduced occlusal thickness conditions. J Adv Prosthodont 9, 423-431.
16. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T (2013) Current status of zirconia restoration. J Prosthodont Res 57, 236-261.
17. Valandro LF, Ozcan M, Amaral R, Leite FP, Bottino MA (2007) Microtensile bond strength of a resin cement to silica-coated and silanized In-Ceram Zirconia before and after aging. Int J Prosthodont 20, 70-72.
18. Zandparsa R, Talua NA, Finkelman MD, Schaus SE (2013) An in vitro comparison of shear bond strength of zirconia to enamel using different surface treatments. J Prosthodont 23, 117-123.
19. Tanış MÇ, Akay C, Karakış D (2015) Resin cementation of zirconia ceramics with different bonding agents. Biotechnol Biotechnol Equip 29, 363-367.
20. Gomes AL, Ramos JC, Santos-del Riego S, Montero J, Albaladejo A (2015) Thermocycling effect on microshear bond strength to zirconia ceramic using Er:YAG and tribochemical silica coating as surface conditioning. Lasers Med Sci 30, 787-795.
21. Cavalcanti AN, Pilecki P, Foxton RM, Watson TF, Oliveira MT, Gianinni M et al. (2009) Evaluation of the surface roughness and morphologic features of Y-TZP ceramics after different surface treatments. Photomed Laser Surg 27, 473-479.
22. Shin YJ, Shin Y, Yi YA, Kim J, Lee IB, Cho BH et al. (2014) Evaluation of the shear bond strength of resin cement to Y-TZP ceramic after different surface treatments. Scanning 36, 479-486.
23. Thompson JY, Stoner BR, Piascik JR, Smith R (2011) Adhesion/cementation to zirconia and other non-silicate ceramics: where are we now? Dent Mater 27, 71-82.
24. Lin CL, Chang YH, Pa CA (2009) Estimation of the risk of failure for an endodontically treated maxillary premolar with MODP preparation and CAD/CAM ceramic restorations. J Endod 35, 1391-1395.
25. Ernst CP, Aksoy E, Stender E, Willershausen B (2009) Influence of different luting concepts on long term retentive strength of zirconia crowns. Am J Dent 22, 122-128.
26. Shin Y, Park S, Park JW, Kim KM, Park YB, Roh BD (2017) Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: an in vitro study. J Prosthet Dent 117, 109-115.
27. Re D, Augusti D, Merlati G, Gianni AB (2015) Effect of thermal cycling and low pressure sandblasting on the bond strength of a self-adhesive cement to Y-TZP zirconia. J Adhes Sci Technol 29, 1745-1757.
28. Blatz MB, Phark JH, Ozer F, Mante FK, Saleh N, Bergler M et al. (2010) In vitro comparative bond strength of contemporary self-adhesive resin cements to zirconium oxide ceramic with and without air-particle abrasion. Clin Oral Investig 14, 187-192.
29. Magne P, Paranhos MP, Burnett LH Jr (2010) New zirconia primer improves bond strength of resin-based cements. Dent Mater 26, 345-352.
30. Demir N, Subaşi MG, Ozturk AN (2012) Surface roughness and morphologic changes of zirconia following different surface treatments. Photomed Laser Surg 30, 339-345.
31. Arami S, Tabatabae MH, Namdar SF, Chiniforush N (2014) Effects of different lasers and particle abrasion on surface characteristics of zirconia ceramics. J Dent (Tehran) 11, 233-241.
32. Atsu SS, Kilicarslan MA, Kucukesmen HC, Aka PS (2006) Effect of zirconium-oxide ceramic surface treatments on the bond strength to adhesive resin. J Prosthet Dent 95, 430-436.
33. Campos F, Valandro LF, Feitosa SA, Kleverlaan CJ, Feilzer AJ, de Jager N et al. (2017) Adhesive cementation promotes higher fatigue resistance to zirconia crowns. Oper Dent 42, 215-224.
34. Blatz MB, Sadan A, Kern M (2003) Resin-ceramic bonding: a review of the literature. J Prosthet Dent 89, 268-274.
35. Wolfart M, Lehmann F, Wolfart S, Kern M (2007) Durability of the resin bond strength to zirconia ceramic after using different surface conditioning methods. Dent Mater 23, 45-50.
36. Zhang S, Kocjan A, Lehmann F, Kosmac T, Kern M (2010) Influence of contamination on resin bond strength to nano-structured alumina-coated zirconia ceramic. Eur J Oral Sci 118, 396-403.
37. Inokoshi M, De Munck J, Minakuchi S, Van Meerbeek B (2014) Meta-analysis of bonding effectiveness to zirconia ceramics. J Dent Res 93, 329-334.
38. Papia E, Larsson C, du Toit M, Vult von Steyern P (2014) Bonding between oxide ceramics and adhesive cement systems: a systematic review. J Biomed Mater Res B Appl Biomater 102, 395-413.
39. Tzanakakis EG, Tzoutzas IG, Koidis PT (2016) Is there a potential for durable adhesion to zirconia restorations? A systematic review. J Prosthet Dent 115, 9-19.
40. Rosentritt M, Siavikis G, Behr M, Kolbeck C, Handel G (2008) Approach for valuating the significance of laboratory simulation. J Dent 36, 1048-1053.