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Original Article

Effects of different surface treatments on the compression-shear strength of CAD-CAM zirconia posts

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Abstract

Aim: Post systems are crucial for the treatment of endodontically treated teeth with excessive crown destruction. Currently, increase in esthetic demands has increased the use of tooth-colored post systems. The aim of this study was to evaluate compression-shear strength after the application of different resin cements and different surface treatments to zirconia post-cores produced by the CAD-CAM milling technique.

Methodology: One hundred twenty crown parts of maxillary central incisors were cut using a 2-mm enamel-cement joint using a water-cooled diamond bur in an air turbine handpiece at 300,000 rpm. Root canals with the same diameter were prepared using Gates-Glidden drills and Snowpost system drills. According to the enlarged canal, zirconia posts were prepared by the CAD-CAM copy-milling technique, and the zirconia post surfaces were roughened by different techniques (hydrofluoric acid, Al_2O_3 partial abrasion, CoJet silica coating). The roughened posts were cemented to the tooth canal using three resin cements: 10-Methacryloyloxydecyl dihydrogen phosphate (MDP)-containing cement, Bis-GMA-based resin, and resin-based adhesive. As the control group, the zirconia post surfaces with no application were fixed using three resin cements. The specimens were set down into 25×25x25 mm fabricated blocks with acrylic resin materials. Compression-shear strength tests of the prepared samples were conducted on the Instron Testing Machine by using appropriate equipment.

Results: In summary, the combination of roughening techniques such as Al_2O_3 partial etching and CoJet silica coating using cement-containing MDP rendered the highest compression-shear strength.

Conclusion: This in vitro study proposes the cementation of zirconia post-cores etched by Cojet silica coating and Al_2O_3 particles using MDP-containing resin cement.

Keywords: Post-core, CAD-CAM, zirconia, resin cement

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Introduction

Enlargement of the access cavity and root canal in endodontically treated teeth causes excessive loss of material from the tooth tissue and weakens the tooth structure. Hence, it is imperative to select an appropriate post-core system for supporting structurally weakened teeth, preserving the integrity of the remaining dental tissue, and providing retention to the planned prosthetic restoration. The applied post-core system is mainly used to replace the missing structure of the dental crown by taking support from the root for desired resistance, durability, support, and retention in the restoration (1, 2).

Several restorative materials are used for the construction of post-core restorations. Metal posts have been used for a number of years. Metal posts that corrode in the oral environment cause discoloration of the periodontal tissues over time and cause esthetic problems. Another disadvantage is the difference in the elastic modulus between the metal posts and dentin tissue, leading to the uneven force distribution on the dentin surface and creating stress areas. (1, 3, 4-6) These disadvantages have led to the development of non-metallic hides over time.

Fiber posts, ceramic posts, and zirconia-reinforced ceramic posts have been developed to eliminate esthetic problems. Currently, zirconia is preferred over metal posts due to its white color and high strength. Zirconia post systems produced by computer aided design/computer aided manufacturing (CAD/CAM) milling technique are currently used (7-10).

The physical properties of zirconium-based ceramic posts are similar to those of steel, which are radiopaque and biocompatible. The fracture toughness and bending resistance of zirconium-based ceramic posts are greater than those of other ceramic posts. However, compared to metal posts, zirconia-based ceramic posts exhibit lower fracture resistance, and they exhibit weak bonding to the dentin and core material. In addition, it is difficult to remove the part remaining inside the root when it is broken (4, 11).

The shape of the post, the connection between the dentin and post, physical properties of the post and bond material, adhesive agent, and restorative material affect the success of the treatment. Various surface treatments have been applied to strengthen the bonding of zirconium posts to dentin and the adhesive resin. Mechanical, chemical, and mechanical-chemical surface treatments have been applied to the post surface. Mechanical surface treatments including acid etching, sandblasting (using aluminum oxide particles and synthetic diamond particles), laser etching, roughening with a diamond rotary tool and bur, and roughening with plasma spray. Chemical surface treatments include silane binding agent and primer application. Mechanical-chemical surface treatments include sandblasting with silicon oxide (SiO_2), pyrochemical silica coating, and tribochemical silica coating using CoJet or Rocatec) (12-21).

In this study, after the application of different resin cements and different surface treatments to zirconia post-cores produced by the CAD-CAM milling technique, compression-shear strength was evaluated.

Materials and Methods

Preparation of Dental Samples

In this study, freshly extracted teeth without cracks, fractures, and caries were used for orthodontic and periodontal purposes. Teeth with different sizes and root dilation were excluded from this study. In our study, 120 single-rooted permanent teeth (upper central and canine) with similar crown length and crown width were used for compression-shear force tests. Anatomical root length, anatomical tooth length, and anatomical root width of teeth were measured using a micrometer (Beerendonk 042-750 Dentaurum, Ispringen, Germany). Residues on the extracted teeth were cleaned using ultrasonic instruments (Mini Piezon, EMS Piezon Systems, Nyon, Switzerland). After the teeth were cleaned, they were stored in 10% formol solution in closed containers. All teeth were cut using a 2-mm enamel-cement joint using a water-cooled diamond bur (R837.014; Diatech, Geneva, Switzerland) in an air turbine handpiece (Midvest 8000, Dentsply, York, PA, USA) at 300,000 rpm. Teeth were cut from the coronal perpendicular to the long axis of the tooth. Root lengths were measured from the cut surface to the apex, and care was taken to ensure that the lengths were similar.

Preparation of Root Canals:

Root canals were prepared using Gates-Glidden (Diatech, Coltene/Whaledent, Altstätten, Switzerland) burs and a micromotor (NSK, Tochigi, Japan) at a medium speed under cooling water to form a 10-mm-long post. After the canals were shaped, a Snowpost (Abrasive tech, OH, USA) post system was used to obtain posts of the same thickness and length to ensure standardization. The thickness of the canal shaping drills of the Snowpost post system varied (1.0, 1.2, 1.4, 1.6 mm) (Fig. 1).

Figure 1. 1.6 mm diameter blue belt Snowpost

Final shaping was conducted to a depth of 10 mm using a 1.6-mm-diameter blue belt post. At the end of the procedure, the channels were cleaned with 5% sodium hypochlorite for 1 min, washed with distilled water, and dried using an air freshener and paper cones (Dentsply Maillefer, Ballaigues, Switzerland).

Preparation of Zirconia Post Samples for the Compression-Shear Test

A SnowPost post blank with a diameter of 1.6 mm and a length of 10 mm was prepared. To conduct compression-shear tests, a 7-mm-high core structure was prepared using a light-cured composite resin (Zirkonzahn, Steger, Ahrntal, Italy) to form the core structure. The prepared post-core structure was scanned using a three-dimensional optical laser scanner (Dental Wings, Montréal, QC, Canada). After scanning, pre-sintered zirconia blocks (Zirkonzahn, Steger, Ahrntal, Italy) were placed on a computer-aided milling machine, and the blocks were milled according to the data in the scanner. After producing samples that were 25% greater than the analog size, the produced samples were sintered at 1500 °C for 16 h, and the zirconia post-cores were allowed to reach their original dimensions (Fig. 2). One hundred twenty zirconia post-core samples were obtained. For the compression-shear tests, the zirconia posts, which were produced with a core structure, were tested on each of the relevant teeth and checked. Before bonding the produced zirconia posts with composite resin cements, groups were formed, and surface applications were conducted.

Figure 2. Example of produced zirconia post-core

Operations on Post Surfaces

Prepared zirconia post samples were divided into 12 experimental groups (n=12). Groups 10, 11, and 12 were control groups and contained zirconia posts that had been cemented without any prior surface treatment.

Surface treatments performed on zirconia posts:

1. **Tribochemical application of silica-coated aluminum oxide (Al_2O_3) (Cojet):** After 30 µm diameter silica-coated Al_2O_3 particles (CoJet, 3M ESPE, Seefeld, Germany) were applied at 2.8 bar pressure for 20 seconds from a distance of 10 mm, the system's silane binding agent (ESPE Sil, 3M ESPE, Seefeld, Germany) was applied and dried for 5 minutes (Groups 1, 2, and 3).
2. **Aluminum oxide (Al_2O_3) application:** Sandblasting was applied with 125 µm Al_2O_3 particles from a distance of 10 mm for 40 seconds (Groups 4, 5, and 6).
3. **Hydrofluoric acid application:** 4% Hydrofluoric Acid (Porcelain Etchant, Bisco, Schaumburg, IL, USA) was applied for 5 minutes. It was washed under air-water spray for 2 minutes and air-dried for 15 seconds (Groups 7, 8, and 9).
4. Control groups without pretreatment (Groups 10, 11, and 12).

Cementing the post

For the cementation of posts, three different dual-cure adhesive resin cements were used according to the instructions for use:

• MDP-containing composite resin cement (Panavia F, Kuraray Dental, Osaka, Japan) (Groups 1, 4, 7, and 10).

• Self-adhesive composite resin cement (Clearfil SA Cement, Kuraray Dental, Osaka, Japan) (Groups 2, 5, 8, and 11).

• Bis-GMA-based composite resin cement (Rely X ARC, 3M Dental Products, St. Paul, MN, USA) (Groups 3, 6, 9, and 12). (Table 1) Before placing the post, a thin layer of cement was applied to the canal and excess cement was removed. The distribution of the groups and the procedures performed are shown in Table 1.

The tip of the light unit (Polofil Lux Halogen Light, VOCO, Cuxhaven, Germany) was positioned in direct contact with the coronal end of the post and polymerized for 40 seconds with light at an intensity of 800 Mw/cm2. The accuracy of the light unit's accuracy was ensured before each exposure by calibrating it with a digital radiometer attached to the light unit. All samples were embedded in 25 × 25 × 25 mm3 standard acrylic blocks (Orthocryl EQ, Dentaurum, Springen, Germany).

Compression-Shear Test

Prepared samples were fixed on the Instron Tester (Model 3345, Norwood, MA, USA) in the labio-lingual direction, at an angle of 135° to the long axis of the root at 1 mm/min. Force was applied at a crosshead speed (Fig. 3). The force values at the times the post was displaced, the post was broken, and the root fracture occurred were recorded. Figure 3 shows the mechanism for applying the compression-shear test.

Table 1. Groups prepared for the compression-shear test

Group No.	Group Name	Surface treatment	Cement
1	CP	Al_2O_3 + Silane Panavia F 2.0 coated with 30 μm silica	Panavia F 2.0
2	CC	Al_2O_3 + Silane Panavia F 2.0 coated with 30 μm silica	Clearfil SA
3	CR	Al_2O_3 + Silane Panavia F 2.0 coated with 30 μm silica	RelyX ARC
4	AlP	125 μ Al_2O_3 sand 40 sec	Panavia F 2.0
5	AlR	125 μ Al_2O_3 sand 40 sec	Clearfil SA
6	AlC	125 μ Al_2O_3 sand 40 sec	RelyX ARC
7	AP	Hydrofluoric Acid	Panavia F 2.0
8	AR	Hydrofluoric Acid	Clearfil SA
9	AC	Hydrofluoric Acid	RelyX ARC
10	KP	Control (not processed)	Panavia F 2.0
11	KC	Control (not processed)	Clearfil SA
12	KR	Control (not processed)	RelyX ARC

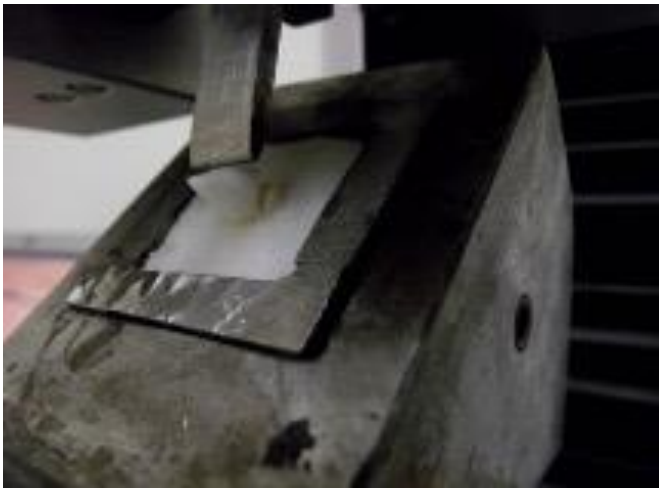

Figure 3. Application mechanism of the compression-tensile test on the instron test device

Statistical analysis

In our study, mean and standard deviation values were given as descriptive statistics, and all data were evaluated in a computer environment. An analysis of variance (ANOVA) test determined the differences between the groups, and Tukey HSD and Dunnett's t multiple comparison tests were used to establish whether the difference between groups was statistically significant. Bilateral p-values were considered statistically significant at $p<0.05$. Statistical analyses were performed using the SPSS 15.0 statistical package for Windows (SPSS, Inc., Chicago, IL, USA).

Results

Average compression-shear loads and their standard deviations for the 12 groups are listed in Table 2 and Figure 4. Among the groups, Group 4 had the highest (438.10 N) and Group 11 the lowest (363.86) median load.

Surface treatments (n=30)

Cojet surface treatment was applied to Groups 1, 2, and Group 3 (RelyX ARC) had the highest median load (427.80). The retention values of the Panavia F 2.0, Clearfil SA, and RelyX ARC groups (Groups 1, 2, and 3, respectively), whose pressure-shear median loads were determined, were not statistically significant ($p<0.05$).

Groups 4, 5, and 6 were surface-treated with Al_2O_3. Group 4 (Panavia F 2.0) had the highest median load (438.10 N). The groups' retention values were not statistically significant ($p<0.05$).

Groups 7, 8, and 9 were administered 4% HF acid. Group 8 (Clearfil SA) had the highest median load (413.98 N). The groups' retention values were not statistically significant ($p<0.05$).

Groups 10, 11, and 12 were the control groups without any surface treatment. Group 10 (Panavia F 2.0) had the highest median load (372.26 N). The retention values of the posts in the control group were not statistically significant ($p<0.05$).

Table 2. Compression-shear test mean values and standard deviation (N=Newton, kg=kilogram) of zirconia post-cores applied with different surface treatments and bonded with different cements.

Cement		Cojet		Al_2O_3		Acid		Control	
		X	Sd	X	Sd	X	Sd	X	Sd
Panavia F 2.0	N	416.26	+50.56	438.10	+52.53	412.35	+35.07	372.26	+66.05
	kg	42.44	+5.15	44.67	+5.36	42.04	+3.57	37.95	+6.73
Clearfil SA	N	405.46	+42.37	425.76	+73.82	413.98	+98.17	363.86	+48.40
	kg	41.34	+4.32	43.41	+7.52	42.21	+10.01	37.10	+4.93
RelyX ARC	N	427.80	+50.73	415.44	+67.36	411.40	+49.25	364.28	+44.91
	kg	43.62	+5.17	42.36	+6.86	41.95	+5.02	37.14	+4.57

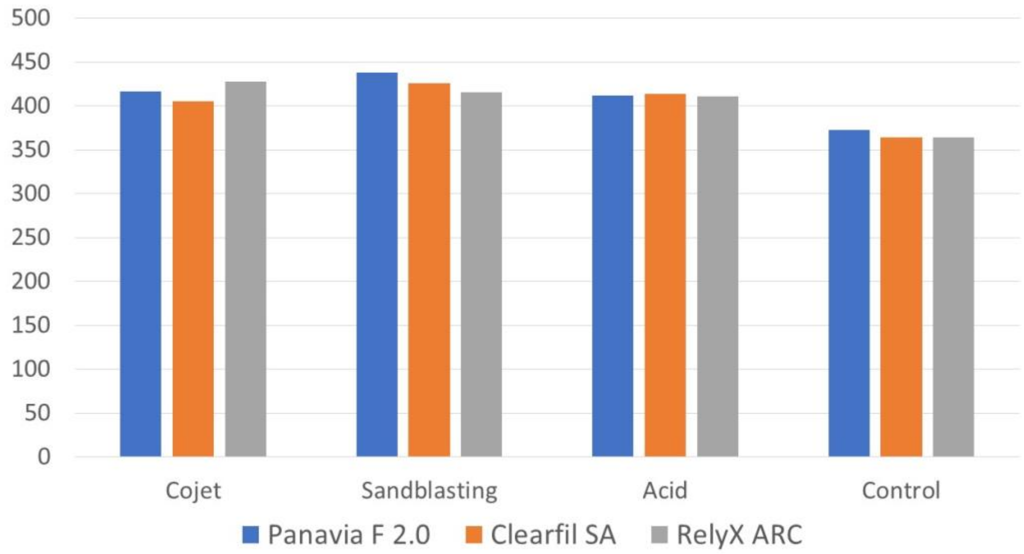

Figure 4. Press-shear test mean values of zirconia post-cores applied with different surface treatments and bonded with different cements (N=Newton, kg=kilogram).

Cementation agents (n=40)

Panavia F 2.0 cement was used in groups 1, 4, 7, and 10. Group 4 (Al_2O_3) had the highest median load (438.10 N). The Al_2O_3 sand-applied group (Group 4) was found to be statistically significant compared to the control group. The Cojet, 4% HF acid and control groups were not statistically significant among themselves ($p<0.05$).

Clearfil SA cement was used in groups 2, 5, 8, and 11. Group 5 (Al_2O_3) had the highest median load (425.76 N). The groups were not statistically significant among themselves ($p<0.05$).

RelyX ARC cement was used in groups 3, 6, 9, and 12. Group 3 (Cojet) had the highest median load (427.80 N). The Cojet group (Group 3) was found to be statistically significant compared to the control group, but the Al_2O_3, 4% HF acid and control groups were not statistically significant among themselves ($p<0.05$).

All values are shown in Table 2 and Figure 4.

Fracture types

When our study's fracture types were examined, vertical root fracture on the root's 1/3 cervical surface was observed in all groups.

Evaluation of SEM findings

When our study's SEM images were examined, it was observed that the surface roughness of the zirconia post-cores with Cojet and Al_2O_3 surface treatment increased significantly. The SEM images of the 4% HF acid-applied and untreated control groups were observed to be similar (Figs. 5-8).

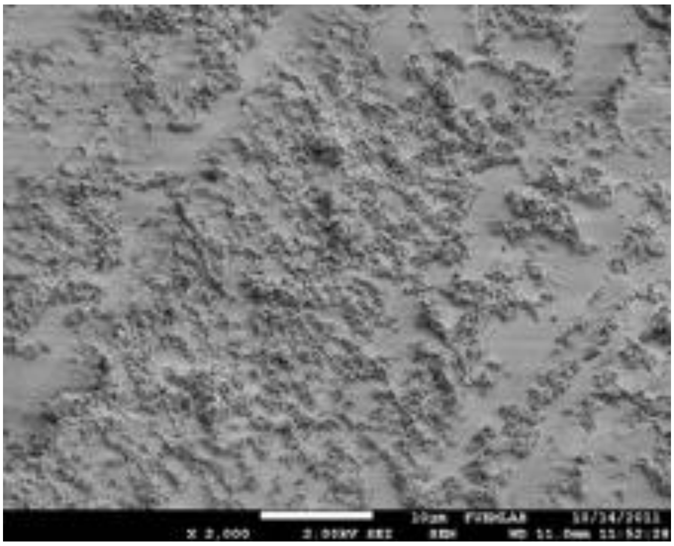

Figure 5. SEM image of zirconia post-cores treated with Cojet (silica coated Al_2O_3) (x2000)

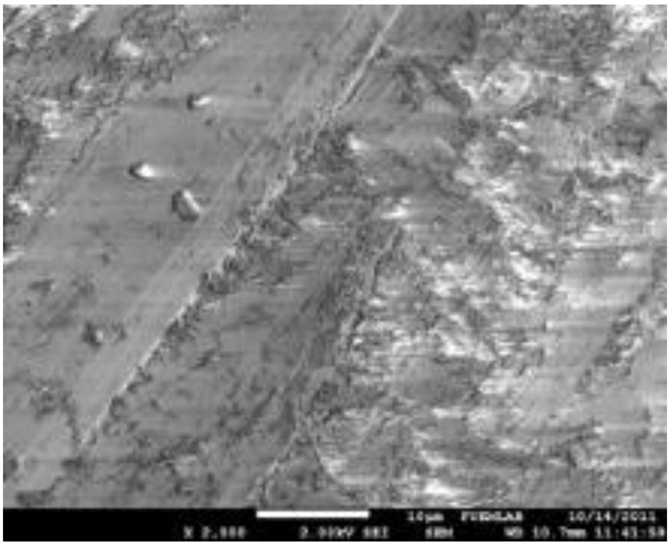

Figure 6. SEM image of zirconia post-cores sandblasted with Al_2O_3 (x2000)

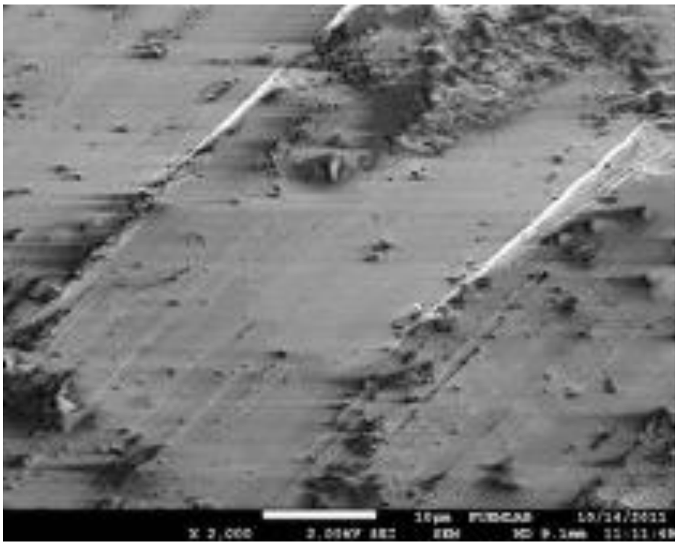

Figure 7. SEM image of zirconia post-cores treated with 4% Hydrochloric acid (x2000)

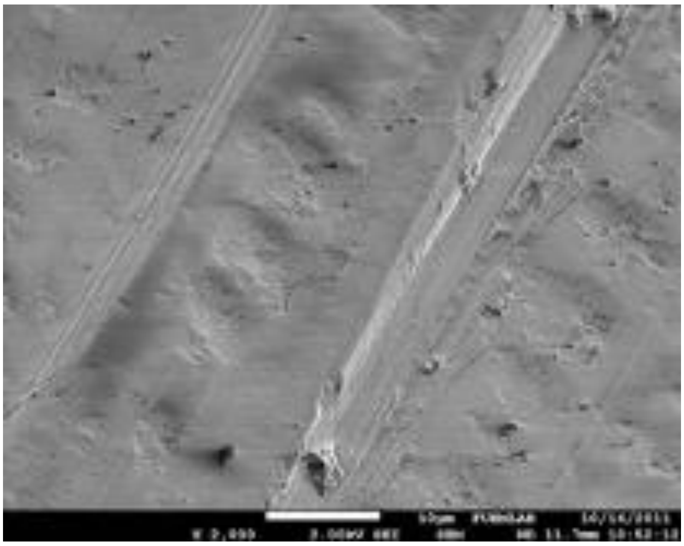

Figure 8. SEM image of untreated control group Zirconia post-cores (x2000

Discussion

Today, the production of zirconium oxide-based ceramics using CAD-CAM technology is increasing in aesthetic dentistry (7, 9). Zirconia post-cores produced with CAD-CAM were used in our study. Studies have reported that zirconia posts are highly resistant to breaking and bending (3, 10, 11). Zirconia posts have also been reported to have a high bonding capacity to resin.

The adhesion of the resin cement applied to the restoration surface depends on micromechanical bonding and chemical bond formation as a result of the activation of the restoration surface (6, 14, 15, 17, 18). To ensure this connection, various surface treatments are applied to the restoration surface. In our study, 125 µm Al_2O_3 sand application, 4% HF acid application for mechanical bonding to zirconia post surfaces, and tribochemical silica coating (Cojet [30 µm Al_2O_3]) were applied for both mechanical and chemical bonding.

When Al_2O_3 is applied to the zirconia post surfaces, the surface roughness and area increase. Micromechanical retention also increases due to the formation of more hydroxyl groups on surfaces exposed to sandblasting (16). In our study, the values of the groups that were treated with 125 µm Al_2O_3 sandblasting were the highest of all the groups. Therefore, we recommend the application of Al_2O_3 on zirconia post surfaces.

In recent years, the use of composite resin cements has increased because they have sufficient retention and good marginal adaptation, increase the fracture strength of restorations and the tooth–ceramic bond, and strengthen the supporting tooth structure (9-11, 16, 23-25). Huber et al. evaluated the surface application on the zirconia and cement bond and the effectiveness of the selected cement type and compared both MDP-containing and BIS-GMA-containing cements (22). They reported that the effectiveness of the MDP-containing primer and silane application was statistically more significant. Our study indicated that in the composite resin cement groups, the resistance value of the group cemented with Panavia F 2.0 (MDP-containing) and sandblasted with Al_2O_3 was the highest. However, this value was not statistically significant compared to the other groups' resistance values ($p < 0.05$).

Although human chewing force varies according to the regions of the mouth, the fracture strengths of the zirconia posts between 363 N and 438 N obtained in our study show that the restorations have sufficient resistance to chewing force, especially in the anterior region.

Conclusions

Zirconia post-cores produced using CAD-CAM technology are preferable because they are biocompatible, meet aesthetic expectations, and are resistant.

Zirconia post-cores produced with CAD-CAM technology need surface treatment for a reliable bond before bonding with composite resin cement. This roughening process is recommended because the zirconia post-core surfaces have the highest resistance value (438.10 N) when roughened with Al_2O_3 particles.

This in vitro study proposes cementation of zirconia post-cores etched with Cojet and Al_2O_3 particles with MDP-containing resin cement.

Ethical Approval: Ethics committee approval was received for this study from Dicle University, Faculty of Dentistry Ethics Committee in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2022/20.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – M.E.; Design – D.T.G., Z.S.P.; Supervision – E.G.B.; Materials – E.A., E.G.B.; Data Collection and/or Processing – M.E., D.T.G.; Analysis and/or Interpretation – Z.S.P.; Literature Review – E.G.B., E.A.; Writer – M.E.; D.T.G.; Critical Review –Z.S.P.

Conflict of Interest: No conflict of interest was declared by the authors.

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