AMERICAN COLLEGE OF PROSTHODONTISTS
Your smile. Our specialty.

In Vitro Comparison of Fracture Strength of Experimental Hollow and Solid Design Zirconia Dowels

Zeynep Özkurt, DDS, PhD,[1] Mehmet Baybora Kayahan, DDS, PhD,[2] & Ender Kazazoğlu, DDS, PhD[1]

[1]Department of Prosthodontics, Yeditepe University Faculty of Dentistry, Istanbul, Turkey
[2]Department of Endodontics, Yeditepe University Faculty of Dentistry, Istanbul, Turkey

Keywords
Zirconia; hollow design; fiber dowel; fracture strength.

Correspondence
Zeynep Özkurt, Yeditepe University, Faculty of Dentistry, Department of Prosthodontics, Bağdat cad. No: 238, 34728, Goztepe, Istanbul, Turkey. E-mail: zeynepozkurt@hotmail.com

The authors deny any conflicts of interest.

Accepted October 24, 2011

doi: 10.1111/j.1532-849X.2012.00846.x

Abstract

Purpose: The aim of this study was to evaluate the fracture strength of experimental hollow and solid design zirconia dowels.
Materials and Methods: Three types of dowels (fiber-reinforced composite [FRC], hollow design, and solid design zirconia dowels) were tested in the study (n = 10). A three-point bending method was conducted, and a load was applied until fracture. The values were recorded as Newtons (N) and then converted to megapascals (MPa) according to the diameter of the dowels. Statistical analyses were performed using one-way ANOVA and Tukey HSD tests. The significance was set at $p < 0.05$.
Results: The mean fracture strength of the hollow design zirconia dowels was significantly higher (960.72 MPa) than solid zirconia dowels (741.78 MPa) and FRC dowels (687.64 MPa) ($p < 0.05$).
Conclusions: The hollow design zirconia dowel seems to have sufficient fracture strength for anterior restorations. This design may be beneficial to access the apical region when retreatment is necessary, without any dowel-removing procedure.

Endodontically treated teeth often require crown restorations due to caries, an access cavity, or excessive removal of dentine during endodontic treatment, which may increase the fracture risk of the teeth.[1] In cases with insufficient dentin to support a crown restoration, a dowel is used to provide retention and support.[2,3] The traditional cast gold dowel and core has been regarded as the "gold standard" because of its superior success rate.[4] Alternatives to gold dowels are titanium, fiber, stainless steel, and zirconia dowels.[5-8] When tooth-colored restorations are preferred, dowels such as fiber-reinforced composite (FRC) and zirconia improve the esthetic appearance.[9,10] On the other hand, metal dowels may negatively affect the esthetic result.[5] In addition, corrosion reactions of the metals can cause metallic taste, oral burning, oral pain, sensitization, and other allergic reactions.[11,12]

Zirconia is a widely used restorative material because of its good chemical stability and high mechanical strength similar to that of stainless steel alloy. The high initial strength and fracture toughness of zirconia results from a physical property known as *transformation toughening*.[13,14] Zirconia also has the esthetic advantage of having a color similar to that of natural teeth.[15,16] Zirconia dowels were first introduced by Meyenberg et al,[5] who reported that the flexural strengths (900 MPa to 1200 MPa) of these dowels were comparable to cast gold or Ti.[5]

It is sometimes necessary to perform endodontic retreatment as a result of persistent peri-apical infection, inadequate root canal treatments, and dowel failures.[17] Endodontic surgery is one of the indications in an endodontically failed tooth with a dowel-core restoration.[18] However, a surgical procedure is very difficult to perform on the palatal root of upper molars and on mandibular molars.[19] In such cases, removal of the crown and the dowel core becomes the first choice for endodontic retreatment.[17] Nevertheless, it is nearly impossible to remove a zirconia dowel from the root canal.[10]

The hollow dowel-and-core system that would allow orthograde retreatment of the root canal was first described by Mosen et al.[19] Since then, the benefits of various hollow dowel designs and the retentive properties of these dowel systems have been investigated.[20-22] The hollow tube configuration can provide access to the root apex and be easily removed when necessary. If a hollow dowel is used, it is easier to retrieve the dowel from the infected root canal system or retreat the root canal with standard endodontic files to remove the infection.[20,23]

Zirconia dowel removal is a complex and difficult procedure that may be traumatic to the patient. Drilling of high-strength zirconia ceramic dowels was found to cause a temperature rise of the root surface.[17] Zirconia hollow dowel designs may be

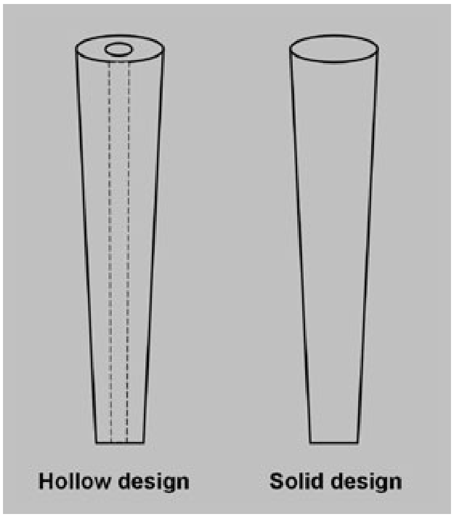

Figure 1 Experimental hollow and solid design zirconia dowels.

beneficial. However, their lack of thickness may decrease the fracture strength of the dowels, and this subject has not been studied yet. Therefore, the purpose of this study was to evaluate the fracture strength of experimental hollow and solid zirconia dowels, and compare them with FRC dowels. The hypothesis was that there would be a difference in the fracture strength of the dowel groups.

Materials and methods

In the first group, 10 specimens (tapered cylindrical patterns) with a 2.2 mm coronal diameter and a 1.8 mm apical diameter were fabricated from zirconia blocks (Lava, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. In the second group, 10 specimens with the same dimensions of solid design were fabricated from zirconia blocks; however, in each zirconia dowel, a hollow space with a 1.2 mm diameter was prepared in the second group (Fig 1). In the third group, 10 FRC dowels with a 2.2 mm coronal diameter and 1.2 mm apical region diameter (DT Light Post, Bisco, Schaumburg, IL) were selected and assigned as the control group. As it was impossible to produce a hollow design according to the thinner FRC dowel dimensions, an appropriate FRC dowel (2.2 mm in the coronal and 1.2 mm in the apical part) was chosen whose dimension matched the coronal dimensions of custom-made zirconia dowels (2.2 mm) to standardize the study. The minimum dimensions that could be produced with the existing production technique of zirconia dowels were 1.8 mm in the apical part.

Three-point bending test

A three-point bending test was conducted according to ISO 10477 using a universal testing machine (Model 3345, Instron Corp., Norwood, MA). A certain point on which the load was applied was marked on the dowels with a permanent pen, and the diameter of this point was measured with a micromeasuring device (Mitutoyo Digimatic Caliper, Mitutoyo Corp., Kawasaki, Japan) before testing. The minimum reading value of the caliper was set at ±0.001 mm. A load was applied to the dowels with a loading angle of 90° and a 1 mm/min crosshead speed until fracture. The two supports and the central loading anvil had 2 mm cross-sectional diameters, and the distance between the two supports was 10 mm. The load required for failure of each dowel was recorded in Newtons (N). All tests were carried out at room temperature. Because the dowels in the three groups had different diameters, a calculation was done to establish the load to be applied on the different dowels, according to their diameters, using the following formula:[24]

$$\delta = 8 \times \mathrm{F} \times \mathrm{l}/\pi \times \mathrm{d}^3$$

where δ is stress (MPa); F, fracture load (N); l, the distance between the two supports (mm); d, diameter of the dowel (mm).

Table 1 Mean fracture strength values (standard deviation) of the groups and the statistical analyses

	Mean (SD) (MPa)	F; *p*	Post hoc
Fiber dowel	687.64 (122.67)	F:5.387;	$P_{1\text{-}2}$:0.012*
Hollow zirconia dowel	960.72 (193.59)	*P*:0.011*	$P_{1\text{-}3}$:0.813
Solid zirconia dowel	741.78 (252.79)		$P_{2\text{-}3}$:0.049*

*$p < 0.05$.

Statistical analyses

The statistical analyses were performed using NCSS 2007&PASS 2008 Statistical Software (Kaysville, UT). All values were analyzed with one-way ANOVA. To reveal the statistical differences between the groups, the Tukey HSD test was subsequently applied. The significance was set at $p < 0.05$.

Results

The mean fracture strength values of the tested dowel systems are presented in Table 1. One-way ANOVA showed a statistically significant difference between the groups ($p < 0.05$). The mean fracture strength of the hollow design zirconia dowel group was significantly higher than the solid design zirconia dowel and FRC dowel groups. There was no statistically significant difference between the fiber dowel and solid-designed zirconia dowel groups ($p > 0.05$).

Discussion

The alternative hypothesis that there was a difference in the fracture strength of the tested dowel groups was accepted. It was found that the fracture strength (960.72 ± 193.59 MPa) of hollow design zirconia dowels was significantly higher than solid design zirconia dowels (741.78 ± 252.79 MPa) and fiber dowels (687.64 ± 122.67 MPa). The fracture strengths of zirconia and FRC dowels were compared in previous studies,[25-28] which stated that FRC dowels had lower fracture strengths than zirconia dowels. These results are in agreement with the current study.

The higher fracture strength obtained in the hollow design zirconia dowels compared to solid design may be related to the elastic properties originating from the space in the middle of the dowels. Zirconia dowels might have a higher resistance to fracture due to the higher elasticity of the hollow design.

Fracture strength is determined by the highest load a material is able to withstand. It is also related to the specimen configuration.[29] Kinney et al stated in their review article that the elastic modulus of dentin ranged between 10 GPa and 30 GPa.[30] It has also been reported that the biomechanical properties of FRC dowels are close to dentin.[24,31] As FRC dowels are flexible, they may allow micromotion and may break the luting agent, resulting in coronal leakage or loss of the restorations; however, they permit the retreatment of the canals when necessary.[32] Zirconia dowels are different from FRC dowels because of the flexural properties. Zirconia dowels have a high elastic modulus (200 MPa), and they are rigid.[33] More-rigid dowels provide support for cores and crowns. The physical and mechanical properties of zirconia dowels may increase the strength of teeth,[25] but if overloaded, they may cause catastrophic failures such as root fractures.[34] It is also very difficult to retrieve a fractured zirconia dowel.[34]

The retreatment of teeth with endodontic dowels is still a challenge for clinicians. In endodontic failures, orthograde retreatment in which removal of the dowel is required is generally more successful than periapical surgery.[35] Dowel removal requires special approaches to avoid root perforations or cracks. Many instruments and techniques can remove dowels: the Masserann Kit, the Eggler post remover, the Gonon post remover, the Ruddle post remover,[36] and ultrasonic vibration.[37] However, zirconia dowels are usually cemented with resin cements, which provide the highest retention compared to other cements. It is very difficult to remove zirconia dowels from root canals[35] because of the luting resin cement and the high strength of the material.[5] It is also very difficult to drill the zirconia dowel with burs and access the root canal system. Therefore, a hollow design of zirconia dowels may be beneficial to access the apical region and to perform retreatment of the roots via the space in the middle of the dowels without need for a removal procedure. According to the values obtained in the present study, none of the tested dowel systems may be at risk for failure under normal occlusal forces reported for anterior teeth, because it was stated that the maximum bite force of a natural dentition, especially for the anterior region, ranges between 100 N and 200 N.[38-40]

The hollow design is a guide to achieve access to the apex of the root. When it is decided to produce this type of dowel during the production process this chamber can be filled with tooth-colored gutta-percha, or thermoplastic synthetic polymer-based root canal core material (Resilon), which can be removed easily from the hollow chamber with nickel-titanium rotary instruments.[41]

The hollow and solid-designed zirconia dowels used in this study are experimental dowel systems. Although prefabricated zirconia dowels are available the solid-designed zirconia dowels used in this study were produced to eliminate variabilities such as material, diameter, or production technique. The FRC dowel group was the third and served as the control group. Instead of a 135° angle between the force and the dowel, which replicates the position of upper central incisors, an angle of 90° was chosen to simulate the worst traumatic scenario for maxillary upper central incisors that can be encountered during an accident.[42]

The limitations of this study were that the dowels were not evaluated in natural or artificial teeth, and thermocycling or long-term storage was not performed. In addition, fracture modes of the dowels were not analyzed. Further studies are needed to investigate the performance of the hollow zirconia dowel/core/tooth/crown restoration complex with long-term storage. Fracture surface analyses should also be evaluated.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. All zirconia dowel systems evaluated in this study had higher fracture strength than FRC dowels.
2. The fracture strengths of the hollow design zirconia dowels were significantly higher than solid design zirconia dowels.

References

1. Mannocci F, Bertelli E, Sherriff M, et al: Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent 2002;88:297-301
2. Goodacre CJ, Spolnik KJ: The prosthodontic management of endodontically treated teeth: a literature review. Part I. Success and failure data, treatment concepts. J Prosthodont 1994;3:243-250
3. Fernandes AS, Dessai GS: Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont 2001;14:355-363
4. Creugers NH, Mentink AG, Käyser AF: An analysis of durability data on post and core restorations. J Dent 1993;21:281-284
5. Meyenberg KH, Luthy H, Schaerer P: Zirconia posts: a new all-ceramic concept for nonvital abutment teeth. J Esthet Dent 1995;7:73-80
6. King PA, Setchell DJ: An in vitro evaluation of a prototype CFRC prefabricated post developed for the restoration of pulpless teeth. J Oral Rehabil 1990;17:599-609
7. Dean JP, Jeansonne BG, Sarkar N: In vitro evaluation of a carbon fiber post. J Endod 1998;24:807-810
8. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, et al: Relative translucency of six all-ceramic systems: part l. Core materials. J Prosthet Dent 2002;88:4-10
9. Sidoli GE, King PA, Setchell DJ: An in vitro evaluation of a carbon fiber-based post and core system. J Prosthet Dent 1997;78:5-9
10. Mannocci F, Ferrari M, Watson TF: Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. J Adhes Dent 1999;1:153-158
11. Hayashi Y, Nakamura S: Clinical application of energy dispersive x-ray microanalysis for nondestructively confirming dental metal allergens. Oral Surg Oral Med Oral Pathol 1994;77:623-626
12. Kedici SP, Aksut AA, Kilicarslan MA, et al: Corrosion behaviour of dental metals and alloys in different media. J Oral Rehabil 1998;25:800-808
13. Piconi C, Maccauro G: Zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25
14. Garvie RC, Hannink RHJ, Pascoe RT: Ceramic steel? Nature 1975;258:703-704

15. Ahmad I: Yttrium–partially stabilized zirconium dioxide posts: an approach to restoring coronally compromised nonvital teeth. Int J Periodontics Restor Dent 1998;18:454-465
16. Vichi A, Ferrari M, Davidson CL: Influence of ceramic and cement thickness on the masking of various types of opaque posts. J Prosthet Dent 2000;83:412-417
17. Satterthwaite JD, Stokes AN, Frankel NT: Potential for temperature change during application of ultrasonic ibration to intra-radicular posts. Eur J Prosthodont Rest Dent 2003;11:51-56
18. Stropko JJ, Doyon GE, Gutmann JL: Root-end management: resection, cavity preparation, and material placement. Endod Topics 2005;11:131-151
19. Mosen PJ, Nicholls JI, Van Hassel HJ: An in vitro comparison of retention between a hollow post and core and a solid post and core. J Endod 1984;10:91-95
20. Cohen BI, Musikant BL, Deutsch AS: Comparison of the retentive properties of two hollow-tube post systems to those of a solid post design. J Prosthet Dent 1993;70:234-238
21. Ludington JR Jr., Nicholls JI, Van Hassel HJ: A hollow post and core system-evaluation of reinstrumentation and reobturation. J Endod 1984;10:140-145
22. Halle EB, Nicholls JI, Van Hassel HJ: An in vitro comparison of retention between a hollow post and core and a custom hollow post and core. J Endod 1984;10:96-100
23. Cohen BI, Deutsch AS, Musikant BL: Cyclic fatigue testing of six endodontic post systems. J Prosthodont 1993;2:28-32
24. Mannocci F, Sheriff M, Watson TF: Three-point bending test for fiber posts. J Endod 2001;27:758-761
25. Rosentritt M, Fürer C, Behr M, et al: Comparison of *in vitro* fracture strength of metallic and tooth-coloured posts and cores. J Oral Rehabil 2000;27:595-601
26. Sahafi A, Peutzfeldt A, Ravnholt G, et al: Resistance to cyclic loading of teeth restored with posts. Clin Oral Investig 2005;9:84-90
27. Forberger N, Göhring TN: Influence of the type of post and core on *in vitro* marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent 2008;100:264-273
28. Heydecke G, Butz F, Strub JR: Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an *in-vitro* study. J Dent 2001;29:427-433
29. Plotino G, Grande NM, Bedini R, et al: Flexural properties of endodontic posts and human root dentin. Dent Mater 2007;23:1129-1135
30. Kinney JH, Marshall SJ, Marshall GW: The mechanical properties of human dentin: a critical review and re-evaluation of the dental literature. Crit Rev Oral Biol Med 2003;14:13-29
31. Drummond JL, Bapna MS: Static and cyclic loading of fiber-reinforced dental resin. Dent Mater 2003;19:226-231
32. Stricker EJ, Goring TN: Influence of different posts and cores on marginal adaptation, fracture resistance, and fracture mode of composite resin crowns on human mandibular premolars: an in vitro study. J Dent 2006;34:326-335
33. Guazzato M, Albakry M, Ringer SP, et al: Strength, fracture toughness and microstructure of a selection of all-ceramic materials: part II. Zirconia-based dental ceramics. Dent Mater 2004;20:449-456
34. Fernandes AS, Dessai GS: Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont 2001;14:355-363
35. Adarsha MS, Lata DA: Influence of ultrasound, with and without water spray cooling, on removal of posts cemented with resin or glass ionomer cements: an in vitro study. J Conserv Dent 2010;13:119-123
36. Castrisos T, Abbott PV: A survey of methods used for post removal in specialist endodontic practice. Int Endod J 2002;35:172-180
37. Garrido AD, Fonseca TS, Alfredo E, et al: Influence of ultrasound, with and without water spray cooling, on removal of posts cemented with resin or zinc phosphate cements. J Endod 2004;30:173-176
38. Kohal RJ, Papavasiliou G, Kamposiora P, et al: Three-dimensional computerized stress analysis of commercially pure titanium and yttrium-partially stabilized zirconia implants. Int J Prosthodont 2002;15:189-194
39. Ho MH, Lee SY, Chen HH, et al: Three-dimensional finite element analysis of the effects of posts on stress distribution in dentin. J Prosthet Dent 1994;72:367-372
40. Holmes DC, Diaz-Arnold AM, Leary JM: Influence of post dimension on stress distribution in dentin. J Prosthet Dent 1996;75:140-147
41. Ezzie E, Fleury A, Solomon E, et al: Efficacy of retreatment techniques for a resin-based root canal obturation material. J Endod 2006;32:341-344
42. Cormier CJ, Burns DR, Moon P: In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. J Prosthodont 2001;10:26-36