Clinical Success of Zirconia in Dental Applications

Zeynep Özkurt, DDS, PhD & Ender Kazazoğlu, DDS, PhD

Department of Prosthodontics, Faculty of Dentistry, Yeditepe University, Istanbul, Turkey

Keywords
Zirconia; success; failure; clinical outcome.

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

Accepted: December 5, 2008

doi: 10.1111/j.1532-849X.2009.00513.x

Abstract

The application of ceramic materials for the fabrication of dental restorations is a focus of interest in esthetic dentistry. The ceramic materials of choice are glass ceramics, spinel, alumina, and zirconia. Zirconia was introduced into dentistry in the 1990s because of its good mechanical and chemical properties and is currently being used as a material for frameworks, dowels, implants, abutments, and orthodontic brackets. Many in vitro studies about zirconia use have been published, but clinical long-term studies are very important. This article presents data regarding the incidence of clinical success and complications of zirconia in these dental applications. Clinical studies published to date seem to indicate that zirconia is well tolerated and sufficiently resistant.

The introduction of zirconia (zirconium dioxide, ZrO_2) as a dental material has generated considerable interest in the dental community.[1] Zirconia is widely used to build prosthetic devices because of its good chemical properties, dimensional stability, high mechanical strength, toughness, and a Young's modulus (210 GPa) similar to that of stainless steel alloy (193 GPa). The mechanical properties of zirconia are the highest ever reported for any dental ceramic. The high initial strength and fracture toughness of zirconia results from a physical property of partially stabilized zirconia known as *transformation toughening*.[2,3] In vitro studies of zirconium dioxide specimens demonstrate a flexural strength of 900 to 1200 MPa and a fracture toughness of 9 to 10 MPa/m^2.[4] On the other hand, its white color, similar to the color of natural teeth, makes it useful in esthetically important areas of the oral cavity, and its ability to transmit light renders it a suitable material in esthetic restorations.[5]

Zirconia has been used for root canal dowels since 1989, for orthodontic brackets since 1994, for implant abutments since 1995, and for all-ceramic fixed partial dentures (FPDs) since 1998.[6] The first use of zirconia as a dental implant material in humans was reported in 2004.[7]

Meyenberg et al[8] introduced zirconia dowel/core systems. The fracture strength of these systems is superior to established dowel/core systems based on titanium or high precious alloys.[9] Zirconia dowels can be used both with direct composite core or indirect glass-ceramic core,[10] and can be cemented conventionally or adhesively.[10,11]

The use of zirconia in dental implant abutments has been introduced because of its high fracture resistance compared to alumina and other dental ceramics.[3,12] Zirconia abutments provide new opportunities for implant restorations and offer sufficient stability to support implant-retained reconstructions, especially in incisor and premolar locations.[6] Zirconia is a radiopaque esthetic abutment with well-documented biocompatibility and is designed to engage the implant directly. Zirconia abutments are indicated in areas with extremely limited gingival tissue height.[13] Zirconia also minimizes the gray color transmitted through the peri-implant tissues associated with metal components.[12]

Zirconia is also a bioinert, nonresorbable metal oxide, which has been used in dental implants.[14] Zirconia dental implants have an excellent resistance to corrosion, a high wear resistance, a high biocompatibility, and high values of bending strength and fracture toughness,[15] however, they had been used only experimentally until 2004. Good biocompatibility of this material was found in animal studies with direct bone apposition to the zirconia dental implants. Zirconia has high affinity for bone tissue, and the bone/implant interface is similar to that seen around titanium dental implants.[14,16,17] Zirconia brackets are commercially available, and in vitro research has been published to assess frictional forces;[18–20] however, no clinical follow-up information has been presented in the literature.

Zirconia-based FPDs have a wider application than other ceramics, because they can be used on molars. They allow the construction of structures resistant to chewing stresses on posterior teeth.[21] Zirconia restorations can be indicated for FPDs supported by teeth or implants. Although, some manufacturers suggest them for full-arch restorations, five-unit FPDs are reported to be the maximum possible.[22] Chamfer and rounded shoulder finish lines with at least 1.5 mm incisal and occlusal reduction, and 1.0 mm axial reduction with 4 to 6° taper are

recommended for zirconia restorations.[23] After conventional impression procedures are performed, zirconia frameworks are produced by milling from both fully sintered and partially sintered zirconia blocks or by slip-casting technique as with In-Ceram zirconia.[24,25] Following the veneering procedure, resin-bonded luting or conventional luting could be performed for cementation.

Although many in vitro research articles have been published on the use of zirconia, clinical long-term evaluation is a crucial factor to understand behavior and reliability. Knowledge regarding the clinical complications enhances the clinician's ability to complete a thorough diagnosis and develop the most appropriate treatment plan.[26] Therefore, the purpose of this article is to discuss the available literature on the clinical success of zirconia, to present data, and to identify the complications associated with each usage.

Methodology

A Medline search was initiated on search terms *zirconia*, *dental*, *success*, *failure*, *complications*, and *clinical studies* associated with *zirconia-based fixed partial denture*, *post*, *dowel*, *abutment*, and *implant* in humans. The literature search covered all years and focused on publications that contained clinical data regarding success, failure, and complications of zirconia. The publications must have presented clinical data that identified the follow-up period and the number of restorations being evaluated, how long they had been in place, and how many were affected by complications. Clinical reports with no short- or mid-term clinical results, reviews, and in vitro studies about zirconia were excluded. Fifteen studies, including eight for FPDs, two for dowels, three for abutments, and two for implants, fit the inclusion criteria. Publications were grouped according to each use of zirconia. Complications and failures were identified.

Clinical studies

Zirconia-based fixed partial dentures

Eight studies were included in the clinical success associated with zirconia-based FPDs.[27-34] A total of 218 FPDs were evaluated in these eight studies. Four of the FPDs were implant-supported,[27] and the others were tooth-supported.[28-34] Two of the included studies evaluated DC-Zirkon (DCS Dental AG, Allschwil, Switzerland),[30,32] and two evaluated DCM (Direct Ceramic Machining).[28,29] The other zirconia frameworks were Denzir (Dentronic AB, Skelleftea, Sweden), Lava (3M ESPE Dental AG, Seefeld, Germany), Procera AllZirkon (Nobel Biocare, Göteborg, Sweden), and In-Ceram Zirconia (Vita, Bad Säckingen, Germany). The restorations were three or more units. Tooth preparations were performed in similar manner: 1 to 1.5 mm axial reduction with 6 to 10° tapering angle, 1.5 to 2 mm occlusal reduction, and circumferentially rounded chamfer/shoulder finish line with depth of 1 to 1.2 mm were made. The length of the eight studies ranged from 1 to 5 years. The patients were examined to assess the clinical situation of the FPDs for the first 6 months in three studies[27,28,33] and for the first 12 months in five studies.[29-32,34] According to clinical evaluation, the following complications were reported: framework fracture,[28] minor veneer chipping,[28-30,32,33] secondary caries,[28,29] loss of retention,[28,30,34] abutment tooth extraction,[28,31] endodontic problems,[28,29] and gingival bleeding.[31]

Table 1 Veneer chipping complications of FPDs

Investigator	Incidence	Follow-up period	Zirconia type
Steyern et al[32]	15%	24 months	DC-Zirkon
Sailer et al[28]	13%	37.2 months	DCM
Sailer et al[29]	15.2%	35.1 months	DCM
Raigrodski et al[33]	25%	31.2 months	Lava
Tinschert et al[30]	6%	37 months	DC-Zirkon

Framework fracture

No framework fractures were reported in seven of the FPD with zirconia studies; therefore the success rate was reported as 100%.[27,29-34] However, one five-unit framework fracture through the connector area was observed in one of these studies, after a clinical service time of 38 months.[28] It was fabricated with DCM. Although precise analyses of this failed FPD after removal revealed that the connector dimensions were adequate ($18.49 \times 19.28\ mm^2$) for a five-unit zirconia framework, trauma and fatigue of the ceramic were assumed to be the primary cause of failure. The success rate of this zirconia framework in the 5-year follow-up was 97.8%.[28]

Veneer fracture

The most frequent technical problem in all studies of zirconia reconstructions is chipping or cracking of the veneer ceramic. In an investigation using a different prototype zirconia ceramic, veneer chipping was found in 15.2% of the cases after 35.1 months of follow-up.[28] In another investigation with the same zirconia ceramic, chipping was found in 13% after 37.2 months.[29] In a third study, chipping of the veneer occurred in 15% of the cases after 2 years.[32] A fourth study reported chipping in 25% of cases after 31.2 months of observation.[33] Finally, a fifth study reported the lowest chipping incidence, 6% after 37 months[30] (Table 1). These results were attributed to low or moderate bond strength between zirconia frameworks and veneering ceramics. It can be concluded that various veneering ceramics available for zirconia possess insufficient mechanical properties.

Secondary caries and marginal gap

Sailer et al reported that the incidence of secondary caries in conjunction with FPD abutments was 10.9 and 21.7% after 3 and 5 years, respectively.[28,29] On the other hand, marginal gaps leading to secondary caries were found in 56.5 and 58.7% of cases after 3 and 5 years, respectively (Table 2). These results were attributed to DCM, the prototype of a currently available system (Cercon, Degudent, Hanau, Germany). In this technique, clinical and dental laboratory procedures were under development. Other studies produced FPDs with established CAD/CAM systems. No marginal gaps or caries were reported

Table 2 Secondary caries and marginal gap complications of FPDs

Investigator	Incidence of secondary caries	Incidence of marginal gap	Follow-up period	Zirconia type
Sailer et al[28]	10.9%	56.5%	3 years	DCM
Sailer et al[29]	21.7%	58.7%	5 years	DCM

for Lava, DC-Zirkon, Procera, or In-Ceram Zirconia FPDs.[27,30-34]

Loss of retention

Three studies reported loss of retention of FPDs. One reported that one of 19 posterior three-unit FPDs cemented with zinc phosphate cement lost retention after 12 months.[34] This FPD was luted with resin cement again, and no further complications were registered. Another study indicated that two of 58 posterior three-unit FPDs cemented with zinc phosphate cement lost retention after 17 and 32 months.[30] Finally, a third study reported that one of 33 posterior four-unit FPDs cemented with resin cement lost retention after a clinical service time of 33.3 months[28] (Table 3).

Need for endodontic treatment

The need for endodontic treatment was presented according to number of abutments and number of prostheses affected. Two studies reported on the incidence of endodontic treatment needed.[28,30] In the first study, one abutment tooth of a three-unit FPD required endodontic treatment after 42 months.[28] Three of 130 abutments in 58 FPDs required endodontic treatment, which was cemented with zinc phosphate cement after 15 and 23 months.[30]

Abutment tooth extraction

The incidence of abutment tooth extraction was recorded in two studies.[28,31] One reported that one abutment tooth was extracted as a result of endodontic problems after 42 months, and in two patients abutments supporting three-unit FPDs were removed because of root fractures after 21.2 and 53.7 months.[28] Another study indicated that one FPD had to be removed 28 months after cementation because of root fracture in an endodontically treated mandibular molar that needed extraction[31] (Table 4).

Periodontal situations

In a majority of the studies, periodontal parameters between the abutments with zirconia frameworks and natural teeth showed no statistically significant differences.[27-30,32-34] Only one study recorded more bleeding at crowned abutments than at contralateral teeth with In-Ceram Zirconia.[31] Gingival bleeding on probing was observed in 28% of the abutments with In-Ceram Zirconia and in 18% of the contralateral natural teeth at the 3-year evaluation. This difference was attributed to increased risk for gingival inflammation around crowned teeth.

Table 3 Loss of retention of FPDs

Investigator	Number of crowns/ affected	Follow-up period	Cement	Units
Molin et al[34]	19/1	12 months	Zinc phosphate	3
Tinchert et al[30]	58/2	17 and 37.2 months	Zinc phosphate	3
Sailer et al[28]	33/1	33.3 months	Composite resin	4

Table 4 Abutment tooth extraction in FPDs

Investigator	Number of crowns/affected	Follow-up period	Reason
Sailer et al[28]	33/1	42 months	Endodontic problem
Sailer et al[28]	33/1	21.2 months	Root fracture
Sailer et al[28]	33/1	53.7 months	Root fracture
Suarez et al[31]	18/1	28 months	Root fracture

Zirconia dowels

Two studies were included in the clinical success associated with zirconia dowels.[10,11] In one study, 25 anterior and five posterior zirconia dowels were evaluated. Two zirconia dowel systems, Cosmopost (Ivoclar Vivadent, Schaan, Liechtenstein) and Cerapost (Brasseler, Lemgo, Germany), combined with heat-pressed ceramic cores (IPS Empress Cosmo, Ivoclar Vivadent) and ceramic crowns (IPS Empress II, Ivoclar Vivadent) were used, and all dowels were cemented conventionally with glass ionomer cement. After an observation period of 29 months, no loss of retention, fracture, or dislodgement were reported.[11] In another study, 79 zirconia dowels (Cosmopost) with direct resin core building were retrospectively evaluated after a mean clinical period of 57.7 months. All dowels were cemented adhesively, and no failures were observed. In the same study, 34 zirconia dowels with indirect glass–ceramic cores showed three failures because of loss of retention[10] (Table 5). According to the results of these studies, zirconia dowels could be clinically acceptable.

Zirconia abutments

Little data is available on the survival rate and average lifetime of zirconia abutments. The incidence of complications associated with zirconia abutments was determined by evaluating data from three studies.[6,35,36] One article presented the clinical success of 36 experimental zirconia abutments on single-tooth implants, after a mean observation period of 49.2 months. No abutment fractures were observed during clinical loading, resulting in a cumulative survival rate of 100%. Loosening of the abutment screw was reported for two restorations (one at 8 months, and one at 27 months). Healthy peri-implant mucosa and stable marginal bone levels were documented at zirconia abutments.[6] In another study, 30 zirconia abutments on single-tooth implants were observed after a follow-up period of 40 months. No abutment fractures or screw loosening were reported, resulting in a cumulative survival rate of 100%.[35] Finally, a third study evaluated the success rate of 37 zirconia–alumina composite abutments (ZirAce, Acucera Inc., Reno, NV). Nine implants were

Table 5 Dowel complications

Investigator	Number of dowels	Cement	Follow-up period	Failures	Failure reason
Nothdurft et al[11]	30	Glass ionomer	29 months	–	–
Paul et al[10]	79 (direct core)	Resin	57.7 months	–	–
Paul et al[10]	34 (indirect core)	Resin	46.3 months	3	Loss of retention

single-tooth, and 28 implants were FPDs. After a 12-month follow-up, no abutment fractures, cracks, screw loosening, or peri-implant infection signs were reported. In this study, neither zirconia–alumina abutment failures nor adverse soft tissue reactions were observed at 12 months.[36] These studies indicate that zirconia abutments could be suitable for clinical use.

Zirconia implants

Kohal and Klaus presented the first clinical report of zirconia dental implants in the literature. A custom-made two-piece zirconia implant was used to replace a left upper central incisor with zirconia abutment and zirconia-based single crown.[7] A second report presented a case in which eight one-piece zirconia implants had been placed;[37] however, middle- or long-term results of zirconia dental implants have not yet been presented. Oliva et al reported the first clinical evaluation in humans of 100 zirconia implants (CeraRoot, Barcelona, Spain) with two surface roughnesses after a 1-year follow-up.[38] Two implants failed after 15 days. These failed implants were placed in situations where sinus elevation was required. The overall success rate was reported as 98%. Considering the sinus elevation requirement, future investigators may exclude patients with less than 5 mm of residual bone. Pirker and Kocher immediately placed a zirconia implant in the maxillary first premolar region and evaluated the clinical outcome of this implant.[39] After a 2-year follow-up, a stable implant and unchanged peri-implant marginal bone level was observed. No bleeding on probing was detected.

Conclusion

Use of zirconia in dental applications is rapidly growing, especially for fixed prostheses. Zirconia-based crowns, dowels, abutments and implants have undergone only a few years of basic science research and laboratory and clinical observation. To date, the research results are promising. The length of the studies mentioned in this article ranged from 1 to 5 years; however, it is well established in the dental literature that evaluation of all-ceramic restorations over 5 years of service is the gold standard.[40] Therefore, continuous follow-up of at least 5 years will provide data regarding the efficacy of zirconia for dental applications in the future. Although clinical long-term evaluation is a critical requirement to conclude that zirconia has good reliability for dental use, biological, mechanical, and clinical studies published to date seem to indicate that zirconia could be well tolerated, especially for FPDs.

References

1. Denry I, Kelly JR: State of the art of zirconia for dental applications. Dent Mater 2008;24:299-307
2. Piconi C, Maccauro G: Zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25
3. Garvie RC, Hannink RHJ, Pascoe RT. Ceramic steel? Nature 1975;258:703-704
4. Christel P, Meunier A, Heller M, et al: Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989;23:45-61
5. Ahmad I: Yttrium-partially stabilized zirconium dioxide posts: an approach to restore coronally compromised nonvital teeth. Int J Periodontics Restorative Dent 1998;18:455-465
6. Glauser R, Sailer I, Wohlwend A, et al: Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004;17:285-290
7. Kohal RJ, Klaus G: A zirconia implant-crown system: a case report. Int J Periodontics Restorative Dent 2004;24:147-153
8. Meyenberg KH, Luthy H, Scharer P: Zirconia posts: a new all-ceramic concept for nonvital abutment teeth. J Esthet Dent 1994;7:73-80
9. Heydecke G, Butz F, Hussein A, et al: Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and core systems. J Prosthet Dent 2002;87:438-445
10. Paul SJ, Werder P: Clinical success of zirconium oxide posts with resin composite or glass-ceramic cores in endodontically treated teeth: a 4-year retrospective study. Int J Prosthodot 2004;17:524-528
11. Nothdurft FP, Pospiech PR: Clinical evaluation of pulpless teeth restored with conventionally cemented zirconia posts: a pilot study. J Prosthet Dent 2006;95:311-314
12. Yildirim M, Fischer H, Marx R, et al: In vivo fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent 2003;90:325-331
13. Brodbeck U: The ZiReal Post. A new ceramic implant abutment. J Esthet Restor Dent 2003;15:10-23
14. Akagawa Y, Ichikawa Y, Nikai H, et al: Interface histology of unloaded and early loaded partially stabilized zirconia endosseous implant in initial bone healing. J Prosthet Dent 1993;69:599-604
15. Josset Y, Oum'Hamed Z, Zarriumpour A, et al: In vitro reactions of human osteoblasts in culture with zirconia and alumina ceramics. J Biomed Mater Res 1999;47:481-493
16. Akagawa Y, Hosokawa R, Sato Y, et al: Comparison between freestanding and tooth-connected partially stabilized zirconia implants after two years' function in monkeys: a clinical and histologic study. J Prosthet Dent 1998;80:551-558
17. Ichikawa Y, Akagawa Y, Nikai H, et al: Tissue compatibility and stability of a new zirconia ceramic in vivo. J Prosthet Dent 1992;68:322-326

18. Keith O, Kusy RP, Whitley JQ: Zirconia brackets: an evaluation of morphology and coefficients of friction. Am J Orthod Dentofacial Orthop 1994;106:605-614
19. Kittipibul P, Godfrey K: In vitro shearing force testing of the Australian zirconia-based ceramic Begg bracket. Am J Orthod Dentofacial Orthop 1995;108:308-315
20. Tanne K, Matsubara S, Hotei Y, et al: Frictional forces and surface topography of a new ceramic bracket. Am J Orthod Dentofacial Orthop 1994;106:273-278
21. Raigrodski AJ: Contemporary materials and technologies for all-ceramic fixed partial dentures: a review of the literature. J Prosthet Dent 2004;92:557-562
22. Larsson C, Vult von Steyern P, Sunzel B, et al: All-ceramic two- to five-unit implant-supported reconstructions. A randomized, prospective clinical trial. Swed Dent J 2006;30:45-53
23. McLaren EA, White SN: Glass- infiltrated zirconia/ alumina-based ceramic for crowns and fixed partial dentures: clinical and laboratory guidelines. Pract Periodontics Aesthet Dent 1999;11:985-994
24. Sorensen JA: The Lava system for CAD/CAM production of high-strength precision fixed prosthodontics. Quintessence Dent Tech 2004;26:57-67
25. Witowski S: (CAD-)/CAM in dental technology. Quintessence Dent Tech 2005;28:169-184
26. Goodacre CJ, Bernal G, Rungcharassaeng K, et al: Clinical complications in fixed prosthodontics. J Prosthet Dent 2003;90:31-41
27. Chang PP, Henegbarth EA, Lang LA: Maxillary zirconia implant fixed partial dentures opposing an acrylic resin implant fixed complete denture: a two-year clinical report. J Prosthet Dent 2007;97:321-330
28. Sailer I, Fehér A, Filser F, et al: Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 2007;20:383-388
29. Sailer I, Fehér A, Filser F, et al: Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 2006;37:685-693
30. Tinschert J, Schulze KA, Natt G, et al: Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. Int J Prosthodont 2008;21:217-222
31. Suárez MJ, Lozano JF, Paz Salido M, et al: Three-year clinical evaluation of In-Ceram Zirconia posterior FPDs. Int J Prosthodont 2004;17:35-38
32. Vult von Steyern P, Carlson P, Nilner K: All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil 2005;32:180-187
33. Raigrodski AJ, Chiche GJ, Potiket N, et al: The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 2006;96:237-244
34. Molin MK, Karlsson SL: Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 2008;21:223-227
35. Canullo L: Clinical outcome study of customized zirconia abutments for single-implant restorations. Int J Prosthodont 2007;20:489-493
36. Bae KH, Han JS, Seol YJ, et al: The biologic stability of alumina–zirconia implant abutments after 1 year of clinical service: a digital subtraction radiographic evaluation. Int J Periodontics Restorative Dent 2008;28:137-143
37. Volz U, Blaschke C: Metal-free reconstructions with zirconia implants and zirconia crowns. Quintessence J Dent Technol 2004;2:324-330
38. Oliva J, Oliva X, Oliva JD: One-year follow-up of first consecutive 100 zirconia dental implants in humans: a comparison of 2 different rough surfaces. Int J Oral Maxillofac Implants 2007;22:430-435
39. Pirker W, Kocher A: Immediate, non-submerged, root-analogue zirconia implant in single tooth replacement. Int J Oral Maxillofac Surg 2008;37:293-295
40. Walton TR: An up to 15-year longitudinal study of 515 metal-ceramic FPDs: part 1. Outcome. Int J Prosthodont 2002;15:439-445